U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Building Technologies Office

Research & Development Needs for Building-Integrated Solar Technologies

January 2014

NOTICE

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government, nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency, contractor or subcontractor thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Available electronically at http://www.osti.gov/home/

Research & Development Needs for Building-Integrated Solar Technologies

Prepared for:
U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy
Building Technologies Office
http://www.eere.energy.gov/buildings

Prepared by:
Navigant Consulting, Inc.
77 South Bedford Street, Suite 400
Burlington, MA 01803

William Goetzler
Matt Guernsey
Michael Droesch

January, 2014

Table of Contents

List of Acronyms

ASES	American Solar Energy Society
ASHP	Air-Source Heat Pump
BIPV	Building Integrated Photovoltaics
BIPV/T	Building Integrated Photovoltaic/Thermal Hybrid
BIST	Building Integrated Solar Technologies
BMS	Building Management System
BTO	Building Technology Office, U.S. Department of Energy
Btu	British thermal unit
CAGR	Compound Annual Growth Rate
CFL	Compact Fluorescent Lamp
COP	Coefficient of Performance
COSEIA	Colorado Solar Energy Industries Association
CRES	Colorado Renewable Energy Society
CSI	California Solar Initiative
DOE	U.S. Department of Energy
SDD	Solar Desiccant Dehumidification
DSC	Dye Sensitized Solar Cells
EERE	U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy
EIA	U.S. Department of Energy, Energy Information Administration
EMS	Energy Management System
ES	Executive Summary
ETC	Evacuated Tube Collector
FDD	Fault Detection and Diagnostics
ft	Feet
GHP	Geothermal Heat Pump
HPWH	Heat Pump Water Heater
HVAC	Heating, Ventilation, and Air Conditioning
ICS	Integrated Collector Storage
IEA	International Energy Agency
IR	Infrared
LED	Light Emitting Diode
Mcf	Hundred Cubic Feet
MREA	Midwest Renewable Energy Association's
MSP	Market Savings Potential
NREL	National Renewable Energy Laboratory
ORC	Organic Rankine Cycle
PCM	Phase Change Material
PV	Photovoltaics
PV/T	Photovoltaic/Thermal Hybrid

Quad	Quadrillion British thermal units
R&D	Research and Development
RD&D	Research, Development, and Demonstration
SAM	System Advisor Model
SAHP	Solar Assisted Heat Pump
SEIA	Solar Energy Industries Association
sq. ft.	Square Foot
SWH	Solar Water Heater
UHV	Ultra-High Vacuum Evacuated Tube Collectors
US	United States
USH_2O	Utility Solar Water Heating Initiative
VCC	Vapor Compression Cycle
W	Watt

Executive Summary

The Building Technologies Office (BTO) within the Department of Energy's (DOE) Office of Energy Efficiency and Renewable Energy (EERE) works with researchers and industry to develop and deploy technologies that can substantially reduce energy consumption in residential and commercial buildings. DOE/BTO (hereafter "DOE") aims to reduce building-related energy consumption by 50% by the year 2030.[1] DOE has identified Building Integrated Solar Technologies (BIST) as a potentially valuable piece of the comprehensive pathway to help achieve this goal. This report helps to identify the key research and development (R&D) needs that will be required for BIST to make a substantial contribution toward that goal. BIST include technologies for space heating and cooling, water heating, hybrid photovoltaic-thermal systems (PV/T), active solar lighting, and building-integrated photovoltaics (BIPV).

DOE retained Navigant Consulting Inc. (hereafter "Navigant") to conduct research and speak with stakeholders to identify key research activities that can overcome the technological barriers and enable widespread adoption of BIST. Navigant's recommended initiatives within this report focus on overcoming first-cost and other primary technical barriers that will promote BIST to compete on their own merits, without subsidies.[2] The objective of this report is to identify the key technology R&D activities that are appropriate for DOE that can reduce barriers to greater BIST market penetration and help achieve DOE's energy savings goals.

We began the research process by engaging industry experts and stakeholders, such as BIST manufacturers, installers, academics, and policy makers, to gather inputs on the key needs in the industry and to understand where targeted R&D could be most effective. We hosted stakeholder forums at the SOLAR THERMAL '12 Conference in Milwaukee, WI (December, 2012), and in Washington D.C. (January, 2013). These forums focused primarily on brainstorming ideas and technologies with the potential to bring about transformative changes in the industry. We also conducted phone interviews with roughly 20 stakeholders who DOE specifically identified for their particular areas of expertise and their willingness to provide additional feedback. At the conclusion of the stakeholder outreach we had compiled a list of 54 unique initiatives.

Initiative evaluation and prioritization focused on the following metrics:

- **Market Savings Potential (MSP) –** How much energy can the initiative save on an annual basis (quads/yr)?
- **Fit with BTO mission –** How closely does the initiative align with BTO's goals and capabilities?
- **Criticality of DOE involvement –** How critical is it to the success of the initiative that DOE is involved?
- **Level of risk –** How much risk is associated with DOE's investment?

---

[1] The Department of Energy, Office of Energy Efficiency and Renewable Energy "Policy Supporting Energy Efficiency and Heat Pump Technology", A. Bouza, Nov. 2012. Available at: www.heatpumpcentre.org/en/hppactivities/hppworkshops/London2012/Documents/04_A_Bouza.pdf

[2] The Department of Energy, Office of Energy Efficiency and Renewable Energy, "Building Technologies Program Multi-Year Work Plan 2011-2015" emphasizes the need to focus on cost reduction of emerging technologies to make them attractive to the marketplace. Multi-Year Work Plan available at: apps1.eere.energy.gov/buildings/publications/pdfs/corporate/myp11.pdf

- **Level of required DOE investment** – How much investment, if any, will DOE be required to make to complete the initiative?
- **Prioritization from industry stakeholders** – How strongly do industry stakeholders support the initiative?

Based on this evaluation of each initiative, we developed a prioritized list of all the initiatives and identified a top tier of 15 high-priority initiatives. We presented our preliminary findings for review at the American Solar Energy Society's (ASES) SOLAR 2013 conference in April 2013 in Baltimore, MD and during a monthly teleconference of the Utility Solar Water Heating Initiative (USH_2O) group. We solicited feedback from stakeholders at these events regarding the prioritized initiatives and revised the prioritization based on this feedback.

This report recommends the top initiatives for DOE's consideration. Through investment in these initiatives, DOE can reduce barriers to greater penetration of BIST technologies and help to achieve their 2030 energy savings goals. The detailed process of initiative identification through stakeholder outreach and prioritization through detailed analysis ensures that the top initiatives are not only the highest impact relative to energy savings goals, but also the most suitable for DOE. Table ES-1 shows the top tier of initiatives; Section 5 describes each initiative in detail.

Table ES-1: Top Tier Initiatives

Category	Initiative/Activity
Solar Water Heating (& Solar Space Conditioning)	Evaluate Optimal Configurations for PV-Driven Electric Water Heating Systems
Storage and System Integration	Develop and Optimize Solar Energy Systems Capable of Serving Multiple End-Uses
Controls and Software	Develop Tool to Compare Solar Thermal and Other Renewable Energy Technologies for a Given Installation
Solar Water Heating (& Solar Space Conditioning)	Reduce Material Costs of Residential and Small Commercial Collectors
Solar Water Heating	Implement a Large-Scale SWH Field Performance Verification Pilot Program for SWH Systems
Controls and Software	Develop Publicly Available Design and Estimation Tools for BIST
Controls and Software	Validate BIST Modeling Software
Controls and Software	Expand Capabilities of System Advisor Model (SAM)
Manf., Installation & Maintenance	Develop Recommended Guidance for Improved State/Local Building Codes, Permits, and Standards
Manf., Installation & Maintenance	Update Test and Certification Standards
Controls and Software	Incorporate BIST Into Architectural Modeling Software to Enable Holistic Design Approach
Other Technologies - Solar Cogen (& Solar Water Heating & Space Cond)	Research and Develop Low-Profile Concentrating, Tracking Solar Collectors
Storage and System Integration	Improve Residential-Scale Solar Thermal Storage
Manf., Installation & Maintenance	Reduce Installation Costs with the Use of Plug-and-Play Systems
Other Technologies	Develop Improved Building Integration Methods for Dye-Sensitized Solar Cells (DSC)

1 Introduction

1.1 Background

The Building Technologies Office (BTO) within the Department of Energy's (DOE) Office of Energy Efficiency and Renewable Energy works with researchers and industry to develop and deploy technologies that can substantially reduce energy consumption in residential and commercial buildings. DOE/BTO (hereafter "DOE") aims to reduce building-related energy consumption by 50% by the year 2030. Further development of Building Integrated Solar Technologies (BIST) has the potential to help DOE achieve this goal. DOE retained Navigant Consulting Inc. (hereafter "Navigant") to develop this report by gathering, refining, and prioritizing industry-stakeholder inputs. The report outlines key initiatives that can help overcome key technological barriers facing BIST.

BIST are a subset of solar technologies that can be integrated with, or incorporated into, the structure, envelope, or systems of a residential or commercial building. This includes those building-integrated technologies, such as traditional solar water heating collectors, which are installed on a roof, but are not integrated into a building's enclosure. Solar energy technologies harvest energy from the sun and either use it directly for lighting, or convert it into other useable forms of energy, such as electricity or heat. BIST include technologies for space heating and cooling, water heating, hybrid photovoltaic-thermal systems (PV/T), active solar lighting, and building-integrated photovoltaics (BIPV). BIST does not include utility-scale solar plants or traditional rack-mounted PV arrays. Some BIST systems, such as solar water heating, have existed for over 100 years with few operating-principle changes. Others, such as BIPV, are far newer to market and in many cases are still under development or commercialization stages. We do not address BIST specific to industrial applications, however we have included some BIST that may also be used in industrial facilities. Figure 1-1 shows a breakdown of BIST included in this report.

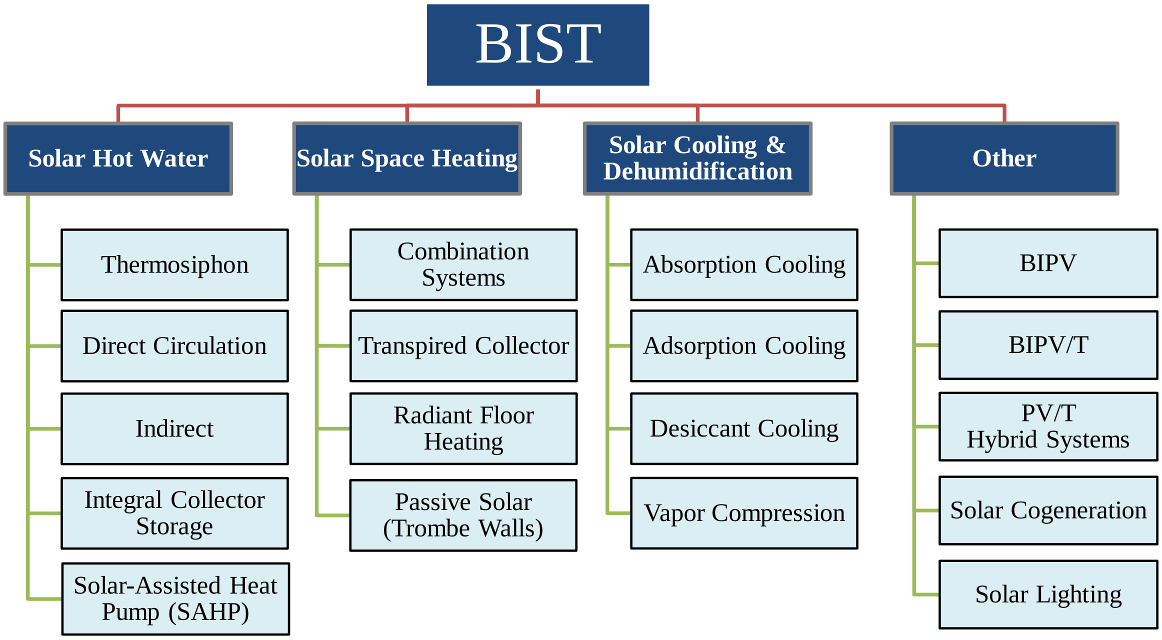


Figure 1-1: BIST Overview

BIST address four specific building energy end uses: space heating, space cooling, water heating, and lighting. As Figure 1-2 shows, these end uses represent four of the largest building energy-use categories, and in aggregate, constitute 61% (24.5 Quads) of the annual primary building energy consumption in the United States (sum of circled end-uses in Figure 1-2).[3]

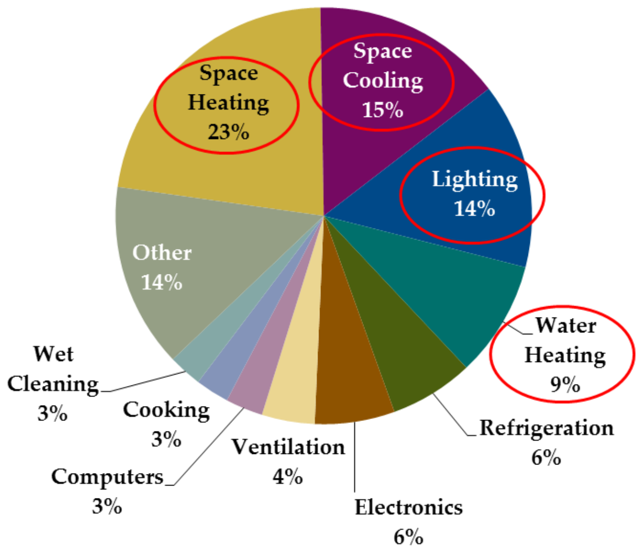


Figure 1-2: Primary Energy Consumption in U.S. Buildings, 2010[4]

[3] Buildings Energy Data Book, 2010, buildingsdatabook.eren.doe.gov/docs/xls_pdf/1.1.4.pdf
[4] Buildings Energy Data Book, 2010, buildingsdatabook.eren.doe.gov/docs/xls_pdf/1.1.4.pdf

Table 1-1 shows the approximate technical energy savings potential of BIST (excluding BIPV and PV/T systems) based on the estimated savings potential for each end use. The technical savings potential represents the energy savings if BIST were to replace all relevant incumbent technologies. In this case, on a national scale, BIST can potentially reduce building energy use by roughly 8.5 quads/year, or 21%.

Table 1-1: BIST Estimated Energy Savings by End-Use (Excluding BIPV and PV/T)

End-Use	Fraction of Building Primary Energy Use[5]	Estimated Energy Savings	Savings Potential[6]	Primary Energy Savings Potential (Quads)
Solar Water Heating	9%	60%[7]	5%	2.0
Solar Space Cooling	15%	40%[8]	6%	2.5
Solar Space Heating*	23%	25%[9]	6%	2.5
Solar Lighting	14%	25%[10]	4%	1.5
	Average BIST Energy Savings ≈	34%		
	TECHNICAL SAVINGS POTENTIAL ≈**		**21%**	**8.5 Quads/Yr**

*Solar space heating "Estimated Energy Savings" based on performance of transpired collector systems without thermal storage. Other solar space heating system designs are capable of achieving energy savings upwards of 40%, although performce is highly dependent on building type, climate, heating demands, and thermal storage resources.[11]

**Savings estimates do not include savings from BIPV or PV/T systems, which may account for roughly 5 to 7 Quads/Yr of additional primary energy savings.[12] Electricity generation technologies are excluded here because they do not apply to a specific end-use, and can be sized to offeset 100% of a building's electricity usage.

1.2 DOE Mission and Goals

As defined in its Multi-Year Work Plan, DOE's mission is to:

[5] Buildings Energy Data Book, 2010, buildingsdatabook.eren.doe.gov/docs/xls_pdf/1.1.4.pdf

[6] "Savings Potential" is the product of the estimated energy savings multiplied by the fraction of building primary energy use. This represents the potential percent reduction in building-related primary energy consumption, attributable to each technology.

[7] "The Technical Potential of Solar Water Heating to Reduce Fossil Fuel Use and Greenhouse Gas Emissions in the United States" NREL Technical Report TP-640-41157. P. Denholm. March 2007

[8] "New technical solutions for energy efficient buildings – State of the art report, solar heating and cooling" Treberspurg et al., July 2011

[9] "Transpired Collectors (Solar Preheaters for Outdoor Ventilation Air)" Federal Technology Alert, DOE/GO-10098-528, 1998

[10] "Daylighting and Energy Performance Prediction of a Light Pipe used in Underground Parking Lot" Shin et al., 5th Intl. Symp. on Sustainable Healthy Buildings, Seoul, Korea, February 2011

[11] "Design Guidelines – Solar Space Heating of Factory Buildings", D. Jaehnig, W. Weiss, available at: http://www.aee-intec.at/0uploads/dateien537.pdf

[12] Savings estimates assume 40% to 50% savings potential applied to 13.7 Quads/Yr of primary energy consumption, which accounts for all electricity consumption not used for water heating, space conditioning, or lighting.

> "Develop and promote efficient and affordable, environmental friendly technologies, systems, and practices for our nation's residential and commercial buildings that will foster economic prosperity, lower greenhouse gas emissions, and increase national energy security while providing the energy-related services and performance expected from our buildings."[13]

As part of this mission, DOE targets reducing building-related energy use by 50% by 2030, with specific savings targets for water heating and HVAC:[14]

- 60% savings in water heating
- 20% savings in HVAC

To achieve this goal, DOE is strategically focusing on the highest opportunity technologies that will aid in this mission. While DOE has no specific mandate to pursue BIST, these technologies have substantial energy saving potential and may therefore provide an effective path to achieving DOE's savings targets as part of their overall portfolio of technologies. DOE builds this portfolio based in part on the cost of conserved energy for each potential investment (including non-BIST). This metric weighs the projected level of investment with the potential achievable market penetration and energy savings potential. Prioritization of a specific energy-efficient BIST does not guarantee funding nor ensure that DOE will pursue the initiative.

In this report, Navigant defines a recommended set of initiatives for overcoming technological barriers and enabling widespread adoption of BIST. DOE may use this report to guide initiatives such as open solicitations, cooperative research agreements, or other mechanisms to help make BIST products more attractive to the market. To achieve this, the initiatives outlined in this report focus on cost reductions that will promote and enable technologies to compete on their own merits, without subsidies.[15]

1.3 Objective of This Report

***The objective* of this report is to advance DOE's goal of reducing building-related energy consumption through R&D initiatives targeted at reducing barriers to greater market penetration of BIST.**

This report aggregates broad stakeholder inputs to provide guidance to DOE on valuable future R&D activities. It aims to identify the highest priority BIST initiatives, which, if pursued, will

[13] Department of Energy, Office of Energy Efficiency and Renewable Energy, "Building Technologies Program Multi-Year Work Plan 2011-2015, available at: apps1.eere.energy.gov/buildings/publications/pdfs/corporate/myp11.pdf

[14] DOE/BTO's target savings general information available at: www1.eere.energy.gov/buildings/technologies/index.html. Specific breakdown by end-use based on discussions with DOE/BTO staff.

[15] DOE/BTO "Building Technologies Program Multi-Year Work Plan 2011-2015" available: apps1.eere.energy.gov/buildings/publications/pdfs/corporate/myp11.pdf

have the greatest potential impact on reducing the total energy consumption of residential and commercial buildings.

2 Approach

Figure 2-1 summarizes each task completed to develop this report. We briefly describe each task below.

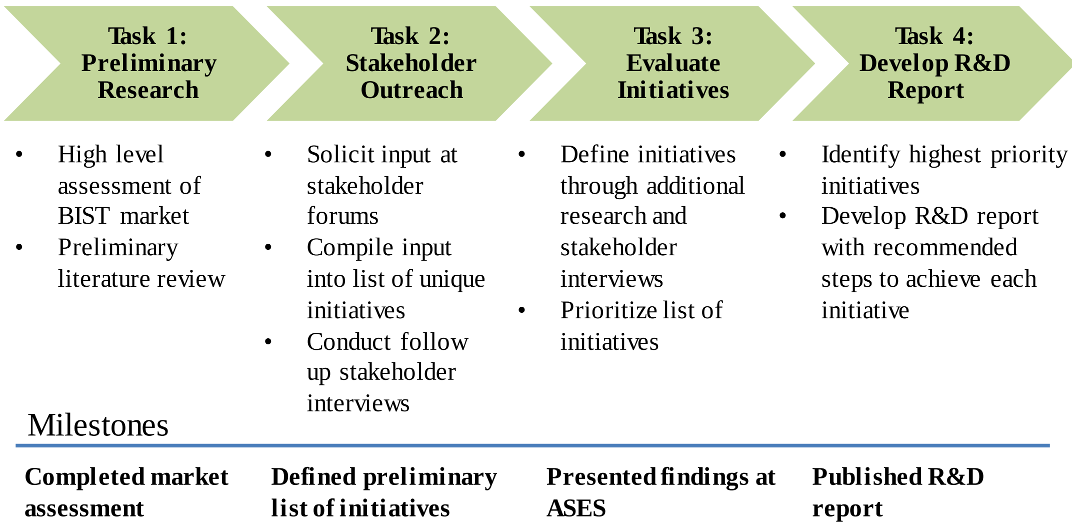


Figure 2-1: Report Development Process Overview

2.1 Task 1: Perform Preliminary Industry Research

We conducted a preliminary assessment of the BIST currently on the market as well as those technologies still in R&D and prototype stages. We identified industry leaders, and reviewed projects and initiatives that these organizations have pursued to address major barriers to BIST. Further, we studied the dynamics of BIST markets by analyzing historical trends to determine the most significant external market factors impacting BIST. Our focus throughout this task was to gain a clear vision of the BIST landscape to better guide our efforts through the remaining tasks in the process.

2.2 Task 2: Obtain Stakeholder Input & Feedback

We reached out to industry stakeholders to solicit their inputs on what they felt were the most critical challenges and barriers to the BIST industry, and what R&D needs and knowledge gaps they felt were important to address. We held two stakeholder forums; Appendix A lists each of the participating organizations at each of the following events:

- **SOLAR THERMAL ’12 BIST Forum**
  This event took place at the Midwest Renewable Energy Association’s (MREA) SOLAR THERMAL ’12 conference in December 2012 in Milwaukee, WI. The forum was open to the public, and stakeholders in attendance included BIST manufacturers, installers, academics, and policy makers. We led a brainstorming session at the forum to generate new ideas for potential R&D initiatives and to solicit stakeholder input on the initiatives or activities that they felt would be most likely to improve the competitiveness of BIST.

