The Influence of Concentrating Solar Power Patents Funded by the U.S. Department of Energy's Solar Energy Technologies Office and Other DOE Offices

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Executive Summary

This report describes the results of an analysis tracing the technological influence of Concentrating Solar Power (CSP) research funded by the U.S. Department of Energy (DOE)'s Solar Energy Technology Office (SETO) and its precursor programs, as well as CSP research funded by other offices in DOE. The tracing is carried out both backwards and forwards in time, and focuses on patents filed in three systems: the U.S. Patent & Trademark Office (U.S. patents); the European Patent Office (EPO patents); and the World Intellectual Property Organization (WIPO patents). The primary period covered in this analysis is 1976 to 2018.

The primary purpose of the backward tracing is to determine the extent to which SETO-funded CSP research has formed a foundation for innovations patented by leading CSP organizations. Meanwhile, the primary purpose of the forward tracing is to examine the broader influence of SETO-funded CSP research upon subsequent technological developments, both within and outside the CSP technology area. In addition to these SETO-based analyses, we also extend many elements of the analysis to other DOE-funded CSP patents, in order to gain insights into their influence.

The main finding of this report is:

- CSP research funded by SETO, and by DOE in general, has had a significant influence on subsequent developments, both within and beyond CSP technology. This influence can be seen on innovations associated with the leading CSP organizations. It can also be seen on innovations associated with large companies across a range of other technologies.

More detailed findings from this report include:

- In CSP technology, in the period 1976-2018, we identified a total of 19,477 patents (7,983 U.S. patents, 5,028 EPO patents and 6,466 WIPO patents). We grouped these patents into 14,582 patent families, with each family containing all patents resulting from the same initial application (named the 'priority application').

- 112 CSP patents are confirmed to be associated with SETO funding (70 U.S. patents, 17 EPO patents, and 25 WIPO patents). We grouped these SETO-funded CSP patents into 56 patent families.

- In addition, we identified a further 176 CSP patents (150 U.S. patents, 8 EPO patents and 18 WIPO patents) that are associated with other DOE funding. These "Other DOE-funded" patents are grouped into 135 patent families.

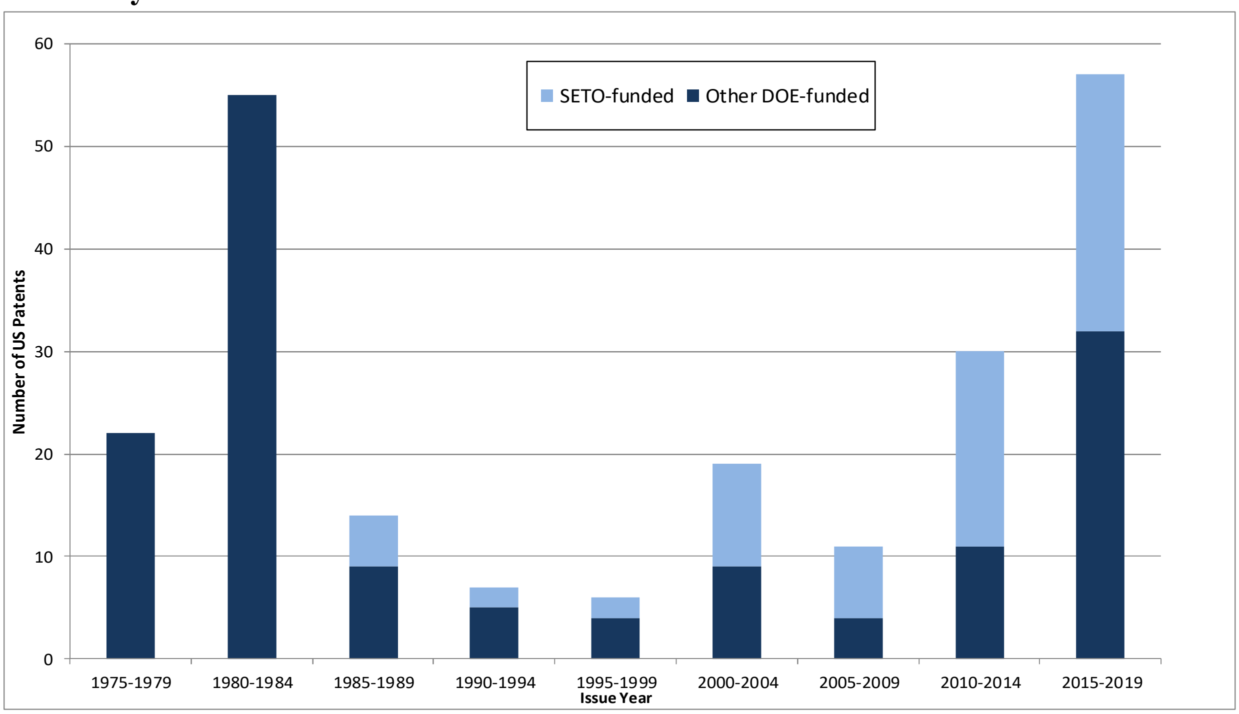
- Out of these 135 Other DOE-funded patent families, 29 are definitely not SETO-funded. Eight of the 29 are associated with funding from other DOE offices: three ARPA-E; two Office of Science; two Hydrogen and Fuel Cell Technologies Office; and one (very old) family funded by the Atomic Energy Commission. The other 21 families were marked as being not SETO-funded by inventors or SETO technology managers, but without specifying funding from another DOE source.

- The remaining 106 Other DOE-funded CSP patent families could not be linked definitively to a DOE office. Many of these patent families are older, and may in fact have been SETO-funded, since they correspond with a particularly active period of CSP funding by SETO. Hence, up to 80% (106 out of 135) of the Other DOE-funded CSP patent families may be SETO-funded. As such, the results presented in this report may understate the influence of SETO-funded CSP research, relative to the influence of CSP research funded by DOE in general.

- The total number of DOE-funded CSP patents (SETO-funded plus Other DOE-funded) is 288, corresponding to 191 patent families. This represents approximately 1.3% of the total number of CSP patent families in the period 1976-2018.

- There are two time periods in which DOE-funded (i.e. SETO-funded plus Other DOE-funded) CSP patenting was particularly active (see Figure E-1). The first was in the earliest time period in the analysis, from 1976-1984. Almost all the patents in this period are defined as Other DOE-funded, due to records from this period not showing a definitive link to SETO. As noted above, many of these patents may have in fact been funded by SETO. There was then a relatively quiet period in DOE-funded CSP patenting, from 1985-2009, before a recent increase since 2010. SETO-funded CSP patents are a much higher proportion of total DOE-funded CSP patents in this recent time period.

Figure E-1 - Number of CSP Granted U.S. Patents Funded by SETO and Other DOE Sources by Issue Year