We compiled a list of all of the potential ideas, and asked attendees to help prioritize the list of initiatives by voting on the initiatives that they felt were most promising.

- **Washington D.C. BIST Forum**
  DOE hosted a second forum at Navigant's Washington D.C Office in January 2013, open to all interested stakeholders. At this day-long event we followed a very similar methodology to the first forum and focused primarily on brainstorming ideas and technologies with the potential to bring about transformative (non-incremental) changes in the industry. This forum provided an opportunity for stakeholders who could not attend the forum in Milwaukee to express their opinions and provide feedback on the industry.

From these two forums, and from independent conversations with stakeholders who were unable to attend, we collected over 120 potential initiatives. We combined overlapping ideas to develop a list of 54 unique initiatives. To ensure that no initiatives were unfairly discarded or prematurely judged, we did not attempt in this step to remove items that may have been out of scope or unpopular among certain groups or individuals.

In the weeks following the forums, we conducted follow-up phone interviews with roughly 20 stakeholders, some of whom had attended one of our previous forums and some who had not. DOE specifically identified these stakeholders for their particular areas of expertise and their willingness to provide additional feedback. We used these interviews to ensure that we were not missing any potentially valuable initiatives in our list of 54 initiatives, and to discuss specific initiatives in greater detail.

2.3 Task 3: Define and Evaluate Potential Initiatives

The scope, goal, and potential impact of each initiative were defined through additional research and through follow-up conversations with stakeholders who had provided feedback during previous outreach efforts. We did not attempt to redefine or substantially alter inputs from stakeholders, but rather to process them into the most efficient and clear initiatives. We divided the initiatives into six distinct categories: three technology-specific categories and three cross-cutting categories. Table 2-1 lists each of the six categories.

Table 2-1: Technology Category Definitions

	Category	Target Focus
Technology Specific	Solar Water Heating	Solar water heating collectors, system designs, and balance of systems components
	Solar Space Conditioning	Solar space cooling, heating, and dehumidification system designs and components
	Other Technologies	BIPV, PV/T, BIPV/T, solar driven cogeneration systems, and solar lighting systems
Cross Cutting	Controls and Software	Design, estimation, and modeling tools, as well as control packages to improve performance of BIST
	Manuf., Installation & Maintenance	Improved methods for manufacturing, installation and maintenance to reduce costs and increase performance of BIST
	Storage & System Integration	Thermal energy storage methods and innovative system integration techniques for BIST

We evaluated each initiative based on:

- **Market Savings Potential (MSP) –** How much energy can the initiative save on an annual basis (quads/yr) by the year 2030, based on the estimated energy savings potential and market penetration of the initiative?
- **Fit with BTO mission –** How closely does the initiative align with BTO's goals and capabilities?
- **Criticality of DOE involvement –** How critical is it to the success of the initiative that DOE is involved?
- **Level of risk –** How much risk is associated with DOE's investment?
- **Level of required DOE investment –** How much investment will DOE be required to make to complete the initiative?
- **Prioritization from industry stakeholders –** How strongly do industry stakeholders support the initiative?

We internally scored each initiative on these metrics using the criteria in Table 2-2. Suggested initiatives that clearly did not fit with DOE's mission were not recorded during stakeholder forums. Suggested initiatives that were moderately out of scope were recorded and included in our analysis, but received low scores in the Fit with BTO Mission and Criticality of DOE Involvement criteria.

Table 2-2: BIST Initiative Scoring Metrics

Score	5	4	3	2	1	Weight
Market Savings Potential	> 0.15 quads/yr	0.15 – 0.09 quads/yr	0.09 – 0.04 quads/yr	0.04 – 0.025 quads/yr	< 0.025 quads/yr	50%
Level of Required Investment	< $0.5M	$0.5M - $2M	$2M - $5M	$5M - $10M	> $10M	20%
Fit with BTO Mission	Core to mission	Semi-core to mission	Relevant to mission	Semi-relevant to mission	Outside scope of mission	10%
Criticality of DOE Involvement	Critical to success	Semi-critical to success	Beneficial to success	Semi-beneficial to success	Not necessary for success	10%
Level of Risk	Low	Low-Moderate	Moderate	High-Moderate	High	10%

Figure 2-2 illustrates the methodology for the prioritization process. The market savings potential (MSP) metric is a quantitative metric calculated based on the inputs shown in Figure 2-2. Three members of Navigant's team, each having different expertise, scored each of the four qualitative metrics. The final score for each metric is the average of the three scores. To ensure appropriate valuation of initiatives that stakeholders strongly supported, we increased final scores by up to 0.5 points (15%) based on the number of votes tallied during stakeholder forum voting.

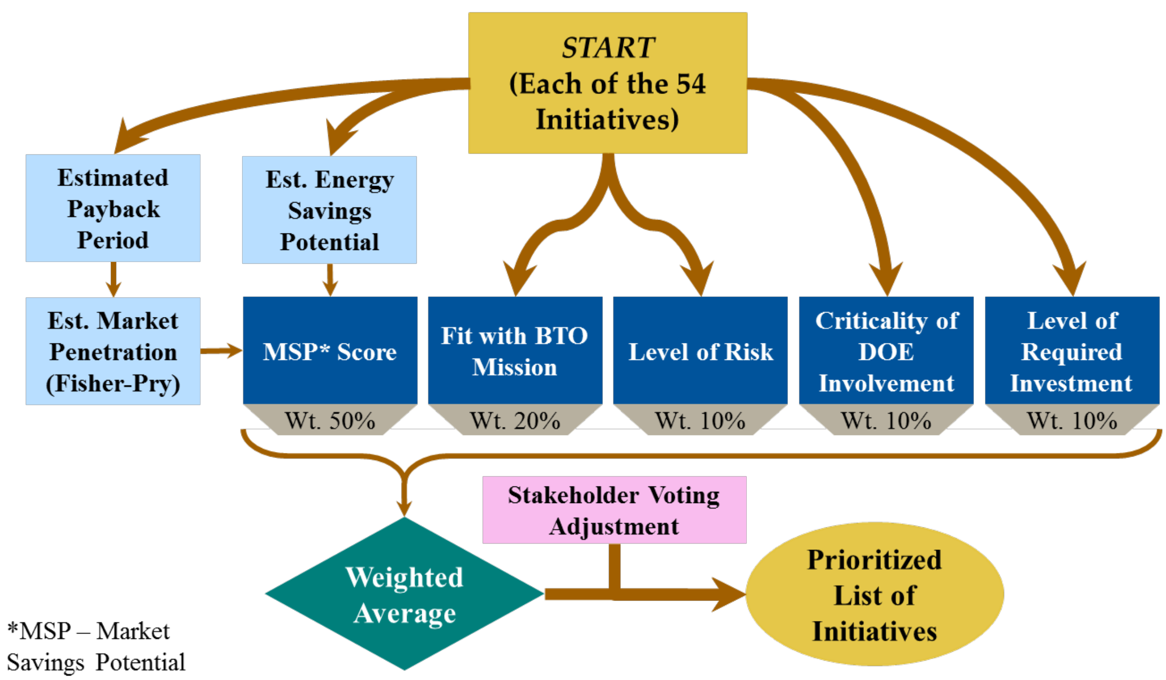


Figure 2-2: BIST Initiative Prioritization Methodology

Using this process, we ranked all 54 initiatives. Section 5 includes the complete discussion of the results of the prioritization process.

We presented preliminary findings at the American Solar Energy Society's (ASES) SOLAR 2013 conference in April in Baltimore, MD. We solicited feedback from stakeholders on the results to understand how well the findings fit with their perceived needs and expectations. In addition to ASES, we presented our draft findings to the members of the Utility Solar Water Heating Initiative (USH_2O) during their monthly teleconference. We asked members of the USH_2O coalition to provide similar feedback regarding our preliminary findings and how well it fit with their needs. DOE incorporated comments and edits as appropriate, and highlighted the top tier of initiatives, consisting of the top 15 initiatives. This report focuses on these high-priority initiatives.

2.4 Task 4: Develop R&D Report

We drafted detailed discussion of the top 15 initiatives (i.e., top tier), as determined in Task 3 and highlighted the barriers that stakeholders identified as the most significant for each of the BIST categories (see Table 2-1, above, for category descriptions). Within each category we presented the prioritization data for each initiative along with a brief description of the objectives and tasks associated with each initiative. Inclusion in the top tier does not imply that any given initiative can be successfully implemented and/or developed within a specific timeframe or budget; the analysis did not evaluate ultimate feasibility in detail of each initiative.

We also evaluated the results of our prioritization and discussed additional findings from the process. By studying the scores for each of the prioritization metrics in depth, we were able to highlight certain subgroups of initiatives. We identified these groups by specific designations, such as "enabling investments" or "DOE/Industry partnership opportunities", to describe the defining characteristics of each group and provide a deeper level of insight into the range of identified initiatives. Section 5.1.2 describes this analysis in detail, including these notable trends and subgroups of initiatives.

Finally, after prioritizing the initiatives and developing the R&D report, we presented a draft of the document to DOE for internal review. DOE circulated this draft among stakeholders and industry experts as part on an extensive external review. We incorporated feedback from all of these reviews into this final report.

3 BIST Market Discussion

3.1 Existing Technologies and Equipment

3.1.1 Solar Water Heating

Solar water heating technologies capture solar energy to heat service water (aka, domestic water) for residential or commercial applications. Solar water heating systems have existed for over 100 years and can be, in principle, quite simple. On the other hand, modern solar water heating systems can be complex, including a range of solar collectors, accessory components, and system configurations.

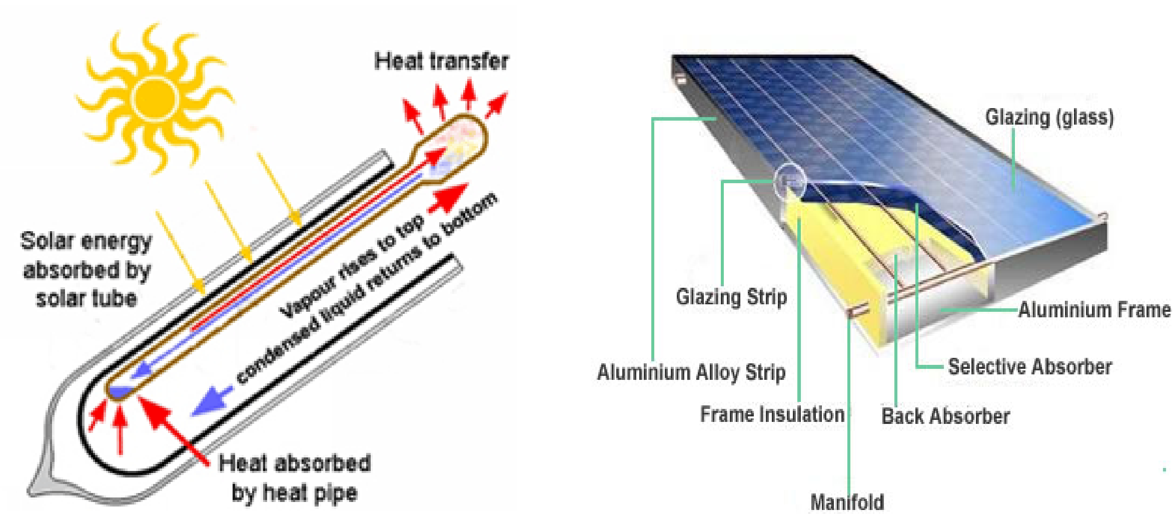
Solar water heating systems can be divided into either active or passive systems:[16]

- ***Active solar water heating systems:***
  - **Direct Circulation –** Uses pumps to circulate water from a storage tank to the collector and back into the tank, where it will be stored until it is used.
  - **Indirect –** Uses pumps to circulate a heat transfer fluid (often a water/glycol mixture) in a closed loop to the collector; a heat exchanger transfers the heat from the transfer fluid to the potable water.
  - **Solar-Assisted Heat Pump (SAHP) –** Combines solar thermal collectors with a vapor compression heat pump to capture solar thermal energy and transport it into a building. These systems are primarily used for domestic water heating or hydronic space heating, although air-to-air SAHP are designed to heat air for space conditioning applications.

- ***Passive solar water heating systems:***
  - **Thermosiphon –** Uses natural convection to transport heated water from the collector to a storage tank positioned above the collector. When there is a demand for hot water, water flows out of the storage tank and into the building; no pumps are required within the solar water heating system.
  - **Passive Integral Collector Storage (ICS) –** Preheats and stores water in the collector. The storage tank is integrated directly with the absorber within the collector where water is stored before flowing via natural convection to the backup water heater. These are also known as batch systems.

Figure 3-1 shows two of the most common solar thermal collector designs used in residential applications, the evacuated tube collector (a) and the flat plate collector (b). Evacuated tube collectors typically consist of individual heat pipes (generally made from copper) encapsulated within glass vacuum tubes, which provide thermal insulation. Most flat plate and evacuated tube collectors are considered medium temperature collectors, which typically operate between 110°F and 180°F. Pool heating solar collectors are typically unglazed low-temperature collectors, which operate below 110°F.

[16] Solar Water Heating System Designations: energy.gov/energysaver/articles/solar-water-heaters



(a) (b)

Figure 3-1: (a) Evacuated Tube Collector[17], (b) Flat Plate Collector[18]

3.1.2 Solar Space Heating

Solar space heating systems can be active or passive, and can heat air directly with solar radiation or indirectly with an intermediate heat transfer medium such as water. In general, residential systems are more likely to be passive (using no fans or pumps), but some systems incorporate active components and thermal storage systems to better manage fluctuations in solar resources and building space heating demands. Commercial-scale systems use both passive and active solar space heating systems, but tend not to use thermal storage, as most commercial buildings are only occupied during the day, when solar resources are most available.

Passive, direct air-heating systems:
Passive direct air-heating systems rely on solar thermal energy to heat and circulate the air within a conditioned space without the aid of powered components. One example of a passive direct air heating system is a Trombe wall, which is a technology that uses solar radiation to heat air in a thin cavity created between two walls, and relies on natural convection to circulate the air throughout the space. Figure 3-2 illustrates the working principles of a Trombe wall.

[17] Image source: www.totallysolar.co.za/solar-info/hot-water-solutions/
[18] Image Source: www.butobu.rs/details/light/index.php?r=1780&usr=greengroup

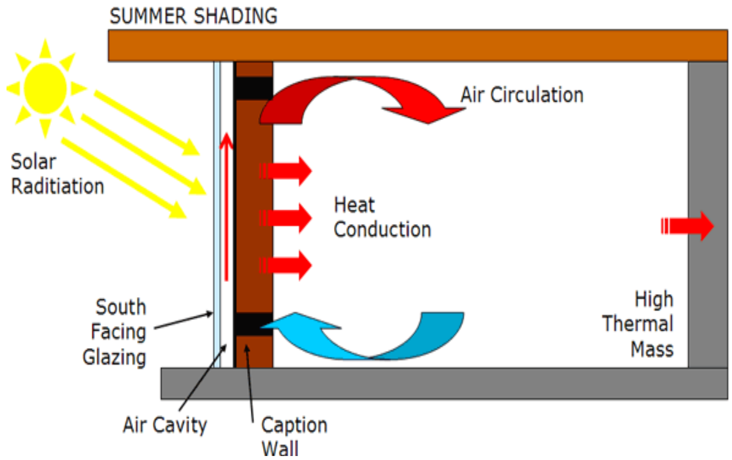


Figure 3-2: Trombe Wall Diagram[19]

Active, direct air-heating systems:

Active, direct air-heating systems use fans to drive solar pre-heating of outdoor ventilation air. Figure 3-3 shows an example of an active air heating system that uses fans to pull air through transpired solar collectors and direct it into the primary distribution ducting. Transpired collectors consist of absorber plates with an array of very small perforations in them to allow air to pass through. These collectors are generally used in commercial and industrial applications, and can be either roof-mounted or wall-mounted to take advantage of the optimum solar incidence angle for a given building location and orientation. Active, direct air-heating systems can also include thermal storage systems to help buildings better manage fluctuations in solar resources and building space heating demands.

[19] Image Source: srd364tljon.blogspot.com/2008/10/trombe-walls.html

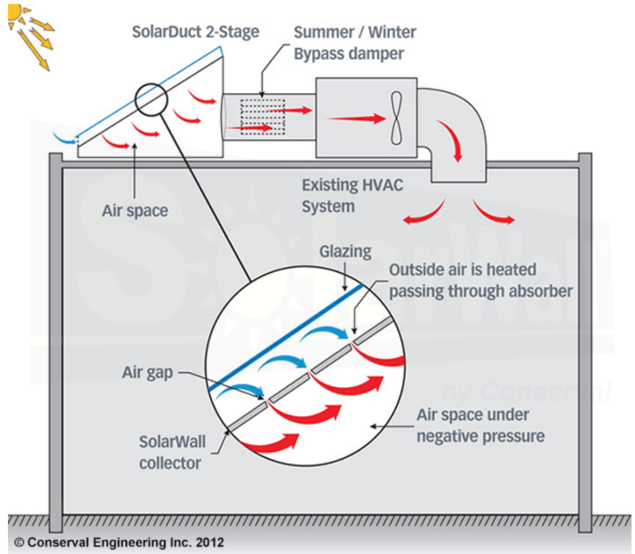


Figure 3-3: Active Solar Space Heating System[20]

Active, indirect space heating systems:
Indirect space heating systems use an intermediate heat transfer medium, such as water or a water/glycol mixture to capture solar thermal energy for space heating purposes. These systems are typically very similar to solar water heating systems. They use solar water heating collectors to heat a fluid and then pipe this heated fluid to heat exchangers where the fluid is used to heat the air in a conditioned space. The heat exchangers used in these systems can include in-duct water-to-air heat exchangers or hydronic radiant heating systems. Indirect space heating systems will often serve dual purposes by providing both space heating and domestic water heating.

3.1.3 Solar Cooling and Dehumidification

Solar-driven cooling systems in general are less mature than other BIST; however, the underlying cooling technologies that they rely on are all proven, mature technologies. Many of the current technologies have been adapted from large-scale, waste-heat-driven cooling or direct gas-fired tri-generation (electricity, heating & cooling) systems, in which heat drives a cooling cycle. To date, the majority of solar space cooling systems have been installed in commercial and industrial buildings, due to the availability of excess heat in these facilities and the cost advantages of large-scale systems. Traditionally, the primary solar cooling and dehumidification technologies include solar desiccant dehumidification, absorption cooling, and adsorption cooling, as described below. However, recent research shows that due in part to the projected reductions in PV prices, PV-driven vapor compression cooling may become a cost-effective alternative to solar thermal cooling.[21]

---

[20] Image Source: solarwall.com/en/products/solarwall-air-heating/solarduct.php
[21] "Prospects for solar cooling – An economic and environmental assessment" T. Otanicar, R. Taylor, P. Phelan, *Solar Energy* 86, pp. 1287 – 1299, 2012

Solar desiccant dehumidification (SDD):
SDD systems use solid or liquid desiccant materials to draw latent heat out of the air in a conditioned space, improving occupant comfort and indoor air quality, and reducing the likelihood of mold/mildew formation. Thermal energy from a solar collector then regenerates the desiccant materials (removing the water from the desiccant) to be reused in the cycle.

Recent R&D of SDD systems includes combining SDD systems with other building cooling technologies such as enthalpy wheel heat recovery systems, or vapor compression cycles (VCC), creating high efficiency hybrid cooling systems. Figure 3-4 shows an example of one such hybrid cooling system.

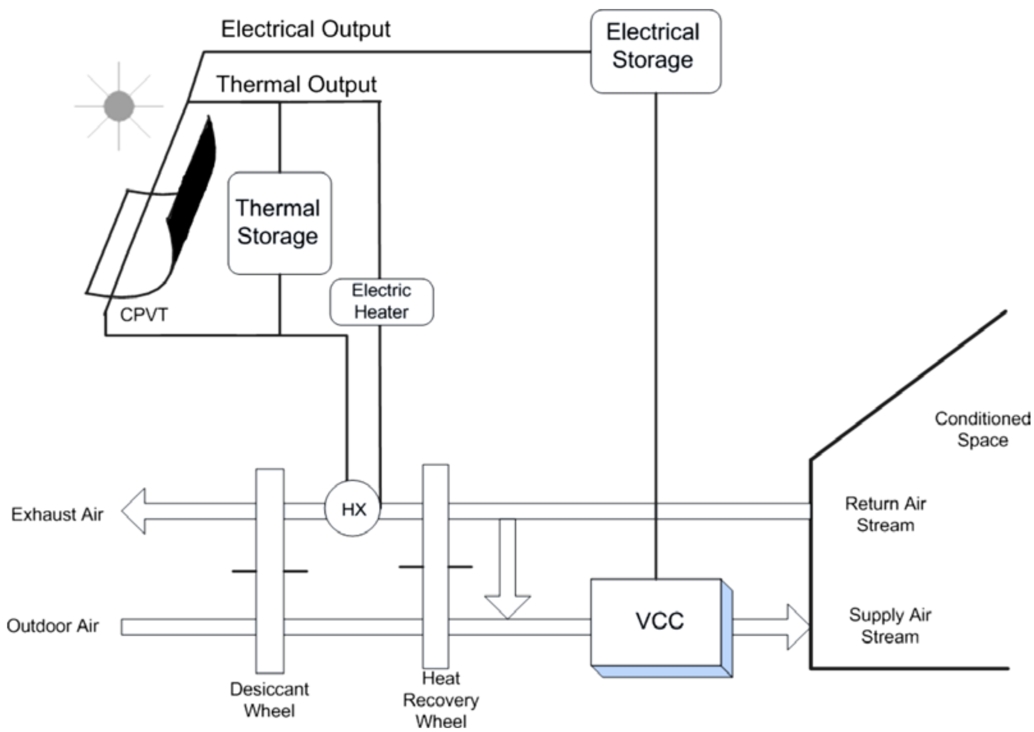


Figure 3-4: Schematic of Hybrid Solar Cooling System[22]

Absorption cooling:
Absorption cooling systems use heated liquid from solar thermal collectors to drive a thermochemical cycle. The system relies on a working fluid consisting of a refrigerant and an absorbent, which have a high affinity for each other.[23] Cooling is achieved in the evaporator as the refrigerant boils, at very low pressure, and extracts heat from the conditioned space. The refrigerant then flows to the absorber, which absorbs the refrigerant into a liquid mixture, giving

[22] Al-Alili, A., Hwang ,Y., Radermacher, R., Kubo, I.,(2012), "A high efficiency solar air conditioner using concentrating photovoltaic/thermal collectors", Applied Energy 93, 138–147
[23] Source: "How Absorption Cooling Works", www.eere.energy.gov/basics/buildings/absorption_cooling.html

off heat in the process. To separate the refrigerant and absorbent for reuse, the solution is boiled in the generator using heat from solar thermal collectors. An air-cooled condenser or a water cooling loop condenses the refrigerant and the process is repeated.[24] A pump circulates the working fluid.

Figure 3-5 shows a simplified schematic of a single-effect absorption cycle, which is the simplest type of absorption chiller. Multi-effect absorption chillers are also available, consisting of multiple absorption cycle generators coupled together to increase the performance of the system. However multi-effect systems typically require higher input temperatures than single-effect systems so they are more difficult to realize for solar applications.[25]

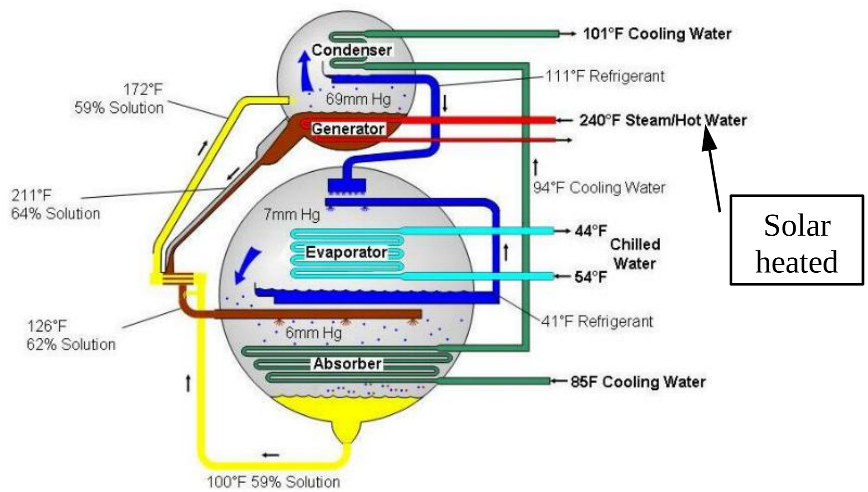


Figure 3-5: Single-Effect Absorption Cooling Cycle[26]

Adsorption cooling:
Figure 3-6 shows a simplified schematic of an adsorption cooling cycle. Adsorption cooling systems use a refrigerant (typically water) and desiccant materials, (often silica-gel) to drive a thermal cycle in which the desiccant attracts and adsorbs the refrigerant vapor, causing the refrigerant to evaporate. As the refrigerant evaporates it removes heat from the warm source (the conditioned space). Thermal energy from solar collectors then regenerates the desiccant so that it can absorb more of the refrigerant and the process can be repeated.[27]

[24] Federal Technology Alert: Parabolic-Trough Solar Water Heating, www1.eere.energy.gov/femp/pdfs/FTA_para_trough.pdf
[25] "A review of absorption refrigeration technologies", P. Srikhirin et al., February 2001, users.ntua.gr/rogdemma/A%20Review%20for%20Absorption%20Refrigeration%20Technologies.pdf
[26] Image Source: www.gasairconditioning.org/absorption_how_it_works.htm
[27] "Development of a new 2.5 kW adsorption chiller for heat driven cooling" E.J. Bakker, R. de Boer, March 2010, www.ecn.nl/docs/library/report/2010/v10008.pdf

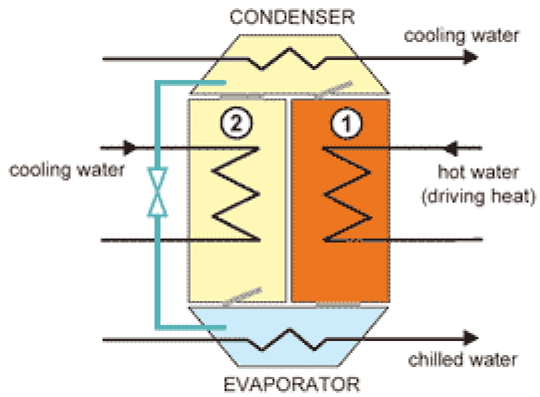


Figure 3-6: Adsorption Cooling Cycle[28]

In general, absorption cooling systems are more common than adsorption cooling systems. Currently, the only widely available solar driven adsorption or absorption chillers are designed for large commercial- and industrial-scale applications. Some chillers exist for small commercial applications, and we have identified at least one manufacturer in the process of developing residential-scale solar driven adsorption and absorption chillers. The most common drawbacks to these systems are that they require relatively high temperature fluids, have limited efficiencies, and have high capital costs.

3.1.4 Other Technologies (Solar Cogeneration, BIPV, and Solar Lighting)

Solar Cogeneration

Solar cogeneration systems are building-integrated systems that are capable of converting solar energy into both electrical and thermal energy. Solar cogeneration systems include technologies for hybrid solar collectors, such as PV/T. Additionally, solar cogeneration includes solar-driven CHP (combined heat and power) engines, such as solar-driven organic Rankine cycle engines (ORC).[29] Utility-scale solar cogeneration systems are outside the scope of this report.

PV/T systems combine PV panels with solar thermal collectors, producing a dual-purpose system. Incorporating a thermal collector into the PV panel improves the performance of the PV system as it provides a way to remove excess heat from the PV material, therefore increasing the efficiency of the PV system. PV/T systems use either solar water heating or air heating technologies for the thermal components. Figure 3-7 shows the basic design of a PV/T water heating system (a), and a PV/T air heating system (b). PV/T systems can also be integrated into the exterior envelope or components of a building. These systems are known as Building-integrated PV/T (BIPV/T) systems.

[28] Image Source: www.raee.org/climatisationsolaire/gb/solar.php
[29] We distinguish between the terms CHP and cogeneration, which are often used interchangeably. In this report CHP is one type of cogeneration. Additional types include both flat-plate and concentrating hybrid PV/T, which produce both electricity and thermal energy.

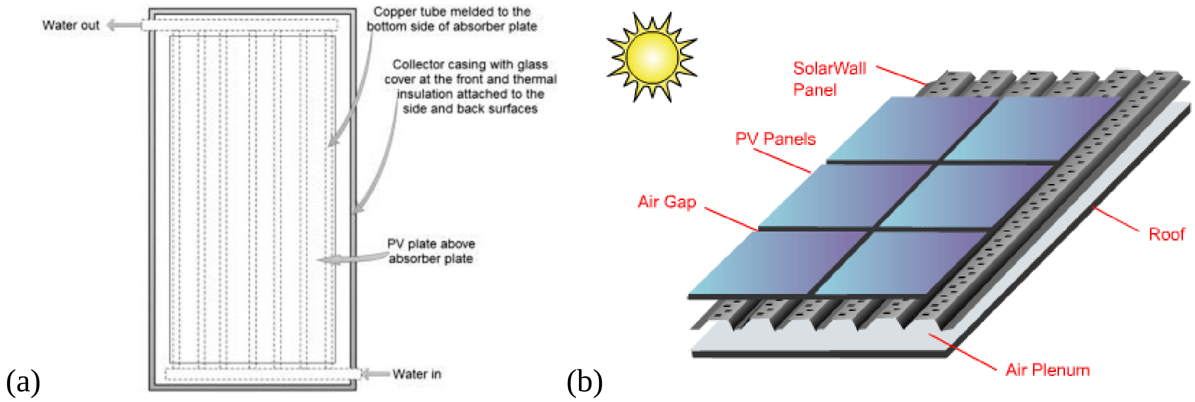


Figure 3-7: (a) PV/T Water Heating System[30] (b) PV/T Air Heating System[31]

Building Integrated Photovoltaics (BIPV)

BIPV include electricity-generating PV modules that are integrated into a building's exterior, including, for example, wall panels, windows/doors, or roofing tiles. BIPV modules can provide the dual benefits of generating electricity and serving as the building envelope.

Solar Lighting

Solar lighting includes passive lighting solutions such as light pipes and skylights, in addition to active solar lighting systems. Figure 3-8 shows the basic components in an active solar lighting system. These systems often use a solar tracking and concentrating collector to focus the collected solar radiation into a fiber-optic cable, which in turn distributes it throughout a building and disperses it via specially designed lighting fixtures. These fixtures often include traditional lighting elements to supplement the solar lighting as necessary. Active solar lighting systems can also incorporate control strategies capable of monitoring available light levels and optimizing the balance of solar and artificial lighting to maximize the efficiency of the system.

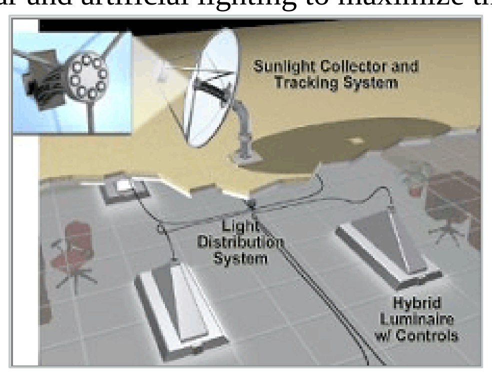


Figure 3-8: Example of Active Solar Lighting[32]

[30] Image Source: www.sciencedirect.com/science/article/pii/S1359431111003310
[31] Image Source: solarwall.com/en/products/solarwall-pvt/how-solarwall-pvt-works.php
[32] Image Source: www.daviddarling.info/encyclopedia/H/AE_hybrid_solar_lighting.html

3.2 BIST Market Summary

The most technologically mature and widely commercialized BIST are those for solar water heating. Solar water heating systems have existed for decades, though the demand for them has varied over time. Although BIST span a number of different markets, most BIST face similar challenges and barriers.

One of the most significant barriers for all BIST is high first cost. Figure 3-9 shows the price trends for medium-temperature solar thermal collectors and PV modules over a 20-year span from 1990 to 2010. During this period the price of solar PV modules dropped by nearly 80%, which is the main driver behind the substantial market growth. However, the price of medium-temperature solar thermal collectors increased over that same period. Studies have found that during this period the average efficiency of solar thermal collectors has remained relatively steady and may have decreased slightly as manufacturers attempt to lower costs by using lower quality materials.[33] This increasing price trend from 1990 onward, can be attributed to a certain degree to the significant rise in the price of copper over that period, as copper is one of the primary materials used in many solar thermal collectors (discussed further in Section 4.1.1).

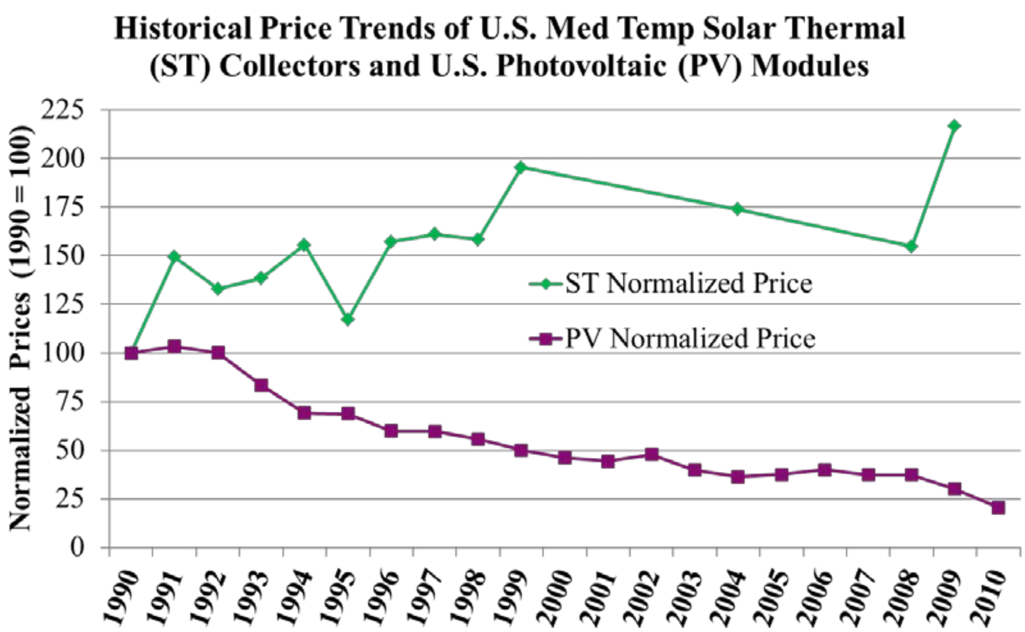


Figure 3-9: Historical Price of Solar Thermal Collectors[34]

[33] Bennouna Amin "The Global Offer of Solar Water Heaters", Faculty of Sciences Semlalia Marrakesh, Morocco, analysis of 546 tests of solar thermal collectors, available: http://smsm.fsac.ac.ma/congres/9congres/Proceedings-PDF/VOLUME-II/T-08/0828.pdf

[34] ST collector prices for medium temperature collectors (110° F to 180° F) only. ST collector shipment data from 2000-2003 & 2005-2007 not available. ST collector prices have been normalized based on the price in 2010 $/Sq Ft. PV module prices have been normalized based on the price in 2010 $/Peak Watt. PV and ST normalized prices based on inflation adjusted prices in 2010 dollars. ST Data Source: EIA Database, www.eia.gov/totalenergy/data/annual/showtext.cfm?t=ptb1006. PV Data Source: EIA Database,

The BIST market has experienced varied growth cycles over time due to external market factors such as conventional energy prices, federal and local policies, and fluctuating financial markets. For example, Figure 3-10 shows the annual shipments of low-temperature and medium-temperature solar thermal collectors from U.S. manufacturers, dating back to 1974. Low-temperature collectors operate below 110° F, while medium-temperature collectors operate between 110° F and 180° F. Typically, low-temperature collectors serve pool heating applications and medium-temperature collectors serve residential and small commercial-scale water heating applications.

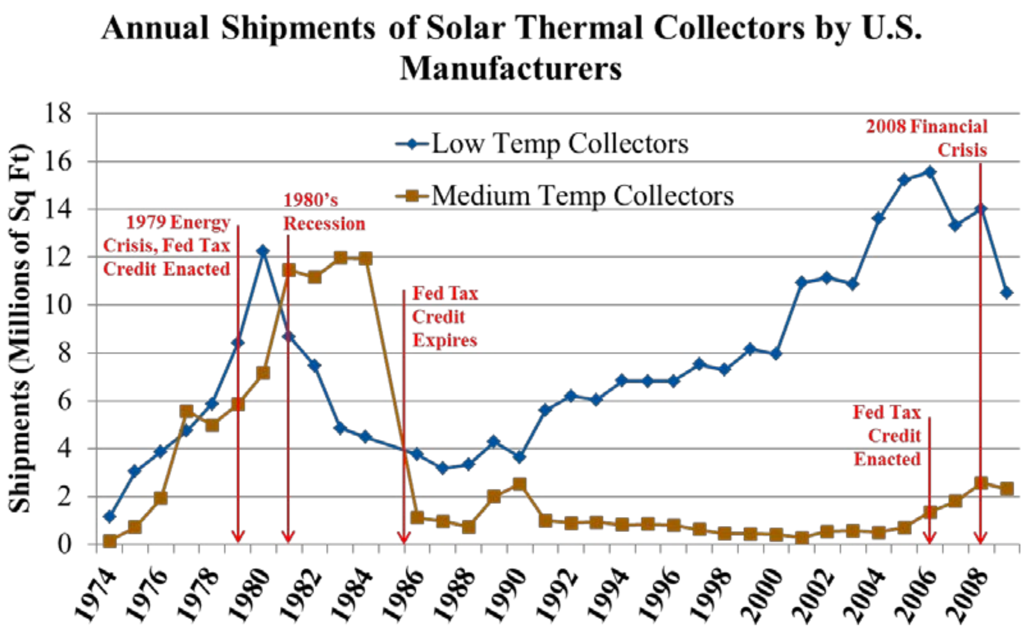


Figure 3-10: Annual U.S. Shipments of Solar Thermal Collectors[35]

The solar thermal market experienced significant growth throughout the 1970s, due to a period of favorable policies and higher conventional fuel prices, however the market declined steeply after this period ended in 1986. From 1987 to 2006, the low-temperature collector market rebounded, growing at a compounded annual growth rate (CAGR) of roughly 8%. In comparison, the market for medium-temperature collectors did not recover and remained relatively stagnant over that same period. The most probable cause for this behavior is the lower installed cost and reduced payback period for low-temperature collectors. Although it should also be noted that low-temperature collectors (used in pool heating applications) are often installed for the added benefit of improving pool comfort, not just energy savings.

---

www.eia.gov/totalenergy/data/annual/showtext.cfm?t=ptb1008. Inflation Data Source: Bureau of Labor Statistics, www.bls.gov/data/inflation_calculator.htm

[35] Data Source: www.eia.gov/totalenergy/data/annual/showtext.cfm?t=ptb1006, Data not available for 1985

Figure 3-11 shows both a) the number of U.S. manufacturers of low- and medium-temperature solar thermal collectors, and b) the annual shipments per manufacturer, dating back to 1974. The favorable environment for solar water heating systems in the 1970's caused the number of manufacturers of medium-temperature solar thermal collectors to rise to nearly 300 manufacturers in 1977. However, as the market began to contract in 1985 the number of U.S. manufacturers of medium-temperature collectors fell dramatically, declining by 83% from 1977 to 1987.

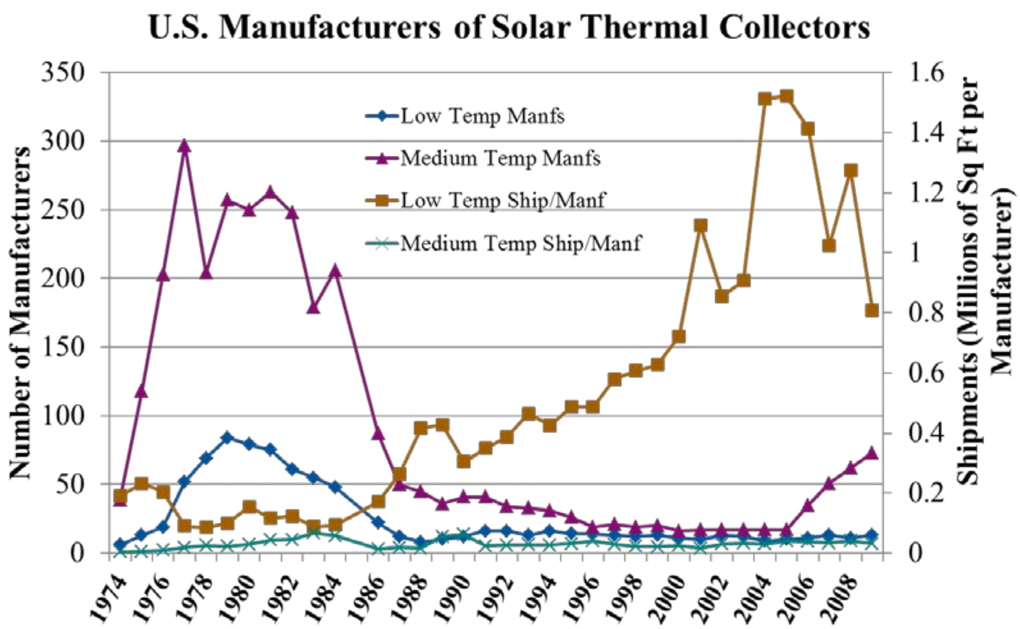


Figure 3-11: U.S. Manufacturers of Solar Thermal Collectors[36]

Although the number of low- and medium-temperature solar thermal collector manufacturers declined in the 1980s, the low-temperature collector market quickly rebounded and U.S. manufacturers of low-temperature collectors were able to increase their output per manufacturer substantially compared to medium-temperature collector manufactures.

As Figure 3-10 above shows, the medium-temperature collector market has not experienced significant growth over the past 20 years. Largely as a result of the price trends shown in Figure 3-9, solar thermal systems have not been able to capture a significant share of the U.S. water heating market. Despite decades of development and federal support, solar water heating still accounts for less than 1% of the U.S. residential and commercial water heating market (see Figure 3-12).

[36] Data Source: www.eia.gov/totalenergy/data/annual/showtext.cfm?t=ptb1006, Data not available for 1985

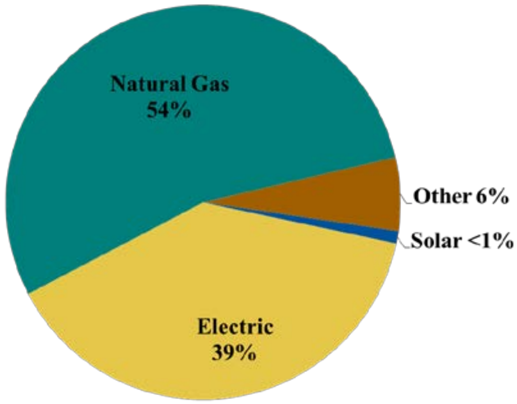


Figure 3-12: Percentage of Residential and Commercial Water Heaters by Energy Source[37]

Other BIST have not been commercially available for as long as solar water heating systems, but many face similar barriers and so far have achieved lower market penetration than solar water heating. Technological barriers and challenges to BIST are described in greater detail in section 3.3.

3.3 Technological Challenges and Barriers

BIST currently face many technical and market challenges. Market challenges such as low customer awareness, policy issues and a lack of financing options are outside the scope of this report (although addressing these challenges will be critical to the success of the BIST industry). However, there are many technological challenges that this report aims to address through potential targeted R&D efforts. Table 3-1 identifies the primary technological barriers, and detailed descriptions of each barrier.

[37] "Low-Cost Solar Water Heating Roadmap" NREL Technical Report TP-5500-54793. K. Hudon, et al. August 2012

Table 3-1: Summary of Technological Barriers

ID No.	Barrier Title	Barrier Description
1	First-cost disadvantage	BIST suffer from a significant first-cost disadvantage relative to incumbent technologies.
2	Solar mismatch	BIST cannot collect energy at night. Further, many buildings have disparities between peak demand for solar energy and peak availability of solar resources.
3	Lack of integration	There is a lack of integrated and packaged turnkey products in the BIST market.
4	Aesthetic Concerns	Some consumers find BIST to be aesthetically unappealing.
5	Perceived unreliability	Historically BIST have had a reputation for being unreliable and not performing as advertised.
6	High temp requirements	Some BIST such as solar cooling require high temperature thermal input to operate efficiently.
7	Insufficient Solar Insolation	Many buildings have insufficient solar insolation due to either the climate, roof orientation, or shading.
8	Physical Space Constraints	BIST can occupy significant amounts of space on or inside buildings, which can limit potential installations.
9	Lack of Well-Validated Tools	The BIST industry lacks well-validated design, estimation, and modeling tools.
10	Permitting and code limitations	Building codes and permits can add significant cost and time to BIST installations.

General sources include: NREL[38] (specifically barrier 10) and Navigant[39] (specifically barriers 1, 2, 3, 6)

- **First-cost disadvantage:**
  The most significant barrier to greater market penetration of BIST is the large installed-cost differential between BIST and incumbent technologies. In many cases the high installed cost of BIST can lead to payback periods beyond what most consumers are willing to accept, severely hindering market penetration. In addition, BIST now have to compete with other energy efficient technologies, which offer similar levels of primary energy savings (depending on location, equipment efficiency, and more), but are significantly cheaper to install. Installing BIST in existing buildings, as opposed to new construction, presents additional cost challenges, particularly for those BIST that require extensive integration with the building (e.g., integration into the envelope/façade).

[38] "Low-Cost Solar Water Heating Roadmap" NREL Technical Report TP-5500-54793. K. Hudon, et al. August 2012

[39] Navigant Presentation, "Solar Heating and Cooling R,D&D Review – Interim Report", April 2011 , W. Goetzler, J. Paidipati, M. Duaime

- **Solar mismatch:**
  Solar technologies inherently face a challenge due to intermittent availability during the day and a lack of solar resources at night. Further, the peak demand for solar energy does not always align with the availability of solar resources. Residential buildings typically experience a mismatch at night, when water and space heating loads can remain high but solar resources are unavailable. This is less of a concern for commercial buildings, which usually have their greatest energy demands during the daytime. However, all building types experience a mismatch during the summer months, when solar resources are generally most abundant but the demand for solar thermal energy is usually low (with the exception of buildings with solar cooling systems).

- **Lack of integration:**
  Although some packaged SWH systems are commercially available, historically, installers custom design BIST system, leading to increased labor and installation costs. To reduce these costs, manufacturers need to offer more fully-integrated systems that are prepackaged and allow for simple plug-and-play installation.

- **Aesthetic concerns:**
  Some consumers may find the appearance of BIST to be unappealing, and would therefore be hesitant to install a BIST system.

- **Perceived unreliability:**
  Early generations of solar technologies developed reputations for poor reliability and poor performance. In particular, solar water heating systems triggered concerns among consumers regarding piping leaks and issues with freezing, which could potentially cause significant damage to buildings, requiring expensive repairs. Recently, improved manufacturing, rating, and certification processes have improved the reliability of these systems significantly; however this notion still remains in the minds of some consumers.

- **High temperature requirements:**
  Some BIST, such as solar cooling systems, require relatively high temperature (above ~180° F) thermal energy to operate. Traditionally, these high temperatures can only be reached using expensive concentrating, tracking collectors, which significantly increase the cost and complexity of the system.

- **Insufficient solar insolation:**
  A fundamental barrier to many BIST installations is limited solar insolation (solar radiation on a given surface). Many buildings have low solar insolation due to either the climate in which the building is located or the orientation of the roof or building relative to the sun. Also, some buildings are shaded for a significant portion of the day, which reduces the solar insolation reaching the building.

- **Physical space constraints:**
  Some BIST can occupy a significant amount of space either on top of or inside of buildings. Particularly in retrofit applications, where buildings may not be designed with

BIST in mind, it can be very difficult to find sufficient space to install some BIST systems.

- **Lack of well-validated tools:**
  The BIST industry has a lack of well-validated design, estimation, and modeling tools. Some tools currently exist but many stakeholders feel that to date, most of these tools have not been properly validated. In addition to validating existing tools, there is also a need for tools with a wider range of capabilities. In particular, the industry needs simplified estimation tools for public use, as well as more powerful BIST design software tools for industry professionals to use in designing and sizing BIST systems.

- **Permitting and code limitations:**
  Many current building codes do not easily accommodate BIST. These codes were developed without BIST in mind. To accommodate BIST, codes would have to be revisited and revised while maintaining the performance and safety needs of buildings. In addition, lengthy permitting processes can add significant cost and time to BIST installations.

3.4 Ongoing Work

Researchers and industry leaders are working to solve many of the challenges and barriers identified in Section 3.3 above. Some examples of recent publications and ongoing programs in the industry are outlined below.

Global Level:

» **International Energy Agency (IEA)**
  - *Technology Roadmap: Solar Heating and Cooling* – "This roadmap aims to identify the primary actions and tasks that must be addressed to accelerate solar heating and cooling development and deployment globally."[40]
  - *IEA Solar Heating and Cooling Programme* – Mission: "To continue to be the preeminent international collaborative programme in solar heating and cooling technologies and designs."[41]

National Level:

» **Solar Energy Industries Association (SEIA)**
  - *U.S. Solar Heating and Cooling Alliance Advocacy Fund* – "The U.S. Solar Heating & Cooling Alliance Advocacy Fund was created specifically to address the needs of the solar heating and cooling industry and to fund industry priorities."[42]

[40] "Technology Roadmap: Solar Heating and Cooling", International Energy Agency, 2012 www.iea.org/publications/freepublications/publication/2012_SolarHeatingCooling_Roadmap_FINAL_WEB.pdf
[41] IEA Solar Heating and Cooling Programme, www.iea-shc.org/programme-description
[42] SEIA, www.seia.org/about/seia/special-initiatives/us-solar-heating-cooling-alliance-division-seia/us-solar-heating

- *U.S. Solar Heating and Cooling Roadmap* – "The roadmap will show how solar heating & cooling can be a fundamental piece of the U.S. energy portfolio, and will be used to advocate to policymakers on the benefits and potential of solar heating & cooling technologies." [43]

» **National Renewable Energy Laboratory (NREL)**

- *Low-Cost Solar Water Heating R&D Roadmap* – Objective: "Identify the target market for solar water heaters (SWHs) that will provide the largest U.S. energy savings potential relative to other advanced water heating technologies." [44]
- *Building Integrated Photovoltaics (BIPV) in the Residential Sector: An Analysis of Installed Rooftop System Prices* – "This report shows the potential for BIPV to achieve lower installed system prices than rack-mounted PV, but BIPV systems are likely to experience reduced performance (i.e., electricity generation) in comparison with PV systems." [45]

<u>*State Level:*</u>

» **State Organizations**

- *Solar Thermal Alliance of Colorado* – "The Solar Thermal Alliance of Colorado (STAC) is a task force under the joint leadership of the Colorado Renewable Energy Society (CRES) and the Colorado Solar Energy Industries Association (COSEIA) in collaboration with dozens of energy leaders across Colorado." [46]
- *California Solar Initiative (CSI) – Thermal Program* – "The CSI-Thermal Program is designed to significantly increase the adoption rate of SWH technologies into the California marketplace. The program strategy and design principles will address the barriers to growth, namely installation costs, lack of public knowledge about SWH, permitting costs and requirements, and a potential shortage of experienced installers." [47]

---

[43] SEIA, "Solar Heating and Cooling: Energy for a Secure Future," 2013, information available: www.seia.org/about/seia/special-initiatives/us-solar-heating-cooling-alliance-division-seia/us-solar-heating

[44] "Low-Cost Solar Water Heating Roadmap" NREL Technical Report TP-5500-54793. K. Hudon, et al. August 2012

[45] "Building-Integrated Photovoltaics (BIPV) in the Residential Sector: An Analysis of Installed Rooftop System Prices" NREL Technical Report TP-6A20-53103. T. James et al. November 2011

[46] Solar Thermal Alliance of Colorado, www.coloradorts.org/

[47] "California Solar Initiative – Thermal Program, Program Handbook", February 2013, www.gosolarcalifornia.org/documents/CSI-Thermal_Handbook.pdf

4 2030 Vision

In developing this report, DOE seeks to define a portfolio of technology R&D opportunities that represent the most cost effective pathway to help achieve DOE's energy savings targets for 2030. DOE's approach focuses on identification of the most viable technologies in the market that can achieve the necessary energy savings, and is not tied directly to specific subsets of technologies. The technology initiatives discussed in section 5, represent potential options that may be a part of a successful technology portfolio.

4.1 Competitive Landscape

Understanding the potential environment in which DOE-supported technologies and processes may operate in between now and 2030 (and beyond) is vital in trying to identify the optimal path to pursue to achieve energy savings goals. For example, changing energy prices affect the potential viability of competitive technologies and the payback of BIST relative to conventional alternatives. The following sections highlight some of the key, external variables that will define the cost-effectiveness of BIST technologies in the future.

4.1.1 Market Factors

As Figure 4-1 shows, U.S. Energy Information Administration's (EIA) Annual Energy Outlook (2013 Early Release) forecasts only 1.4% growth in electricity prices between 2012 and 2030; this slow growth is certainly good for consumers, but means that the cost dynamics of BIST investments will not be able to benefit from increasing conventional energy prices (a common assumption). Weak demand in the post-2008 recession years actually led to slight reductions in electricity prices driven by slightly negative demand growth in both 2009 and 2010.[48]

EIA projects that residential prices for natural gas and fuel oil, the other two primary competitive energy sources for solar thermal technologies, will increase by 31% and 18%, respectively, by 2030. For natural gas, this growth brings prices back to mid-2000s levels, before the recession and the growth of hydraulic fracturing opened up new shale gas reserves in the U.S. that initiated the price reductions in the late 2000s. Fuel oil prices are projected to grow steadily and may still provide some opportunity for solar thermal technologies to be cost competitive; however, fuel oil infrastructure is limited, mostly to the northeast. For BIST, these projected energy prices show promise for markets where building/home owners commonly heat with fuel oil, but less so for those who use natural gas or electricity, unless substantial gains are made in cost effectiveness.

[48] EIA data show gradual decrease in demand growth since 1950 when demand growth was greater than 10% annually. Since 1950, no other year exhibited negative demand growth. Data available at: www.eia.gov/forecasts/aeo/MT_electric.cfm

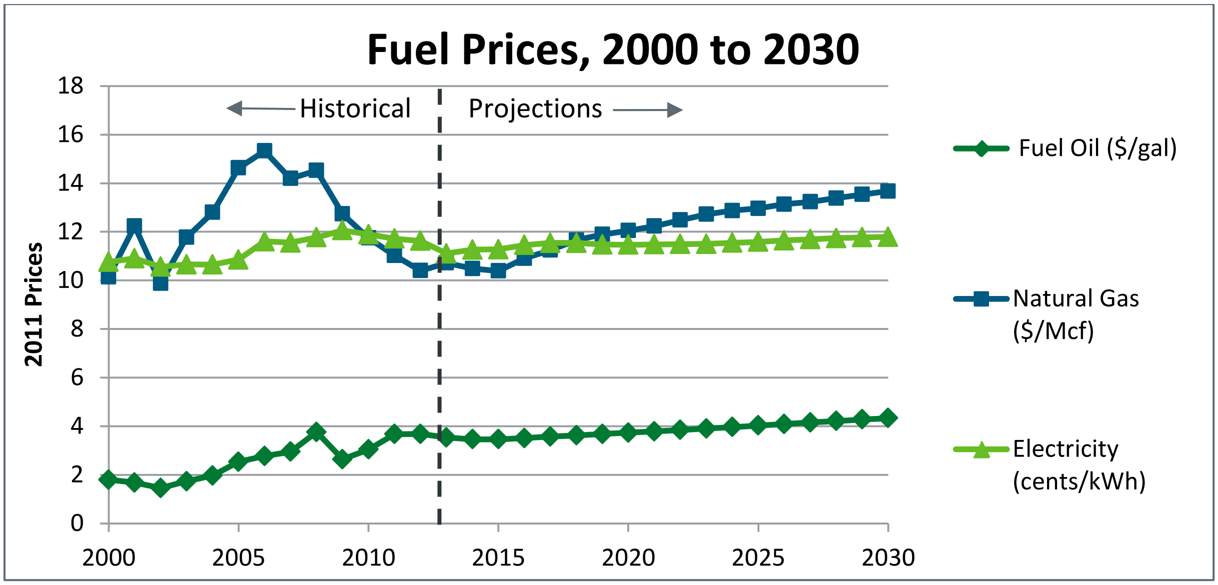


Figure 4-1: Historical and Projected Residential Energy Prices[49]

New energy efficient technologies often capitalize on high and increasing energy prices to get initial market traction and help reach greater economies of scale. Lower energy prices may require the BIST industry to make larger up-front investments to achieve better economies of scale and lower prices before gaining substantial market penetration; the industry does not benefit from gradually decreasing payback periods simply due to increasing energy prices. This scenario challenges the common assumptions about the optimal technologies solutions and opens doors for new, transformative innovations.

In addition to fuel prices, raw material prices greatly impact the cost of BISTs to consumers. BIST, especially solar thermal technologies, are particularly susceptible to increasing copper and other commodity prices. The cost of copper increased from $1,813 per metric ton (mt) in 2000 to $7,962/mt in 2012, an increase of 440% over 12 years. Current projections from The World Bank are more favorable and show copper prices decreasing gradually by 14% to $6,800/mt by 2025.[50] Unless industry is able to move away from the use of large quantities of commodities like copper, solar thermal technologies will be at a price disadvantage compared to PV, which relies on polysilicon, for which DOE expects a continuing downward pricing trend.[51]

---

[49] Units are as follows: Natural gas – dollars per thousand cubic feet ($/mcf), electricity – cents per kilowatt-hour (c/kWh), oil – dollars per gallon ($/gal). Projected prices from the Energy Information Administration's (EIA) Annual Energy Outlook (AEO) 2013, Early Release, available at: www.eia.gov/forecasts/aeo/er/index.cfm. Historical data from EIA records, available at www.eia.gov/forecasts/steo/realprices/

[50] Copper prices from WorldBank.org "Commodity Price Forecast Update" January 2013; available at: siteresources.worldbank.org/INTPROSPECTS/Resources/334934-1304428586133/Price_Forecast.pdf

[51] Polysilicon prices from forecast on p. 34 of "2008 Solar Technologies Market Report," January 2010, U.S. Dept. of Energy. Available at: www1.eere.energy.gov/solar/pdfs/46025.pdf.

4.1.2 Advanced Alternative Technologies

Advanced alternative technologies may be able to provide a lower cost of conserved energy and therefore a more cost-effective path for DOE to achieve energy savings goals. Energy efficiency in general can provide lower-cost energy savings than traditional BIST. The California Solar Initiative, among other rebate programs, requires that homeowners undergo energy audits prior to installing expensive renewables.[52] By reducing energy consumption for BIST-impacted loads, such as water heating (e.g., low-flow showerheads), space conditioning (e.g., insulation and windows), or other electric loads, the BIST system can be sized more appropriately and cost less to install. Other specific technologies that compete with BIST are described below:

Water Heating:

Heat Pump Water Heaters (HPWH) are highly efficient alternatives to traditional electric water heaters. The annual energy cost of a heat pump water heater installed in an average household is approximately $190 per year (although this can vary significantly based on climate and location within the building). In comparison, the annual energy cost for a standard electric water heater installed in the same home is roughly $463 per year.[53] Performance expectations in 2030 are unclear, but based on recent mass-market availability and cost competitiveness; HPWH are already presenting challenges to long-standing water heating technologies.

Condensing Gas-Fired Water Heaters are now available from many manufacturers and provide a cost-effective high-efficiency water heating option for consumers with access to natural gas. While this technology is most common in commercial applications, residential products may be available on the market in the coming years. The ACEEE estimates that annual energy cost for a condensing gas water heater is approximately $244 per year, compared with roughly $350 per year for a conventional gas storage water heater.[54] The operating costs are reduced even further in regions with particularly high electricity prices.

Space Conditioning:

Advanced Heat Pumps, both modern air-source (ASHP) and geothermal (ground-source, i.e., GHP), provide high efficiency alternatives to conventional heating and cooling technologies, plus increased comfort due to variable-speed operation. Though GHPs have higher installed costs due to the need for an in-ground heat exchanger, ASHP's save energy with a much lower installed cost. A Navigant Consulting Report from 2009 estimates that the best available GHP costs $5250 per ton to install, while the best available ASHP costs $2300 per ton to install. The report also estimates that the same GHP, installed in a mid-Atlantic state, would consume 42% less energy in a given year than the ASHP.[55]

---

[52] The California Solar Initiative, for California's investor owned utilities, is an example of such requirements to have an energy audit before a utility rebate can be awarded. Information available: www.gosolarcalifornia.ca.gov/documents/csi_application_help.php

[53] ACEEE life-cycle cost estimates for residential water heaters, available at: aceee.org/consumer/water-heating

[54] ACEEE life-cycle cost estimates for residential water heaters, available at: aceee.org/consumer/water-heating

[55] Navigant Consulting, Inc., "Ground-Source Heat Pumps: Overview of Market Status, Barriers to Adoption, and Options for Overcoming Barriers," Final Report to U.S. DOE, 2009. Cost data from table 3-1. Residential energy use data from Appendix B plot for Mid-Atlantic region. The high-efficiency ASHP consumes 32% less than the

Condensing Gas-Fired Furnaces and Boilers are much like condensing gas-fired water heaters (see above). For consumers with access to natural gas, these commonly available products provide viable, cost-effective, highly reliable alternatives with a lower first cost than current BIST options. However, the energy savings benefits of these technologies do not match those of BIST.

Lighting:

Compact fluorescent lights (CFL) and light emitting diodes (LED) improve efficiency in many cases to the point where installing active solar lighting may not be cost effective. ENERGY STAR light bulbs reduce lighting energy by as much as 80%.[56] Further, solar lighting always requires artificial backup lighting.

Photovoltaics:

With PV modules now selling for less than 60 cents per Watt, photovoltaics present a potential challenge to traditional solar thermal technologies.[57] PV-driven heat-pump water heaters or even PV-driven electric resistance water heaters could become cost-competitive with traditional solar thermal solutions in the near future. In regions with high penetration of electric water heating and high electricity prices, the economics could become very attractive.

For example, a homeowner in 2012 could install a PV-driven 550-Watt heat-pump water heating system for under $8,000 (without grid interconnection). Rooftop PV costs, on average, $5 per watt (also see Figure 4-2 for historical prices).[58] A residential HPWH of this size consumes on average 1830 kWh/yr. For such a home in Boston, Massachusetts, a homeowner with 1.2 kW of PV (for $6,000) would be able to supply enough electricity to cover roughly 80% annual water heating usage (not including any rebates); however, due to solar mismatch with the load, the solar fraction would likely be slightly less.[59] Assuming $1,300 MSRP for the HPWH, and $500 for installation, it would cost the homeowner a total of $7,800.[60] This compares to a solar water heating system that may cost between $6,000 and $10,000 installed.[61, 62]

One potential configuration ties the PV directly to the water heater's controller, thereby requiring no grid interconnection for the PV. It is unclear at this time if such a configuration is optimal.

---

typical AC & natural gas furnace installation in this region. Available at www1.eere.energy.gov/geothermal/pdfs/gshp_overview.pdf

[56] Based on ENERGY STAR savings calculator for qualified light bulbs. Spreadsheet available at www.energystar.gov/?c=cfls.pr_cfls_savings

[57] Data from PV Magazine as of December 2012

[58] PV cost based on 2012 residential average installed cost from Solar Energy Industries Association (SEIA) data, available at: www.seia.org/research-resources/solar-industry-data

[59] Assumes 4.28 kWh/m^2/day solar radiation based on PVWatts data for Boston, MA. See www.nrel.gov/rredc/pvwatts/

[60] Labor cost is a high estimate; Homewyse estimates closer to $300 for labor (www.homewyse.com/services/cost_to_replace_hot_water_heater.html)

[61] "Low-Cost Solar Water Heating Roadmap" NREL Technical Report TP-5500-54793. K. Hudon, et al. August 2012

[62] Wattage, costs, and savings based on GE GeoSpring hybrid heat pump water heater – specifications from: www.geappliances.com/heat-pump-hot-water-heater/water-heater-efficiency-savings.htm

Of course, to achieve 100% energy savings, such a PV-HPWH system would require a large storage tank and/or grid interconnection and net metering to provide energy storage. The cost-effectiveness of a PV-HPWH installation is highly dependent on the climate, storage resources, and conventional fuel prices for a given building. Analysis of large-scale penetration of a grid-tied system with net metering would need to account for the impact to all utility ratepayers of using the grid for storage.

Additionally, a PV-driven water heater may provide greater reliability because it:

- Eliminates all piping to/from the roof (and potential pipe leakage)
- Eliminates the need for freeze and overheat protection

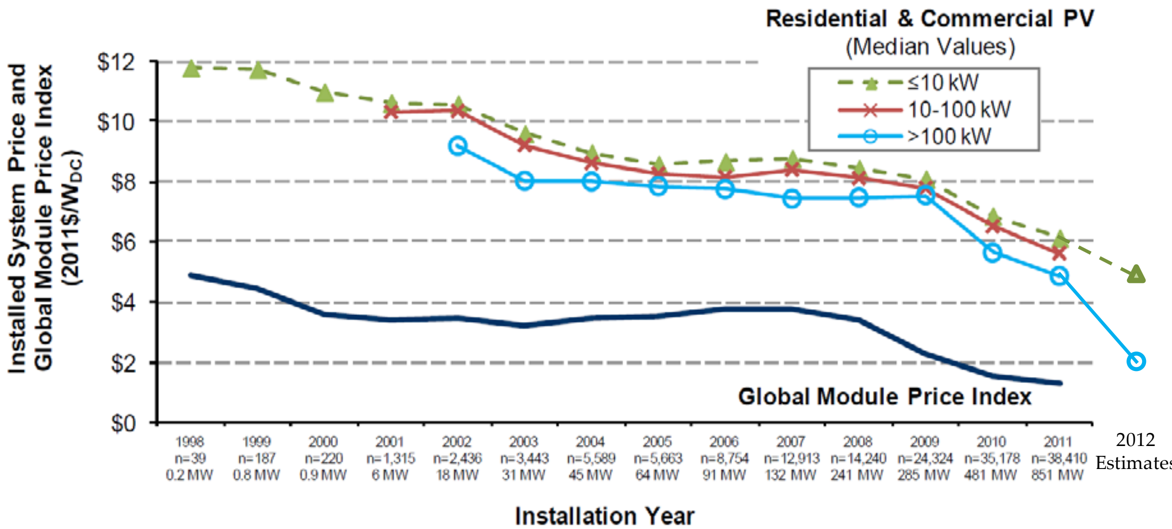


Figure 4-2: PV Installed Price and Module Price 1998-2011[63, 64]

4.2 2030 BIST Market Penetration

To achieve the specified 50% energy savings target by 2030 (see section 1.2), DOE seeks revolutionary new approaches to BIST that provide greater than 60% cost savings compared to current BIST options. For example, a HPWH may cost $2,000 to install, compared to a solar thermal system that may cost between $6,000 and $10,000. Improved BIST efficiency is desirable, but not vital; high-efficiency technologies that are cost-competitive with today's technologies may provide a quicker path to national energy savings targets than best-in-class-efficiency technologies at much higher costs. For each potential R&D activity, DOE targets a 5-year or less simple payback period. This is the cost-effectiveness threshold at which significant market penetration generally begins to occur.

---

[63] DOE Sunshot Initiative Report, "Photovoltaic (PV) Pricing Trends: Historical, Recent, and Near-Term Projections," November 2012. Available at: www.nrel.gov/docs/fy13osti/56776.pdf

[64] 2012 estimates from: SEIA, U.S. Solar Market Insight 2012 Year in Review, Available at www.seia.org/research-resources/us-solar-market-insight-2012-year-review

To understand what portion of DOE savings goals may be achievable with BIST technologies, we looked at the potential penetration rates based on the Fisher-Pry model for predicting diffusion of new technologies.[65] The Fisher-Pry model is one of many models commonly used to forecast market penetration of new technologies, and it is well-suited for our analysis because it is primarily based on simple payback period, one of our primary metrics. We used this model to estimate market penetration in two steps. First we determined the maximum achievable market penetration for a given technology based on its simple payback period, using curves such as those found in Figure 4-3. These curves in particular are based on market penetration estimates for PV technologies, but we assume that they are equally appropriate for BIST. Second, we estimated how long it would take for this technology to reach the maximum achievable market penetration based on the curves found in Figure 4-4. For example, assuming a 5-year target payback (without rebates), we can expect an achievable market penetration of ~25%, based on the residential retrofit market curve in Figure 4-3. While the rate of penetration will vary depending on a variety of market factors (which are outside the scope of this analysis) we use Figure 4-4 to estimate that it will take approximately 25 years to reach a market penetration of 25%.

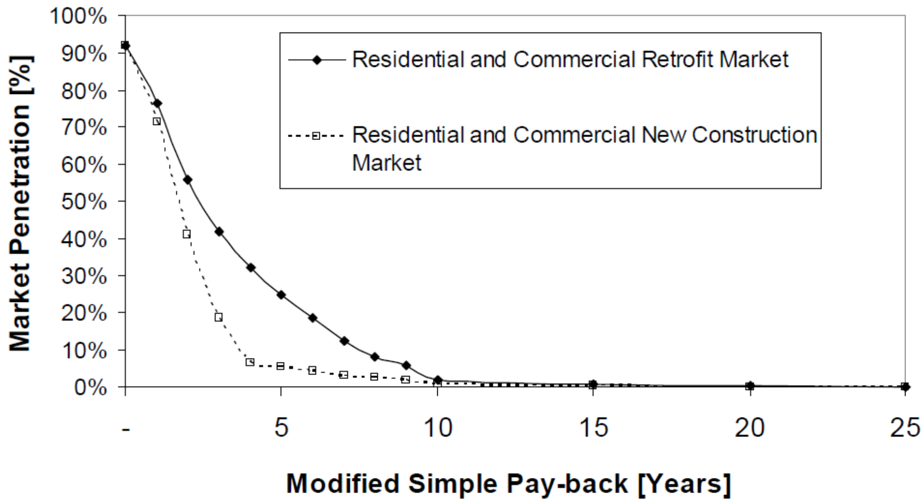


Figure 4-3: Estimated Achievable Market Penetration Curves (for PV)[66]

Transformative changes are needed for the industry to be able to achieve these targets. As Figure 4-4 shows, if we assume today's technologies have an average payback of 9 years (for illustrative purposes only) we would only expect a market penetration of ~8% within 20 years.[67]

[65] The Fisher-Pry model is one of many models commonly used for forecasting product sales and market penetration. Though originally based around industrial technologies, using common assumptions we adjust the model to accommodate commercial and residential technologies. For a discussion and comparison of different models, see Gilshannon and Brown, Pacific Northwest National Laboratory, "Review of Methods for Forecasting the Market Penetration of New Technologies," December 1996. Available at: www.osti.gov/bridge/servlets/purl/432867-q0MdUq/webviewable/432867.pdf

[66] National Renewable Energy Laboratory Subcontractor Report by Navigant Consulting, "Rooftop Photovoltaics Market Penetration Scenarios," February 2008. Assumes that market acceptance for BIST is similar to solar PV.

[67] The assumed 9 year payback is for illustrative purposes only and is not achievable in all markets.

Such a curve is certainly only representative, as the exact nature is dependent upon many variables, including incentives/rebates, turn-over rate, technology risk, regulation, and the strength of the economy as a whole. However, it is clear that, on this current trajectory, the achievable market penetration and associated energy savings falls short of the 50% saving by 2030 target.

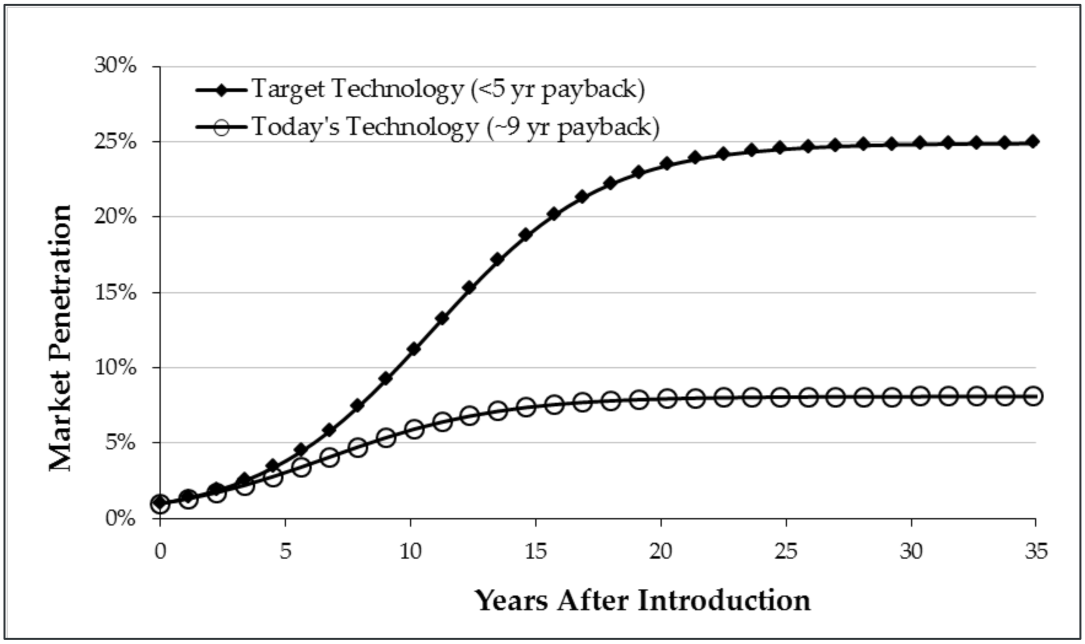


Figure 4-4: Market Penetration Over Time for BIST[68]

As an example, due to the high savings potential for solar water heating, DOE hopes to achieve substantial savings with this technology. However, DOE would need 90-100% market penetration of solar water heating systems to achieve the DOE's goal of 60% savings in water heating with solar technologies alone (which may be feasible, but only in select locations). By pursuing a broad array of technologies, such as HPWH, advanced gas-fired water heaters, and advanced water fixtures, DOE can leverage BIST R&D gains as part of a portfolio of technologies which will help achieve DOE's goal nationwide.

[68] Based on Navigant Fisher-Pry analysis

5 Research & Development Initiatives

5.1 Summary

We selected the top-tier (top 15) initiatives that have the greatest potential to help DOE reach their 2030 energy savings goals using the prioritization process described in section 2.3, above. Table 5-1 lists the top tier initiatives; the applicable barrier numbers for each initiative correspond to the barrier numbering in Table 3-1, above. DOE will evaluate this list of top tier initiatives in the context of their overall portfolio of energy technology funding.

Table 5-1: Top Tier Initiatives

Initiative/Activity	Technology Category	Applicable Barriers
Evaluate Optimal Configurations for PV-Driven Electric Water Heating Systems	Solar Water Heating (& Solar Space Conditioning)	1, 2, 4
Develop and Optimize Solar Energy Systems Capable of Serving Multiple End-Uses	Storage and System Integration	1, 2, 3,9
Develop Tool to Compare Solar Thermal and Other Renewable Energy Technologies for a Given Installation	Controls and Software	9
Reduce Material Costs of Residential and Small Commercial Collectors	Solar Water Heating (& Solar Space Conditioning)	1, 5
Implement a Large-Scale SWH Field Performance Verification Pilot Program for SWH Systems	Solar Water Heating	5, 8, 10
Develop Publicly Available Design and Estimation Tools for BIST	Controls and Software	9
Validate BIST Modeling Software	Controls and Software	9
Expand Capabilities of System Advisor Model (SAM)	Controls and Software	9
Develop Recommended Guidance for Improved State/Local Building Codes, Permits, and Standards	Manf., Installation & Maintenance	10
Update Test and Certification Standards	Manf., Installation & Maintenance	5
Incorporate BIST Into Architectural Modeling Software to Enable Holistic Design Approach	Controls and Software	1, 3, 4, 9, 10
Research and Develop Low-Profile Concentrating, Tracking Solar Collectors	Other Technologies - Solar Cogen (& Solar Water Heating & Space Cond)	1, 6, 8
Improve Residential-Scale Solar Thermal Storage	Storage and System Integration	1
Reduce Installation Costs with the Use of Plug-and-Play Systems	Manf., Installation & Maintenance	1, 3
Develop Improved Building Integration Methods for Dye-Sensitized Solar Cells (DSC)	Other Technologies	1, 3, 4, 8

5.1.1 Discussion

We evaluated 54 initiatives on both market savings potential (as defined in section 2.3) and a spectrum of suitability between DOE and industry for each initiative. Figure 5-1 plots the results for all 54 initiatives and Table 5-2 lists the corresponding ID number for each initiative (See Appendix B for a list of the individual scores for each initiative). The suitability score is based on an average of the "Fit with BTO Mission" and "Criticality of DOE involvement" scores from the prioritization process. The figure helps visualize which initiatives have the best combination of high market savings potential while also being very suitable for DOE to undertake.

Each region of Figure 5-1 represents a different value proposition:

- **DOE Transformative (Top right) –** This is the primary target area for DOE. These initiatives provide the greatest potential contribution to DOE's goals, and are well aligned with DOE's capabilities. *Example Initiative:* Initiative 1, "Develop Tool to Compare Solar Thermal and Solar PV for a Given Installation"

- **DOE Incremental (Bottom right) –** Initiatives in this quadrant are highly suitable for DOE, but provide less market savings potential. DOE considers many of these as second-tier options to be pursued once higher savings initiatives are exhausted. *Example Initiative:* Initiative 26, "Develop Low-Cost Adsorption Chiller"

- **Industry Incremental (Bottom left) –** These are the least desirable initiatives for DOE. They have both low market savings potential and are better suited for industry to address. *Example Initiative:* Initiative 50, "Incorporate Low Cost/High Reliability Storage Tanks Into Solar Thermal Systems"

- **Industry Transformative (Top left) –** These initiatives have high market savings potential, but are best left to industry to address because they are likely to be achieved without DOE involvement. This category is sparsely populated because such initiatives have typically already been addressed by industry, including many low-hanging-fruit for industry. *Example Initiative:* Initiative 29, "Design Easily Deployable Large-Scale Solar Collectors"

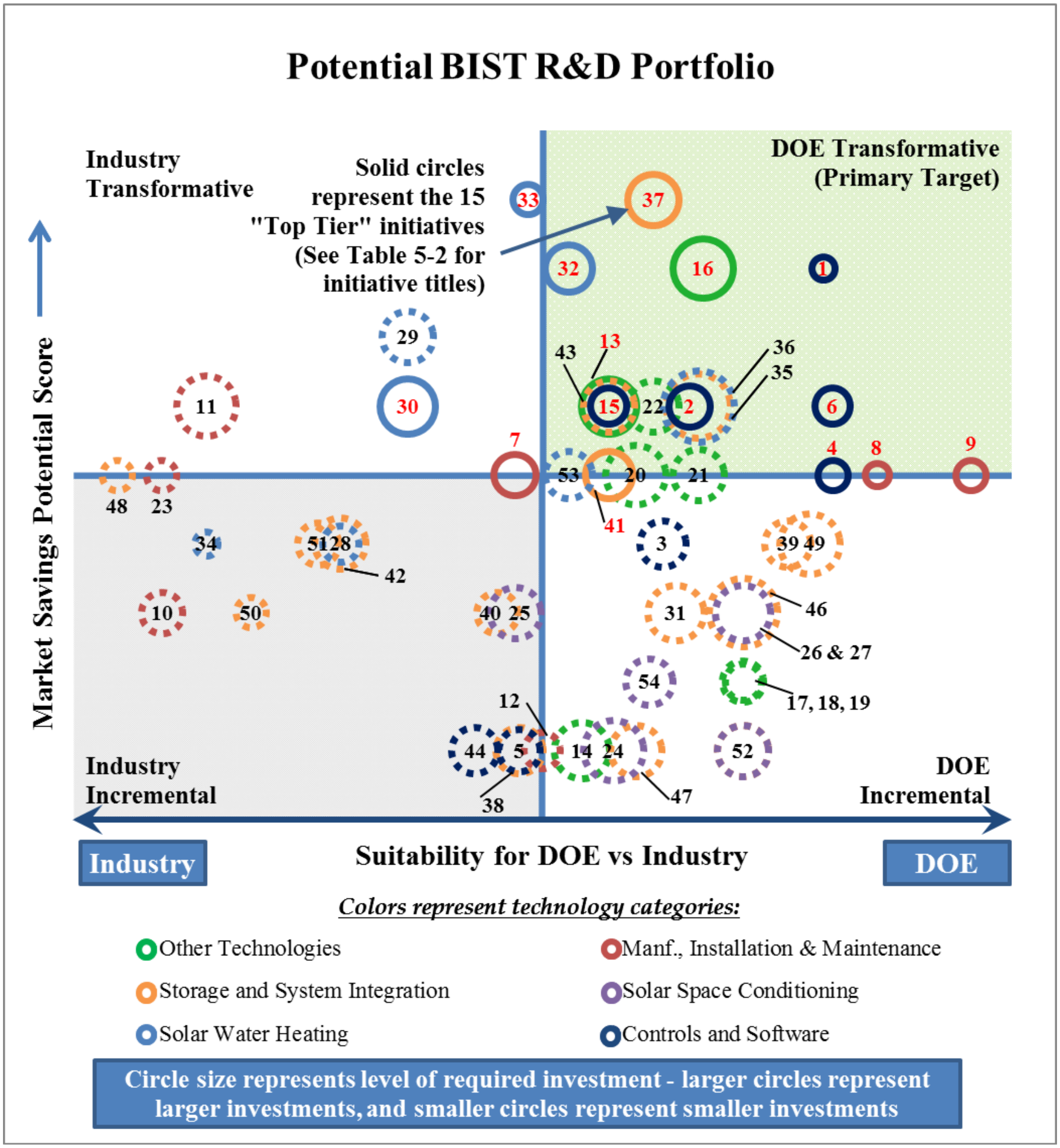


Figure 5-1: Portfolio Summary of All R&D Initiatives

In addition to the quadrants in Figure 5-1, the border areas also provide important findings. Initiatives on the border between the DOE Incremental and DOE Transformative quadrants can be considered as “Enabling Investments.” These initiatives may not have high market savings potential but they may enable advancements in other BIST. The initiatives on the border between the DOE Transformative and Industry Transformative quadrants can be considered as “Partnership Opportunities.” These initiatives may include opportunities for DOE to partner with industry to achieve significant energy savings, such as initiative 33, "Evaluate Optimal Configurations for PV-Driven Electric Water Heating Systems"

Initiatives outside of the DOE transformative quadrant are not necessarily less worthwhile initiatives, they just may not be as valuable to DOE. For example, many of the initiatives in the Industry Incremental quadrant are activities that will benefit BIST, however they only offer incremental improvements and do not require DOE's involvement to be successful. DOE needs to prioritize its decision making to focus on initiatives that require DOE involvement to succeed, and that provide high energy savings potential. DOE can maximize its potential return on investment by supporting R&D initiatives in the DOE transformative quadrant.

Figure 5-1 displays some clear trends of initiative performance by category. Solar water heating initiatives are primarily located in the DOE Transformative region. Solar space conditioning initiatives, however, are primarily located outside of the primary target area for DOE, and all present low market-savings potential. The remaining technology categories are broadly distributed across the plot, including Storage and System Integration; Manufacturing, Installation, and Maintenance; Controls and Software; and Other Technologies (Solar Cogeneration, BIPV, & Solar Lighting). The level of investment for each of the initiatives is fairly evenly distributed across the chart, including the DOE transformative region.

Further, seven initiatives (listed below) fall within the DOE transformative quadrant, but are NOT part of the top tier of initiatives. Primarily this is because these initiatives have risk levels that do not warrant an investment from DOE/BTO (a metric that was not included in the "Suitability for DOE vs. Industry" values used in Figure 5-1). DOE/BTO must ensure that their investments can be commercialized within approximately five years to achieve real, measureable impacts. DOE's Office of Science focuses on those fundamental science and early-stage R&D initiatives that BTO does not. These seven initiatives include: (20) "Research and Develop Systems to Change Reflectivity of Buildings' Envelopes", (21) "Research Potential Opportunities for Solar-Assisted CHP Systems", (22) "Conduct Pilot Testing for Day-Lighting Mirrors with IR-Selective Films", (35) "Research and Develop Thermo/Photo Chemical Processes", (36) "Research and Develop Thermal Storage Systems Based on Latent Heat of Evaporation", (43) "Develop Innovative Mechanisms for Improved Building Integration", (53) "Develop Innovative Stagnation Control Technologies for Solar Thermal Systems".

Table 5-2 lists all initiatives, including their corresponding ID numbers.

Table 5-2: Initiative ID Numbers, by Category

Controls and Software Initiatives	
ID	**Title**
1	Develop Tool to Compare Solar Thermal and Solar PV for a Given Installation
6	Develop Publicly Available Design and Estimation Tools for BIST
2	Validate BIST Modeling Software
4	Expand Capabilities of System Advisor Model (SAM)
15	Incorporate BIST Into Architectural Modeling Software to Enable Holistic Design Approach

Controls and Software Initiatives	
ID	**Title**
3	Develop Low Cost Monitoring Tools for Solar Thermal Systems
44	Integrate BIST into BMS/EMS
5	Integrate Fault Detection and Diagnostics (FDD) Capabilities Into BIST Monitoring Systems

Manufacturing, Installation, and Maintenance Initiatives	
ID	**Title**
8	Develop Recommended Guidance for Improved State/Local Building Codes, Permits, and Standards
9	Update Test and Certification Standards
7	Reduce Installation Costs with the Use of Plug-and-Play Systems
11	Provide DOE Manufacturing Assistance to Collector Manufacturers
23	Target Correct Markets for BIST Installations by Application/Technology
10	Reduce Failure Rates and Increase Reliability
12	Develop Low-Cost Balancing Tools for Commissioning Large Systems

Other Technologies (Solar Cogen, BIPV, & Solar Lighting) Initiatives	
ID	**Title**
16	Research and Develop Low-Profile Concentrating, Tracking Solar Collectors
13	Develop Improved Building Integration Methods for Dye-Sensitized Solar Cells (DSC)
22	Conduct Pilot Testing for Day-Lighting Mirrors with IR-Selective Films
21	Research Potential Opportunities for Solar-Assisted CHP Systems
20	Research and Develop Systems to Change Reflectivity of Buildings' Envelops
17	Develop Open-Source Tracking Controllers & Hardware
18	Develop Guide to Best Practices for Double Roof Design
19	Develop High Efficiency Integrated Solar Harvesting/Dimming Packages
14	Overcome Temp Limitations for PV Cells in PV/T systems

Solar Water Heating Initiatives	
ID	**Title**
33	Evaluate Optimal Configurations for PV-Driven Electric Water Heating Systems
32	Develop Low-Cost-Material Based Residential or Small Commercial Collectors
30	Implement a Large-Scale SWH Field Performance Verification Pilot Program for SWH Systems
29	Design Easily Deployable Large-Scale Solar Collectors
28	Evaluate Ultra High Vacuum (UHV) Collectors
53	Develop Innovative Stagnation Control Technologies for Solar Thermal Systems
34	Design Systems for Specific Climate Zones
35	Research and Develop Thermo/Photo Chemical Processes

Solar Space Conditioning Initiatives	
ID	**Title**
27	Investigate and Demonstrate Performance Improvements of Desiccant-Based Solar Cooling

Solar Space Conditioning Initiatives	
ID	Title
26	Develop Low-Cost Adsorption Chiller
25	Develop Packaged Solar Driven Adsorption/Absorption Cooling
24	Demonstrate Successful Large-Scale Solar Cooling Projects
54	Develop Air-to-Air Solar Assisted Heat Pump
52	Explore Opportunities for Nighttime Radiant Cooling

Storage and System Integration Initiatives	
ID	Title
37	Develop Solar Energy Systems Capable of Serving Multiple End-Uses
43	Develop Innovative Mechanisms for Improved Building Integration
41	Improve Residential-Scale Solar Thermal Storage
39	Research New Opportunities for District/Community-Scale Solar Thermal Storage
48	Develop Solar Hot Water Storage Tanks with Integrated Heating Components
40	Reduce Balance of Systems Costs for Solar Thermal Systems
36	Research and Develop Thermal Storage Systems Based on Latent Heat of Evaporation
42	Design and Manufacture New Low Cost Heat Exchangers
51	Improve and Optimize integration of BIST with Hydronic or Geothermal Systems
50	Incorporate Low Cost/High Reliability Storage Tanks Into Solar Thermal Systems
49	Develop Envelope Heat Recovery Systems
31	Develop Alternatives to Piping for Transporting Thermal Energy
38	Improve Commercial-Scale Solar Thermal Storage
46	Research and Develop Systems to Control Building Loads Using Thermal Mass
45	Expand Applications of Transparent Thermal Insulating Materials
47	Incorporate Active Thermal Envelope Flushing Technologies

5.1.2 R&D Portfolio

Initiatives in cross-cutting categories, in general, had higher market savings potentials because many of them impacted all BIST, therefore expanding their applicable end-use consumption and technical savings potential. However, because of slightly lower baseline payback periods and a larger current market share, the solar water heating initiatives received the best average score. Conversely, the solar space conditioning initiatives received the lowest average score due in large part to the long baseline payback periods for the solar cooling initiatives.

During initiative identification, many stakeholders suggested relevant space heating initiatives, however, the vast majority of proposed solar space heating initiatives were applicable to solar water heating as well, and were therefore incorporated with solar water heating initiatives or combined with other initiatives in the cross-cutting categories.

Figure 5-2 shows the number of initiatives in each category, as well as the average score of each category from the prioritization process.

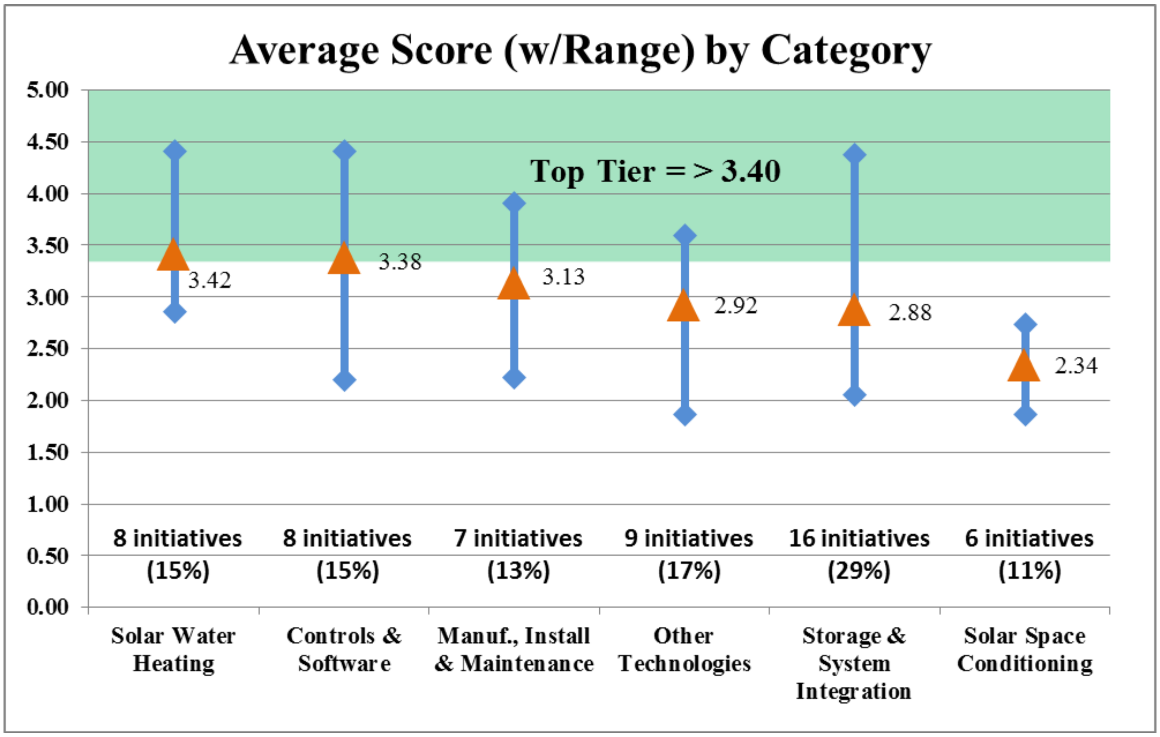


Figure 5-2: Average Scores for each Initiative Category

As discussed above, DOE does not preferentially target any end-use or technology type. The selected portfolio therefore does not attempt to balance across any given categories, but rather focuses on those technologies that best meet the scoring criteria (see section 2.3, above). DOE does, however, recognize that a balanced portfolio provides additional value beyond the concrete scoring criteria. Focusing all investments in an individual area may result in undue risk that a diversified portfolio could avoid.

Sections 5.2 through 5.7 discuss the initiatives that were evaluated for each of the six technology categories. In each category the top tier initiatives are identified.

5.2 Solar Water Heating R&D

5.2.1 Overview

The initiatives in this category target solar water heating systems and components, but also apply to other end-use categories beyond domestic water heating. Solar water heating systems can drive combination or multi-end-use systems, capable of providing space heating and/or space cooling. Therefore many solar water heating initiatives have the potential to impact several different end-uses. In addition, since solar water heating faces similar barriers to many other BIST, the initiatives in this category may well contribute to reducing barriers for other technology categories.

Barriers

Many stakeholders felt that little work has been done in the industry to verify the long-term field performance of solar water heating systems. Stakeholders commented that degradation in performance of solar water heating systems over time is a major concern for the industry. Inconsistent performance of solar water heating systems, either due to poor installation or long-term degradation, can have a significant impact on consumers' impression of the reliability of these systems.

Stakeholders also identified the high material and labor costs of solar water heating systems as significant barriers. Solar water heating systems are labor-intensive to install, particularly in retrofit applications requiring new piping runs. Typically solar water heating systems also require a significant amount of on-site, engineering, assembly, testing, and calibration, all of which add to the time and cost of installation. The material costs of solar water heating systems are high because these systems often consist of expensive materials, such as copper or aluminum. Stakeholders repeatedly mentioned the need to reduce these costs, including the need to develop low-cost materials, integrate components, and increase standardization throughout the industry.

5.2.2 Initiatives

Figure 5-3 shows the relative scores for each of the solar water heating initiatives.

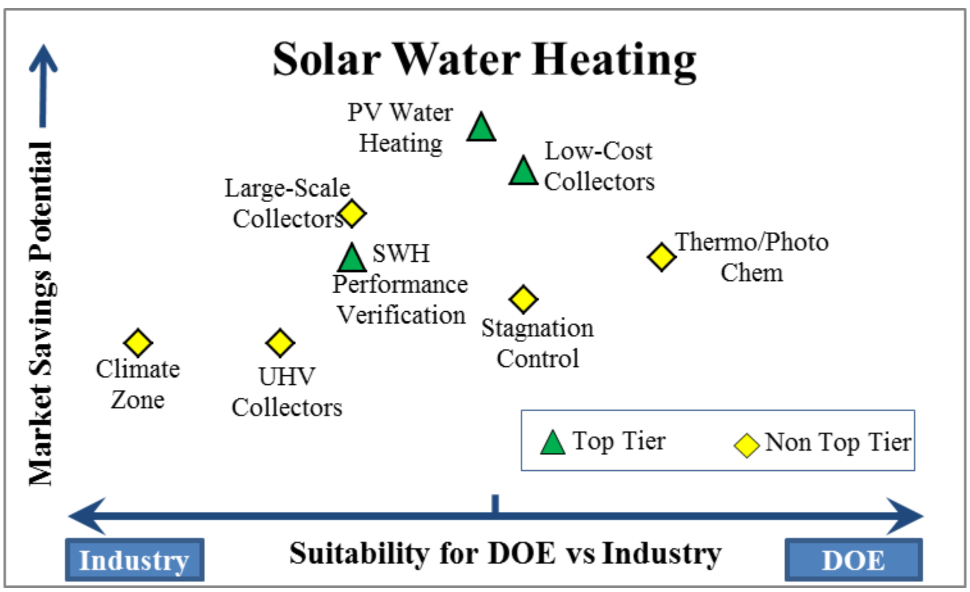


Figure 5-3: Overview of Solar Water Heating Initiatives

Table 5-3 describes the solar water heating top-tier initiatives, shows their scores for each metric, and identifies the barriers that each initiative addresses. Appendix C describes each of the non-top-tier initiatives in this category.

Table 5-3: Solar Water Heating Top Tier Initiatives

Activity/Initiative	MSP Score	Fit with BTO Mission	Crit. of DOE Involvement	Level of Risk	Level of Req. Investment
Evaluate Optimal Configurations for PV-Driven Electric Water Heating Systems					
	5.0	**4.0**	**3.0**	**3.7**	**4.0**
Description: Conduct studies to determine the most cost-effective configurations for solar electric water heating. Recent price reductions in PV modules may enable new solar electric water heating methods. PV systems coupled directly to electric resistance or heat pump water heaters may become cost competitive with traditional solar thermal solutions. These technologies eliminate much of the balance-of-system and labor costs associated with traditional solar thermal systems. ***Applicable Barriers:*** First-cost disadvantage					
Reduce Material Costs of Residential and Small Commercial Collectors					
	4.5	**3.3**	**3.0**	**3.7**	**3.0**
Description: Develop new low-cost materials and manufacturing techniques for solar thermal collectors. These may include UV-durable polymers for collectors and piping, transparent thermoplastics for Evacuated Tube Collectors (ETC), and new manufacturing processes for one-piece collector frames. ***Applicable Barriers:*** First-cost disadvantage					
Implement a Large-Scale SWH Field Performance Verification Pilot Program for SWH Systems					
	3.5	**4.0**	**4.3**	**4.0**	**2.3**
Description: Implement large-scale field performance verification programs for SWH systems. After most SWH systems are installed, they are not monitored or tested to track their performance over time and compare to expected performance. A lack of long term field performance data has sparked the need for comprehensive methods to ensure SWH systems perform in the field as expected for the duration of their design life. A pilot monitoring program could facilitate widespread data collection and verification of field performance. Coordination between, and/or partnering with, existing, smaller scale monitoring programs may be a logical starting point that will leverage existing program knowledge. ***Applicable Barriers:*** Perceived unreliability					

5.3 Solar Space Conditioning R&D

5.3.1 Overview

Solar space conditioning covers all initiatives related to solar cooling, space heating, and dehumidification. Solar cooling technologies are promising because solar cooling systems could provide an efficient way to use solar energy during the summer when the demand for water or space heating may be reduced.

Barriers
Stakeholders commented that aside from the high installed costs of solar cooling systems, one of the most significant barriers is a lack of successful large-scale demonstration projects. Stakeholders felt that the industry needs these types of pilot programs to prove that solar cooling technologies are viable options for large commercial buildings and to provide real world data to enable future innovation and technological improvements.

Many solar cooling technologies require high temperature thermal energy, meaning they rely on concentrating, tracking solar collectors. Stakeholders identified that the high temperature requirements and relatively low efficiencies of solar-driven cooling systems currently limit the applicability of these technologies to large commercial or industrial scale facilities. These stakeholders pointed to the need for solar cooling systems capable of operating on smaller scales, to make these technologies applicable to a broader consumer base.

Stakeholders in the solar space heating industry commented that the biggest needs for space heating technologies include advancements in: building integrated thermal storage, combined heating and cooling systems, and installation methods focused on reducing labor costs and improving aesthetics and code compliance. Many of the initiative in this report address these needs. However since most of these initiatives also benefit other BIST, we have incorporated them under the cross-cutting categories in sections 5.5, 5.6, and 5.7.

5.3.2 Initiatives

Figure 5-4 shows the relative scores for each of the solar space conditioning initiatives.

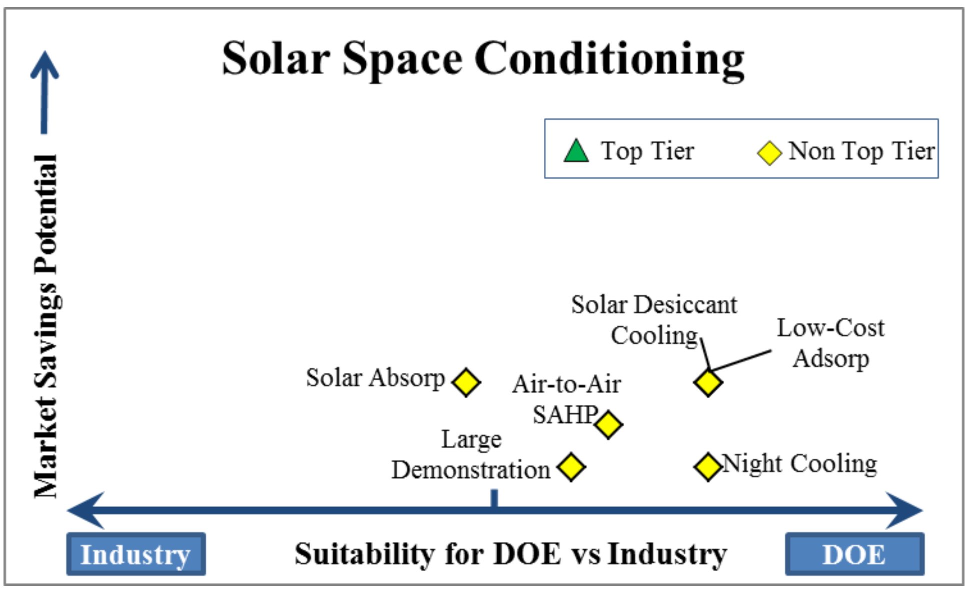


Figure 5-4: Overview of Solar Space Conditioning Initiatives

The top tier contained no initiatives from the solar space conditioning category. Appendix C describes each of the non-top-tier initiatives in this category.

5.4 Other Technologies (Solar Cogeneration, BIPV, & Solar Lighting) R&D

5.4.1 Overview

This category covers a broad spectrum of initiatives that have the potential to impact multiple end-uses. In particular, all of the technologies in this category have the potential to reduce electricity consumption, which represents a significant fraction of building primary energy use that the other categories of BIST do not address.

Barriers

Stakeholders identified the high first costs associated with these systems as the most notable barrier. Solar cogeneration, BIPV, and solar lighting systems are all relatively new to the BIST market, and although these technologies have been successfully demonstrated, they are still very expensive compared to incumbent technologies. In today's market the payback periods for these products far exceed what typical consumers are willing to accept.

Solar cogeneration systems tend to rely on high temperature thermal energy supplied by concentrating, tracking solar collectors. Stakeholders commented that this high temperature requirement is a significant barrier to these technologies because it requires building owners to install expensive concentrating, tracking collectors to use these systems. Concentrating, tracking collectors increase the cost, complexity and space demands of any BIST system, making systems that require these collectors a difficult sell, particularly for residential and small commercial building owners.

Stakeholders in the solar lighting industry provided feedback focusing on the lack of open-source solar tracking and collecting hardware and software packages. Stakeholders felt that making these technologies more widely available would enable more companies to enter the solar lighting market, leading to greater technological innovation and more competitive pricing.

5.4.2 Initiatives

Figure 5-5 shows the relative scores for each of the Other Technology initiatives.

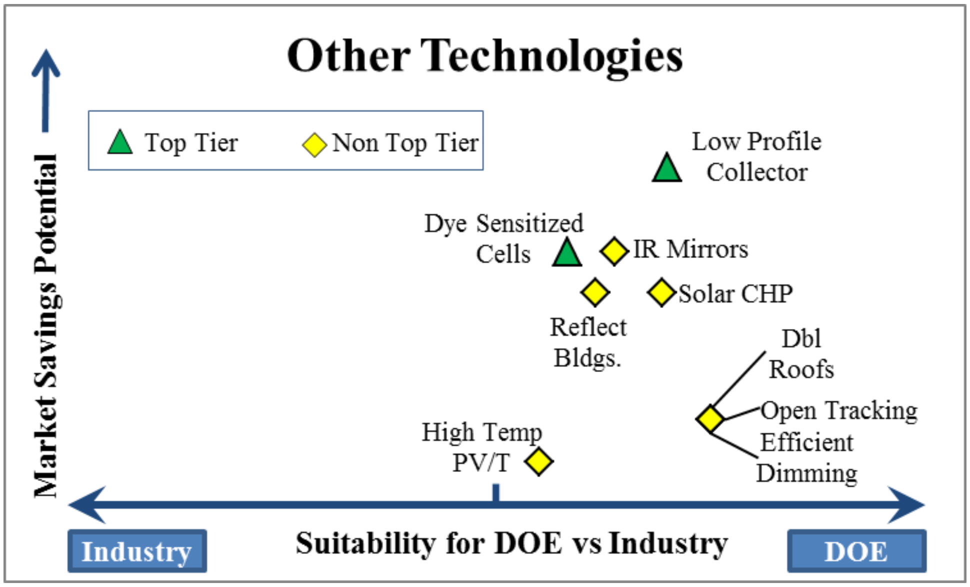


Figure 5-5: Overview of Other Technology Initiatives

Table 5-4 describes the solar cogeneration, BIPV, & solar lighting top-tier initiatives, shows their scores for each metric, and identifies the barriers that each initiative addresses. Appendix C describes each of the non-top-tier initiatives in this category.

Table 5-4: Other Technology Top Tier Initiatives

Activity/Initiative	MSP Score	Fit with BTO Mission	Crit. of DOE Involvement	Level of Risk	Level of Req. Investment
Research and Develop Low-Profile Concentrating, Tracking Solar Collectors					
	4.5	**3.3**	**3.3**	**1.7**	**2.0**
Description: Develop low-profile concentrating, tracking solar collectors to reduce the complexity and space demands of concentrating, tracking collectors. Currently most concentrating solar collectors are complex, requiring many moving parts that are susceptible to damage and wear. Researchers at the University of California San Diego are currently developing a flat plate collector that uses a combination of lenses and mirrors to track and concentrate sunlight, without the large footprint and overall size of typical concentrating collectors. Some industry manufacturers have also begun developing variations of a flat panel concentrating collector. Further R&D is needed to make these technologies competitive in the market. These systems could potentially offer advantages over traditional concentrating collectors that may include fewer moving parts, and the ability to integrate them directly into building facades. ***Applicable Barriers:*** First-cost disadvantage**,** High temp requirements**,** Physical Space Constraints					

Activity/Initiative	MSP Score	Fit with BTO Mission	Crit. of DOE Involvement	Level of Risk	Level of Req. Investment
Develop Improved Building Integration Methods for Dye-Sensitized Solar Cells (DSC)					
	3.5	**3.7**	**3.0**	**3.0**	**2.3**
Description: Develop improved methods for integrating Dye-Sensitized Solar Cells (DSC) into buildings. DSC are photoelectrochemical materials that convert solar energy to electricity. Thin films of DSC can be applied to glass panels to create transparent BIPV window panels. Some companies are starting to manufacture these products, but further R&D is needed to make DSC seamless and cost-effective to install. ***Applicable Barriers:*** First-cost disadvantage**,** Lack of integration**,** Aesthetic Concerns**,** Physical Space Constraints					

5.5 Controls and Software R&D

5.5.1 Overview

The controls and software category includes all initiatives related to control methodologies, monitoring equipment, and software tools for BIST. BIST controls serve a broad variety of purposes, including performance optimization, data collection and monitoring, metering, fault detection and diagnostics, and providing inputs that drive additional research and development. Software tools, including modeling, estimation, and system design tools help engineers and architects design and optimize BIST. The initiatives in this category apply across all technology categories.

Barriers

One of the primary barriers that stakeholders identified is a lack of well-validated tools for BIST systems. Although a few models and tools are available to the industry, the consensus among stakeholders is that there are discrepancies and variations between the current models that need to be validated and resolved for these models to provide meaningful data. Some stakeholders suggested developing a common validation tool to test and compare BIST models throughout the industry, as has been done for general building energy models.

In addition stakeholders expressed a need to compare the performance of solar thermal systems with that of other renewable technology options to allow building owners to select the most appropriate option for a given installation. Some software programs with this capability currently exist, such as NREL's HOMER program, but they do not incorporate the ability to analyze solar thermal systems.

BIST stakeholders have also recognized that there is a lack of architectural modeling and design packages that incorporate BIST. Architects and systems designers need robust software packages that can enable them to integrate solar technologies into building designs early in the design process.

5.5.2 Initiatives

Figure 5-6 shows the relative scores for each of the controls and software initiatives.

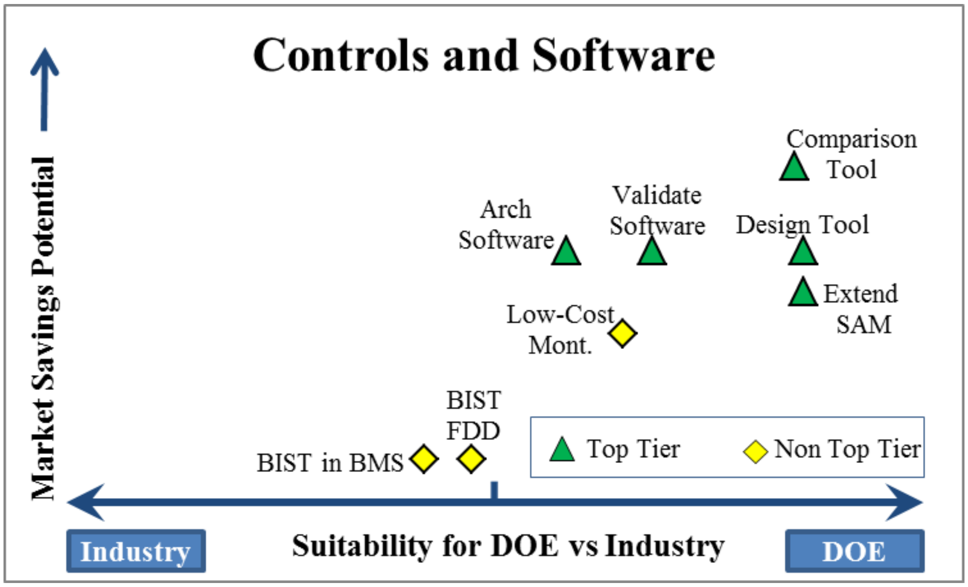


Figure 5-6: Overview of Controls and Software Initiative Scores

Table 5-5 describes controls and software top-tier initiatives, shows their scores for each metric, and identifies the barriers that each initiative addresses. Appendix C describes each of the non-top-tier initiatives in this category.

Table 5-5: Controls & Software Top Tier Initiatives

Activity/Initiative	MSP Score	Fit with BTO Mission	Crit. of DOE Involvement	Level of Risk	Level of Req. Investment
Develop Tool to Compare Solar Thermal and Other Renewable Energy Technologies for a Given Installation					
	4.5	**3.0**	**4.7**	**4.3**	**4.3**
Description: Develop a tool to enable BIST systems designers to compare solar thermal systems with other renewable energy technologies for a given installation site. With such a tool, installers, designers, and building owners would be able to better determine which systems would provide the optimal performance and best value. NREL's HOMER software may be an appropriate platform to build off. ***Applicable Barriers:*** First-cost disadvantage**,** Physical Space Constraints**,** Lack of Well-Validated Tools					

Activity/Initiative	MSP Score	Fit with BTO Mission	Crit. of DOE Involvement	Level of Risk	Level of Req. Investment
Develop Publicly Available Design and Estimation Tools for BIST					
	3.5	**3.7**	**4.7**	**4.3**	**3.7**
Description: Develop design and estimation tools for the designers and engineers planning BIST systems. There is a need for simple and accurate publicly available estimation tools for solar thermal systems, similar to NREL's PVWatts program for the Photovoltaics industry. ***Applicable Barriers:*** First-cost disadvantage**,** Lack of Well-Validated Tools					
Validate BIST Modeling Software					
	3.5	**3.3**	**4.0**	**4.0**	**3.3**
Description: Validate BIST modeling-software tools. Modeling software can be used to develop improved BIST systems, however there are many discrepancies and variations among current models that need to be validated and resolved for these models to provide meaningful data. One potential solution is to develop a validation tool similar to NREL's BESTEST that could be used to validate BIST modeling software. ***Applicable Barriers:*** Lack of Well-Validated Tools					
Expand Capabilities of System Advisor Model (SAM)					
	3.0	**3.7**	**4.7**	**4.0**	**4.0**
Description: Develop extension for the System Advisor Model (SAM) to incorporate BIST. SAM is a performance and financial model for renewable energy technologies, which is designed to facilitate decision making for project managers, engineers, incentive program designers, technology developers, and researchers. Currently SAM offers limited capabilities for BIST and solar thermal systems. SAM needs to be expanded to provide capabilities for solar thermal systems to match those it offers for PV systems. For example, system designers would benefit from having generic water consumption profiles for a range of building types available in SAM, to help them size water heating systems appropriately. ***Applicable Barriers:*** Lack of Well-Validated Tools					
Incorporate BIST Into Architectural Modeling Software to Enable Holistic Design Approach					
	3.5	**3.7**	**3.7**	**3.3**	**3.7**
Description: Incorporating BIST into architectural design programs will enable architects to integrate solar technologies into building designs early in the design process. BIST can play a large role in reducing the energy consumption of buildings, particularly through architectural integration of PV (i.e., BIPV), active solar lighting, and solar thermal systems; however, the lack of robust design software for this purpose limits architects and engineers. Holistic solutions to reduce building energy consumption require comprehensive design tools to allow multidisciplinary teams of architects, engineers, and interior designers to design buildings from the ground up with BIST. ***Applicable Barriers:*** First-cost disadvantage**,** Lack of integration**,** Aesthetic Concerns**,** Lack of Well-Validated Tools					

5.6 Storage and System Integration R&D

5.6.1 Overview

System integration initiatives focus on integrating components within a single system, integrating multiple systems to serve multiple end-uses, and integrating entire systems into buildings. Thermal storage initiatives target storage systems ranging in scale from small residential water storage tanks to community-scale in-ground thermal storage facilities.

Barriers

Industry stakeholders have widely expressed the need for more multi-end-use and combination BIST systems. Multi-end-use systems can help maintain a balanced load, and therefore waste less excess solar energy. In addition, multi-end-use systems can help address the high cost barrier that all BIST face. These technologies enable one set of collectors to drive multiple end-uses, rather than having separate collecting systems for each end-use, which thereby reduces the capital cost.

Stakeholders have also provided significant feedback regarding the need for improved thermal storage systems to enable significant improvements in the performance and cost effectiveness of BIST. Currently, a significant barrier to all solar technologies is the inconsistent availability of solar resources. Thermal storage systems allow buildings to store solar energy harvested when the sun is available and save it for consumption when solar resources are less abundant. The thermal storage systems that are currently available at the commercial and residential scales provide some of these capabilities, but they are limited in the duration and amount of energy that they can store. Stakeholders have expressed a need for compact thermal storage systems with high energy densities and the ability to easily store and extract thermal energy with minimal losses.

5.6.2 Initiatives

Figure 5-7 shows the relative scores for each of the storage and system integration initiatives.

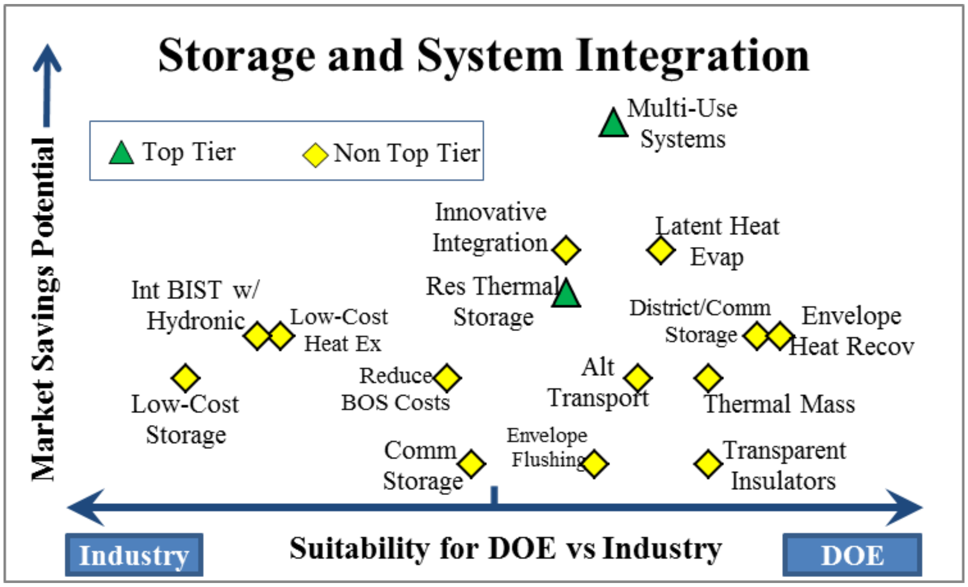


Figure 5-7: Overview of Storage and System Integration Initiatives

Table 5-6 describes the storage and system integration top-tier initiatives, shows their scores for each metric, and identifies the barriers that each initiative addresses. Appendix C describes each of the non-top-tier initiatives in this category.

Table 5-6: Storage and System Integration Top Tier Initiatives

Activity/Initiative	MSP Score	Fit with BTO Mission	Crit. of DOE Involvement	Level of Risk	Level of Req. Investment
Develop and Optimize Solar Energy Systems Capable of Serving Multiple End-Uses					
	5.0	**3.7**	**3.3**	**3.0**	**2.7**
Description: Improving integration of solar energy systems to serve multiple end-uses (e.g., water heating and space heating) takes better advantage of all the collected thermal energy. Multi-end-use systems combine several BIST into one system, and therefore lower the capital costs of the total installation. ***Applicable Barriers:*** First-cost disadvantage**,** Solar mismatch**,** Lack of integration					
Improve Residential-Scale Solar Thermal Storage					
	3.0	**3.3**	**3.3**	**3.3**	**3.0**
Description: Improving residential-scale storage options will allow residential buildings to take greater advantage of excess energy harvested during times of peak solar generation. Current residential scale thermal storage options are limited primarily to hot water tanks. Using alternative storage media (e.g., solid-to-liquid phase change materials (PCMs)) and building integrated storage solutions may provide increased storage density and duration that is needed to impact building energy consumption when solar generation is not available. ***Applicable Barriers:*** First-cost disadvantage**,** Solar mismatch**,** Insufficient Solar Insolation					

5.7 Manufacturing, Installation, and Maintenance R&D

5.7.1 Overview

The initiatives in this category focus on reducing the cost of producing, installing, and maintaining BIST systems. This includes improving manufacturing processes, reducing the permitting-complexity burden on installers, and designing systems for easy manufacture, maintenance, and installation.

Barriers

Stakeholders across the BIST industry have identified building codes and standards as a significant barrier to all BIST. Many existing building codes and standards are not designed to consider or accommodate BIST. These codes can lead to lengthy and costly certification and building permitting processes, which present significant deterrents to contractors and homeowners that may consider installing these systems. Many stakeholders have also identified the need to require new construction buildings to be "solar ready," meaning that piping and other infrastructure required for BIST would be installed during the construction of a new building, making it cheaper to install BIST systems later on.

In addition, stakeholders have highlighted outdated testing and certification standards as another barrier that needs to be addressed. Test and certification standards for BIST collectors, system components, and installing personnel need to be continuously updated to keep up with the rapid evolution of BIST. Stakeholders have commented that current testing methods do not accurately represent the performance of all systems, particularly emerging technologies. For example, there are currently no standard test methods or certifications designed specifically for PV/T systems. In addition, stakeholders have identified that certifications for personnel installing BIST systems need to be updated to ensure that these individuals are qualified to work with the latest technologies in the industry.

5.7.2 Initiatives

Figure 5-8 shows the relative scores for each of the manufacturing, installation, and maintenance initiatives.

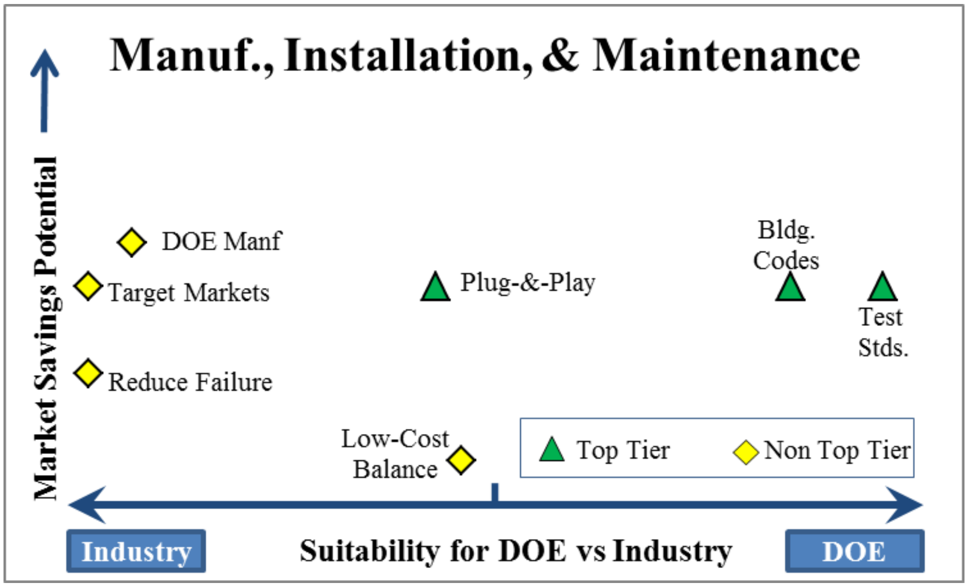


Figure 5-8: Overview of Manufacturing, Installation, and Maintenance Initiatives

Table 5-7 describes the manufacturing, installation, and maintenance top tier initiatives, shows their scores for each metric, and identifies the barriers that each initiative addresses. Appendix C describes each of the non-top-tier initiatives in this category.

Table 5-7: Manufacturing, Installation, and Maintenance Top Tier Initiatives

Activity/Initiative	MSP Score	Fit with BTO Mission	Crit. of DOE Involvement	Level of Risk	Level of Req. Investment
Develop Recommended Guidance for Improved State/Local Building Codes, Permits, and Standards					
	3.0	**2.7**	**3.3**	**4.3**	**4.3**
Description: Develop recommendations for improving state and local building codes, permits and standards. Many existing building codes and standards do not consider or accommodate BIST. This can lead to lengthy and costly certification and building permitting processes, which present significant deterrents to contractors and homeowners that may consider installing these systems. Further study and review of the codes is needed to help identify areas for improvement. Potential areas for improvement should focus on streamlining the inspection and permitting process and requiring new construction buildings to be "solar ready". Developing a clear set of best practices for codes and standards could enable reform of such codes.					
Applicable Barriers: Permitting and code limitations					

Activity/Initiative	MSP Score	Fit with BTO Mission	Crit. of DOE Involvement	Level of Risk	Level of Req. Investment
Update Test and Certification Standards					
	3.0	**2.7**	**3.7**	**4.3**	**4.0**
Description: Revise and improve testing and certification standards for BIST collectors, system components, and installing personnel. New certification procedures should take into account factors such as the location and orientation of the solar collectors. Additionally, test and certification standards should be updated to account for recent (and ongoing) evolution of BIST. For example, there are currently no standard test methods or certifications designed specifically for PV/T systems. These systems are generally tested and certified separately as PV cells and thermal collectors. However this approach does not account for the interactive operation effects between the PV cell and the thermal collector. Personnel certifications should be updated to ensure installers are qualified to work with the latest technologies. ***Applicable Barriers:*** Perceived unreliability					
Reduce Installation Costs with the Use of Plug-and-Play Systems					
	3.0	**2.7**	**2.3**	**4.3**	**3.3**
Description: Reducing installation costs of BIST can be achieved by designing systems with fewer components, such as "plug-and-play" systems, and also designing them to use light weight and easy to work with materials. Plug-and-play systems are becoming more common in the industry; however, there is still room for further integration and standardization of BIST components. In addition, BIST should also be simplified where possible to enable "do it yourselfers" to install them. ***Applicable Barriers:*** First-cost disadvantage**,** Lack of integration					

6 Appendix A – Stakeholder Outreach Organizations

Table 6-1: Stakeholder Forum, SOLAR THERMAL'12 Conference, Milwaukee, WI – Participating Organizations

Org Type	Organization
Commercial Firm	A.O. Smith
Commercial Firm	Advanced Green Technologies
Commercial Firm	Alternate Energy Technology
Commercial Firm	Beam Engineering
Government Org	City of Milwaukee
Commercial Firm	Cogenra Solar
Research Institute	Florida Solar Energy Center
Commercial Firm	Johnson Controls
Research Institute	Oak Ridge National Labs
Commercial Firm	Power Panel
Non-Profit Org	Rural Renewable Energy Alliance (RREAL)
Commercial Firm	Solar Service/Sun-Way Solar
Commercial Firm	Sun Tap Energy
Commercial Firm	TUV Rheinland PTL, LLC
Government Org	U.S. EPA Climate Protection Partnerships

Table 6-2: Stakeholder Forum, Washington D.C. – Participating Organizations

Org Type	Organization
Commercial Firm	3M
Commercial Firm	A.O. Smith
Commercial Firm	Advanced Green Technologies
Commercial Firm	American Solar Roofing Company
Research Institute	ARPA-E
Government	District of Columbia Department of the Environment
Government	DOE Solar Energy Technology Program
Research Institute	Florida Solar Energy Center
Research Institute	Fraunhofer Institute
Commercial Firm	Henkel Solar
Non-Profit Org	Institute for Sustainable Power
Commercial Firm	Lennox Industries
Academic Institute	Massachusetts Institute of Technology
Research Institute	National Renewable Energy Laboratory
Research Institute	Oak Ridge National Laboratory
Commercial Firm	Pfister Energy
Commercial Firm	Power Panel
Research Institute	Sandia National Laboratory

Org Type	Organization
Commercial Firm	Solar Energy Consulting
Industry Org	Solar Energy Industries Association
Rating Agency	Solar Rating and Certification Corporation
Non-Profit Org	Solar Water Heating Task Force
Commercial Firm	SunChiller
Commercial Firm	Sunnovations, Inc.
Government	U.S. EPA Climate Protection Partnerships
Academic Institute	University of Louisville

7 Appendix B – R&D Portfolio Chart Scores

Table 7-1: R&D Portfolio Plot Scores by Category

Controls and Software Initiatives	Market Savings Potential	Suitability for DOE vs. Industry
Develop Tool to Compare Solar Thermal and Solar PV for a Given Installation	4.5	4.3
Develop Publicly Available Design and Estimation Tools for BIST	3.5	4.3
Validate BIST Modeling Software	3.5	3.8
Expand Capabilities of System Advisor Model (SAM)	3.0	4.3
Incorporate BIST Into Architectural Modeling Software to Enable Holistic Design Approach	3.5	3.5
Develop Low Cost Monitoring Tools for Solar Thermal Systems	2.5	3.7
Integrate BIST into BMS/EMS	1.0	3.0
Integrate Fault Detection and Diagnostics (FDD) Capabilities Into BIST Monitoring Systems	1.0	3.2
Manufacturing, Installation, and Maintenance Initiatives	**Market Savings Potential**	**Suitability for DOE vs. Industry**
Develop Recommended Guidance for Improved State/Local Building Codes, Permits, and Standards	3.0	4.5
Update Test and Certification Standards	3.0	4.9
Reduce Installation Costs with the Use of Plug-and-Play Systems	3.0	3.2
Provide DOE Manufacturing Assistance to Collector Manufacturers	3.5	2.0
Target Correct Markets for BIST Installations by Application/Technology	3.0	1.8
Reduce Failure Rates and Increase Reliability	2.0	1.8
Develop Low-Cost Balancing Tools for Commissioning Large Systems	1.0	3.3

Other Technologies (Solar Cogen, BIPV, & Solar Lighting Initiatives)	Market Savings Potential	Suitability for DOE vs. Industry
Research and Develop Low-Profile Concentrating, Tracking Solar Collectors	4.5	3.9
Develop Improved Building Integration Methods for Dye-Sensitized Solar Cells (DSC)	3.5	3.5
Conduct Pilot Testing for Day-Lighting Mirrors with IR-Selective Films	3.5	3.7
Research Potential Opportunities for Solar-Assisted CHP Systems	3.0	3.8
Research and Develop Systems to Change Reflectivity of Buildings' Envelops	3.0	3.6
Develop Open-Source Tracking Controllers & Hardware	1.5	4.0
Develop Guide to Best Practices for Double Roof Design	1.5	4.0
Develop High Efficiency Integrated Solar Harvesting/Dimming Packages	1.5	4.0
Overcome Temp Limitations for PV Cells in PV/T systems	1.0	3.4
Solar Water Heating Initiatives	**Market Savings Potential**	**Suitability for DOE vs. Industry**
Evaluate Optimal Configurations for PV-Driven Electric Water Heating Systems	5.0	3.2
Develop Low-Cost-Material Based Residential or Small Commercial Collectors	4.5	3.4
Implement a Large-Scale SWH Field Performance Verification Pilot Program for SWH Systems	3.5	2.8
Design Easily Deployable Large-Scale Solar Collectors	4.0	2.8
Evaluate Ultra High Vacuum (UHV) Collectors	2.5	2.5
Develop Innovative Stagnation Control Technologies for Solar Thermal Systems	3.0	3.4
Design Systems for Specific Climate Zones	2.5	2.0
Research and Develop Thermo/Photo Chemical Processes	3.5	3.8

Solar Space Conditioning Initiatives	Market Savings Potential	Suitability for DOE vs. Industry
Investigate and Demonstrate Performance Improvements of Desiccant-Based Solar Cooling	2.0	4.0
Develop Low-Cost Adsorption Chiller	2.0	4.0
Develop Packaged Solar Driven Adsorption/Absorption Cooling	2.0	3.2
Demonstrate Successful Large-Scale Solar Cooling Projects	1.0	3.5
Develop Air-to-Air Solar Assisted Heat Pump	1.5	3.7
Explore Opportunities for Nighttime Radiant Cooling	1.0	4.0
Storage and System Integration Initiatives	**Market Savings Potential**	**Suitability for DOE vs. Industry**
Develop Solar Energy Systems Capable of Serving Multiple End-Uses	5.0	3.7
Develop Innovative Mechanisms for Improved Building Integration	3.5	3.5
Improve Residential-Scale Solar Thermal Storage	3.0	3.5
Research New Opportunities for District/Community-Scale Solar Thermal Storage	2.5	4.2
Develop Solar Hot Water Storage Tanks with Integrated Heating Components	3.0	1.7
Reduce Balance of Systems Costs for Solar Thermal Systems	2.0	3.1
Research and Develop Thermal Storage Systems Based on Latent Heat of Evaporation	3.5	3.8
Design and Manufacture New Low Cost Heat Exchangers	2.5	2.5
Improve and Optimize integration of BIST with Hydronic or Geothermal Systems	2.5	2.4
Incorporate Low Cost/High Reliability Storage Tanks Into Solar Thermal Systems	2.0	2.2
Develop Envelope Heat Recovery Systems	2.5	4.3
Develop Alternatives to Piping for Transporting Thermal Energy	2.0	3.8
Improve Commercial-Scale Solar Thermal Storage	1.0	3.2
Research and Develop Systems to Control Building Loads Using Thermal Mass	2.0	4.0
Expand Applications of Transparent Thermal Insulating Materials	1.0	4.0
Incorporate Active Thermal Envelope Flushing Technologies	1.0	3.6

8 Appendix C – Descriptions of Non Top Tier Initiatives

Table 8-1: Solar Water Heating Initiatives

Activity/Initiative	MSP Score	Fit with BTO Mission	Crit. of DOE Involvement	Level of Risk	Level of Req. Investment
Design Easily Deployable Large-Scale Solar Collectors	**4.0**	**4.3**	**3.7**	**2.3**	**2.7**
Description: Design large-scale easily deployable collectors specifically to address large commercial and industrial applications. Large-scale BIST collector arrays are typically constructed from many smaller, residential-scale collectors, making for a costly and labor intensive installation. This initiative should not focus on prefabricating large-format flat panel collectors, but instead should target innovative solutions for commercial collectors. One potential solution would be large-scale polymer collectors, which could be easily rolled up for transportation and unrolled upon installation. ***Applicable Barriers:*** First-cost disadvantage**,** Lack of integration					
Evaluate Ultra High Vacuum (UHV) Collectors	**2.5**	**3.0**	**3.0**	**3.7**	**3.7**
Description: Solar thermal collectors with a very low pressure vacuum can reduce the thermal losses of the collector, leading to more efficient operation at higher temperatures. Such collectors should be studied further and evaluated against traditional ETC to help guide the direction of future ETC development. ***Applicable Barriers:*** High temp requirements**,** Physical Space Constraints					
Develop Innovative Stagnation Control Technologies for Solar Thermal Systems	**3.0**	**4.0**	**3.0**	**3.0**	**3.0**
Description: Stagnation and overheating can damage and degrade solar water heating systems. Developing techniques to control or prevent stagnation and overheating would improve the durability and reliability of solar water heating systems, and would also enable the use of more polymer collectors and components. ***Applicable Barriers:*** First-cost disadvantage**,** Perceived unreliability					
Design Systems for Specific Climate Zones	**2.5**	**2.3**	**2.7**	**4.0**	**4.3**
Description: Solar collectors do not necessarily perform equally across various climate zones. Systems that are tailored to specific climates would have improved efficiency for the typical weather conditions. ***Applicable Barriers:*** First-cost disadvantage**,** Perceived unreliability**,** Insufficient Solar Insolation					

Activity/Initiative	MSP Score	Fit with BTO Mission	Crit. of DOE Involvement	Level of Risk	Level of Req. Investment
Research and Develop Thermo/Photo Chemical Processes					
	3.5	**3.3**	**4.3**	**1.3**	**1.0**
Description: Chemical processes provide alternative ways to convert solar energy into thermal energy through photochemical reactions, or convert thermal energy into chemical energy (for storage) through thermochemical processes. Although some research has been conducted in these fields, increased research efforts focused on solar energy applications are needed to develop promising concepts into viable technologies.					
Applicable Barriers: First-cost disadvantage**,** Solar mismatch					

Table 8-2: Other Technologies (Solar Cogeneration, BIPV, & Solar Lighting) Initiatives

Activity/Initiative	MSP Score	Fit with BTO Mission	Crit. of DOE Involvement	Level of Risk	Level of Req. Investment
Conduct Pilot Testing for Day-Lighting Mirrors with IR-Selective Films					
	3.5	**3.7**	**3.7**	**3.0**	**2.7**
Description: Infrared (IR) mirrors allow visible light to pass through the mirrors and into the building for day lighting purposes, and reflect IR light towards adjacent solar thermal or PV panels. These mirrors can be integrated into the outer structure of buildings, along with complementary solar panels (either PV or solar thermal) in an opposing, corrugated structure. . This technology has been proven to work at smaller scales, but still needs to be deployed in full scale pilot programs.					
Applicable Barriers: First-cost disadvantage**,** Lack of integration**,** Physical Space Constraints					
Research Potential Opportunities for Solar-Assisted CHP Systems					
	3.0	**3.7**	**4.0**	**2.3**	**2.7**
Description: Solar energy can be used to drive or assist CHP systems; however, it is not yet clear which CHP engines or cycles are best suited for solar energy and how to integrate solar energy into the cycle. For example, high temperature solar thermal energy can be used to drive an Organic Rankine Cycle (ORC) but solar thermal energy can also preheat air or water prior to entering the CHP engine. Research is needed to evaluate best possible solar CHP options and prioritize the CHP systems that are most suitable for solar energy applications.					
Applicable Barriers: First-cost disadvantage**,** Lack of integration					

Activity/Initiative	MSP Score	Fit with BTO Mission	Crit. of DOE Involvement	Level of Risk	Level of Req. Investment
Research and Develop Systems to Change Reflectivity of Buildings' Envelopes					
	3.0	**3.3**	**3.3**	**2.0**	**2.0**
Description: Controlling the reflectivity of a building's surface could improve the heat absorption or reflection of the building's envelope. The building's envelope could be adjusted for weather and season variations, retaining heat in the cold weather and reflecting heat in the warm weather, allowing for reduced heating and cooling loads for the building. One manufacturer has developed an approach to this concept, which is nearing commercialization, using a combination of phase-change materials (PCM) and self-regulating IR selective materials to capture or reflect solar radiation as needed. ***Applicable Barriers:*** Physical Space Constraints					
Develop Open-Source Tracking Controllers & Hardware					
	1.5	**3.7**	**4.0**	**2.7**	**3.7**
Description: Solar tracking hardware and software packages are typically well-guarded proprietary technologies. The lack of readily available tracking equipment is a major barrier to new market entrants who are attempting to innovate on solar lighting and other concentrating solar concepts that rely on tracking equipment. Open source controller technology would enable a wider range of potential systems to reach prototype and demonstration stages. ***Applicable Barriers:*** First-cost disadvantage					
Develop Guide to Best Practices for Double Roof Design					
	1.5	**3.0**	**3.3**	**2.3**	**3.3**
Description: Double roofs are 2 roofs, one built on top of the other, with an integrated air gap or duct between them. This creates an integrated thermal air collector that avoids the need for running piping in the roof. Additionally, shading the inner roof helps to eliminate summer heat gain and reduces the building's cooling load. This may provide better customer acceptance, as it averts the risk of having roof integrated SWH collectors that may fail or leak leading to potentially very expense repairs. The outer roof may also include PV panels creating an integrated PV/Thermal hybrid roof. Since double roofs will need to be custom designed for most applications, a clear guide of best design practices is needed. ***Applicable Barriers:*** First-cost disadvantage**,** Physical Space Constraints					
Develop High Efficiency Integrated Solar Harvesting/Dimming Packages					
	1.5	**3.0**	**3.0**	**3.3**	**3.3**
Description: Develop low-cost dimming solutions to make solar lighting commercially viable. Typical dimming systems, which employ photo sensors and dimming light bulbs, tend to be expensive, and often sacrifice efficiency by dimming bulbs designed only for on/off use. End users would benefit from low-cost commercial troffers that: (1) enable high efficiency dimming, via an array of bulbs in which individual bulbs are turned on or off to meet necessary lighting levels rather than dimming individual bulbs, or by using high efficiency LED dimmers, and (2) integrate dispersion of natural light harvested by active solar lighting collectors. ***Applicable Barriers:*** First-cost disadvantage, Lack of integration					

Activity/Initiative	MSP Score	Fit with BTO Mission	Crit. of DOE Involvement	Level of Risk	Level of Req. Investment
Overcome Temp Limitations for PV Cells in PV/T systems					
	1.0	**4.0**	**2.7**	**2.3**	**2.3**
Description: Commercial and industrial facilities have a demand for PV/T systems capable of delivering high temperature thermal output (approx. 300° F and higher). However, the performance of typical PV materials degrades significantly at these temperatures. New materials or PV/T manufacturing techniques need to be developed that allow PV/T systems to operate at elevated temperatures up to 300° F with reduced degradation of PV performance. ***Applicable Barriers:*** High temp requirements					

Table 8-3: Solar Space Conditioning Initiatives

Activity/Initiative	MSP Score	Fit with BTO Mission	Crit. of DOE Involvement	Level of Risk	Level of Req. Investment
Investigate Performance Improvements of Desiccant-Based Solar Dehumidification					
	2.0	**4.0**	**4.0**	**2.7**	**2.3**
Description: Solar Desiccant Dehumidification (SDD) uses liquid or solid desiccants to reduce latent heat in a conditioned air stream. Solar thermal energy is then used to regenerate the desiccant materials. Standalone SDD systems have limited cooling capacities, however they can be paired with other building technologies such as heat recovery wheels or vapor compression cycles to create more efficient hybrid cooling systems. More investigation is needed into the ways SDD System can be used in new hybrid systems and improve SDD performance. ***Applicable Barriers:*** First-cost disadvantage**,** Lack of integration					
Develop Low-Cost Adsorption Chiller					
	2.0	**3.7**	**3.0**	**2.3**	**2.3**
Description: Adsorption chillers have lower temperature requirements than absorption chillers, potentially making them better suited for solar thermal applications. However adsorption chillers can be significantly more expensive than absorption chillers. Research into potential cost saving measures for adsorption chillers need to be conducted to see if absorption-level costs (for similar sized equipment) can be achieved. ***Applicable Barriers:*** First-cost disadvantage					

Activity/Initiative	MSP Score	Fit with BTO Mission	Crit. of DOE Involvement	Level of Risk	Level of Req. Investment
Develop Packaged Solar Driven Adsorption or Absorption Cooling					
	2.0	**2.7**	**2.3**	**3.0**	**2.7**
Description: Adsorption and absorption cooling chillers are both commercially available for use with waste-heat streams and/or for direct gas-fired applications. To date, both cycles have had limited success in solar-driven applications due to high temperature requirements and a lack of cost-effective, small scale solutions. For these systems to be more successful in solar applications, they need to be designed specifically to be driven by solar thermal energy, and they should be packaged with appropriately sized solar collectors and balance of system (BOS) components. ***Applicable Barriers:*** First-cost disadvantage**,** Lack of integration**,** High temp requirements					
Demonstrate Successful Large-Scale Solar Cooling Projects					
	1.0	**4.3**	**4.0**	**2.7**	**2.0**
Description: Solar cooling technologies to date have had limited market penetration and commercial exposure, which in turn has limited the industry's ability to prove their value. The industry needs a pilot program to demonstrate the use of solar cooling on a large scale and showcase the latest solar cooling technologies. In addition, a successful solar cooling pilot program could provide much needed performance data for use in improving designs. ***Applicable Barriers:*** Perceived unreliability					
Develop Air-to-Air Solar Assisted Heat Pump					
	1.5	**4.0**	**3.0**	**3.0**	**3.0**
Description: Air-to-water solar assisted heat pump (SAHP) water heaters have been used successfully for water heating and hydronic space heating applications, particularly in European markets where there are many commercially available SAHP products. However, there is a lack of air-to-air SAHP for space heating. Further research and development of air-to-air SAHP technologies could lead to an efficient solar space heating system for forced-air heating applications. ***Applicable Barriers:*** First-cost disadvantage**,** Lack of integration					
Explore Opportunities for Nighttime Radiant Cooling					
	1.0	**2.7**	**3.0**	**2.7**	**2.7**
Description: Nighttime radiant cooling is the process of expelling hot air from a building at night and therefore reducing the building's cooling loads during the day. Solar thermal collectors could potentially be used as heat exchangers for conducting nighttime radiant cooling operations. A study of the efficiency of nighttime radiant cooling is needed to determine if is worthwhile to pursue, and in what markets and/or climate zones it is most effective. ***Applicable Barriers:*** Solar mismatch					

Table 8-4: Controls & Software Initiatives

Activity/Initiative	MSP Score	Fit with BTO Mission	Crit. of DOE Involvement	Level of Risk	Level of Req. Investment
Develop Low Cost Monitoring Tools for Solar Thermal Systems					
	2.5	**2.3**	**2.7**	**3.3**	**3.0**
Description: Many of the most promising BIST control methodologies rely on real-time data from sophisticated and expensive sensors. Low-cost flow and temperature sensors could enable systems to become much more cost effective in the future. In addition, stakeholders would benefit from sensors and monitoring equipment with improved wireless capabilities, allowing sensors to communicate with building management systems and/or independent monitoring equipment without the complexity and labor costs associated with extensive low-voltage wiring. ***Applicable Barriers:*** First-cost disadvantage**,** Lack of Well-Validated Tools					
Integrate BIST into BMS/EMS					
	1.0	**2.3**	**2.7**	**3.7**	**3.0**
Description: Properly operated smart Building Management Systems (BMS) and Energy Management Systems (EMS) can improve building efficiencies and optimize building energy consumption. BIST monitoring and real-time optimization capabilities need to be integrated into EMS/BMS. These systems will need to track available solar resources, monitor stored thermal energy, and gauge building loads. Using this data the BMS/EMS will dynamically decide whether to use solar thermal energy from collectors, extract thermal energy from storage equipment, or use supplementary power to meet building demands. BMS/EMS could also include the capability to integrate sub metering and smart grid technology. These systems will require advanced building models and building energy consumption forecasts as well as real time weather and solar pattern data. ***Applicable Barriers:*** Solar mismatch**,** Lack of integration**,** Perceived unreliability**,** Insufficient Solar Insolation					
Integrate Fault Detection and Diagnostics (FDD) Capabilities Into BIST Monitoring Systems					
	1.0	**2.7**	**3.3**	**3.0**	**3.3**
Description: BIST monitoring equipment and controls software could be extended to provide fault detection and diagnostics to help avoid or reduce downtime and ensure optimal equipment performance at all times. Further research into the common BIST failure modes may be needed in order to develop reliable fault detection systems. ***Applicable Barriers:*** Lack of integration**,** Perceived unreliability					

Table 8-5: Storage and System Integration Initiatives

Activity/Initiative	MSP Score	Fit with BTO Mission	Crit. of DOE Involvement	Level of Risk	Level of Req. Investment
Develop Innovative Mechanisms for Improved Building Integration					
	3.5	**4.0**	**3.7**	**2.0**	**2.7**
Description: Developing a range of innovative integration processes that improve the way that BIST interact with buildings has the potential to expand the market for BIST. The target technologies for this initiative include solar thermal collectors, BIPV, and PV/T modules. PV/T modules for instance have primarily been standalone products that are attached to buildings, however there are now some manufacturers developing building integrated PV/T (BIPV/T) products. Other innovations underway include BIPV roofing tiles, thin-film PV laminates for building surfaces, and building integrated evacuated tube collectors. New opportunities for improved building integration methods should continue to be explored with a focus on making BIST easier to install and use. ***Applicable Barriers:*** First-cost disadvantage**,** Lack of integration**,** Aesthetic Concerns					
Research New Opportunities for District/Community-Scale Solar Thermal Storage					
	2.5	**4.3**	**4.0**	**3.0**	**3.0**
Description: Community or district scale seasonal energy storage involves storing thermal energy from solar thermal systems. Typically either warm or cool thermal energy can be stored in the ground directly, via large in-ground reservoirs. Energy can also be stored in the form of warm or cool water in large flooded underground caverns. The thermal energy is later extracted as needed throughout the year when solar resources are less abundant. Seasonal energy storage projects have been implemented on a limited basis, one successful, but high-cost example is the Drake Landing Solar Community in Alberta, Canada.[69] New opportunities for seasonal thermal energy storage systems should be investigated and evaluated to promote future installations. ***Applicable Barriers:*** First-cost disadvantage**,** Solar mismatch**,** Insufficient Solar Insolation					
Develop Solar Hot Water Storage Tanks with Integrated Heating Components					
	3.0	**2.7**	**1.3**	**4.3**	**4.0**
Description: Typical SWH systems use a solar water storage tank and an additional, backup water heater to provide supplementary heating when the SWH system alone is not adequate. To reduce the cost and complexity of these SWH systems, the backup system can be integrated with the solar hot water storage. While some available systems enable the use of integrated systems, stakeholders comment that many still require a completely separate system that increases cost by adding in duplicative equipment and takes up space in the building. ***Applicable Barriers:*** First-cost disadvantage**,** Lack of integration**,** Physical Space Constraints					

[69] Drake Landing Solar Community: www.dlsc.ca/

Activity/Initiative	MSP Score	Fit with BTO Mission	Crit. of DOE Involvement	Level of Risk	Level of Req. Investment
Reduce Balance of Systems Costs for Solar Thermal Systems					
	2.0	**3.0**	**2.7**	**4.0**	**3.3**
Description: Further integration of BIST system components can reduce the labor required to install such systems, reduce system costs, and increase the overall reliability of the system. Integration can also lead to increased overall system efficiency by designing systems that require less auxiliary components and therefore less supplementary power. ***Applicable Barriers:*** First-cost disadvantage					
Research and Develop Thermal Storage Systems Based on Latent Heat of Evaporation					
	3.5	**3.0**	**3.7**	**1.7**	**1.7**
Description: Thermal storage based on the latent heat of evaporation, i.e., liquid to vapor PCM, has the potential to offer increased thermal storage capacity compared to systems based on the latent heat of fusion. Although further R&D is needed to bring this technology to market, this could lead to more effective thermal storage. ***Applicable Barriers:*** Solar mismatch					
Design and Manufacture New Low Cost Heat Exchangers					
	2.5	**3.3**	**2.3**	**3.0**	**2.7**
Description: Heat exchangers are one of the more expensive BOS components in BIST systems. There is a need for R&D of new low cost heat exchanger designs, materials, and manufacturing techniques for solar thermal systems. Development of new low cost heat exchangers can also benefit other building technologies that rely on heat exchangers beyond BIST. ***Applicable Barriers:*** First-cost disadvantage					
Improve and Optimize integration of BIST with Hydronic or Geothermal Systems					
	2.5	**2.3**	**3.0**	**3.3**	**3.3**
Description: Integrating solar thermal systems with other systems such as geothermal or hydronic heating systems, which already have heat exchangers installed in residential buildings, could reduce the cost of solar thermal systems. ***Applicable Barriers:*** Lack of integration					
Incorporate Low Cost/High Reliability Storage Tanks Into Solar Thermal Systems					
	2.0	**2.3**	**2.0**	**3.7**	**4.0**
Description: One approach to low cost storage tanks is to use unpressurized rather than pressurized tanks. Unpressurized plastic vessels are cheap, lightweight (lowered installation cost), and have excellent corrosion resistance (longer lifetimes). However, in such a system, the water must be re-pressurized, requiring additional energy. There are also other low cost options such as using roof mounted batch collectors. ***Applicable Barriers:*** First-cost disadvantage					

Activity/Initiative	MSP Score	Fit with BTO Mission	Crit. of DOE Involvement	Level of Risk	Level of Req. Investment
Develop Envelope Heat Recovery Systems					
	2.5	**2.7**	**3.7**	**2.0**	**2.0**
Description: Building envelopes naturally absorb solar energy. In addition to using solar collectors to harvest this energy, thermal energy can be extracted directly from building envelopes and harnessed for other applications. However, more R&D is needed to transform these concepts into fully integrated market ready products. ***Applicable Barriers:*** First-cost disadvantage, Lack of integration					
Develop Alternatives to Piping for Transporting Thermal Energy					
	2.0	**3.0**	**3.7**	**2.0**	**2.3**
Description: Alternative methods to piping thermal energy from the roof into the building include ideas such as using forced air rather as an alternative to piped water as a means to transport thermal energy. However, these ideas are all preliminary and a detailed study would be needed to determine if there are any advantages to replacing piping with an alternative system. ***Applicable Barriers:*** Physical Space Constraints					
Improve Commercial-Scale Solar Thermal Storage					
	1.0	**3.3**	**3.0**	**3.0**	**3.0**
Description: Improving commercial-scale thermal storage options will enable commercial buildings to take greater advantage of excess energy harvested during times of peak solar generation. Using new storage infrastructure may provide increased storage density and duration that could impact overall building energy consumption when solar resource are not available and shift load to periods of off-peak rate schedules. Another alternative to using storage tanks for storing thermal energy is using the structure of commercial buildings as the medium for thermal storage. In particular, large concrete buildings with high thermal mass can be used to store heat from solar collectors. ***Applicable Barriers:*** Solar mismatch**,** Insufficient Solar Insolation					
Research and Develop Systems to Control Building Loads Using Thermal Mass					
	2.0	**2.7**	**4.0**	**1.0**	**1.3**
Description: The idea is to control the rate of change of heat in a building by increasing or decreasing the thermal mass of the building. This concept is still preliminary and will require R&D efforts to determine if and how it could be implemented effectively. ***Applicable Barriers:*** Solar mismatch					
Expand Applications of Transparent Thermal Insulating Materials					
	1.0	**2.0**	**2.7**	**2.7**	**2.7**
Description: Transparent thermal insulating materials have been utilized by many solar technologies for their ability to allow solar radiation to pass through while capturing thermal energy. However, there are more potential applications for these products that need to be explored including providing additional insulation for windows and roof integrated solar collectors. ***Applicable Barriers:*** Insufficient Solar Insolation					

Activity/Initiative	MSP Score	Fit with BTO Mission	Crit. of DOE Involvement	Level of Risk	Level of Req. Investment
Incorporate Active Thermal Envelope Flushing Technologies					
	1.0	**2.7**	**3.0**	**2.0**	**2.7**
Description: During cooling seasons, the roof, walls, and floors of a building can be flushed with cool outside air at night, either by forced or natural convection, thus removing excess heat from the structure of the building, therefore offsetting cooling loads during the day. Further R&D is needed to transform these concepts into market ready technologies. ***Applicable Barriers:*** Solar mismatch					

Table 8-6: Manufacturing, Installation, and Maintenance Initiatives

Activity/Initiative	MSP Score	Fit with BTO Mission	Crit. of DOE Involvement	Level of Risk	Level of Req. Investment
Provide DOE Manufacturing Assistance to Collector Manufacturers					
	3.5	**3.7**	**3.7**	**3.0**	**2.0**
Description: DOE in the past has assisted manufactures in developing improved manufacturing techniques and processes. Stakeholders see substantial room to improve BIST production methods to make manufacturing of BIST components more cost effective. With increased automation and manufacturing volumes, manufacturers can reduce BIST costs. ***Applicable Barriers:*** First-cost disadvantage					
Target Correct Markets for BIST Installations by Application/Technology					
	3.0	**1.7**	**2.0**	**4.0**	**4.0**
Description: Focusing BIST installation efforts on specific markets or market segments with anticipated building or roof lifecycles that coincide with those of a specific application. ***Applicable Barriers:*** First-cost disadvantage					
Reduce Failure Rates and Increase Reliability					
	2.0	**1.7**	**3.0**	**3.3**	**3.3**
Description: The reliability of solar thermal systems needs to be increased. Particular areas of focus should include polymer materials that degrade quickly in UV light and at high temperatures, and components with moving parts such as pumps, which tend to be the first components in the system to fail. ***Applicable Barriers:*** Perceived unreliability					
Develop Low-Cost Balancing Tools for Commissioning Large Systems					
	1.0	**2.7**	**2.3**	**3.3**	**3.7**
Description: When commissioning large SWH systems, installers need tools to help them balance the flow evenly through all of the collectors in the system. In many large SWH systems, containing multiple solar collectors, the heating fluid will not flow evenly through each collector in the array. ***Applicable Barriers:*** First-cost disadvantage**,** Perceived unreliability					

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

DOE/EE-1022 • January 2014

Printed with a renewable-source ink on paper containing at least 50% wastepaper, including 10% post-consumer waste.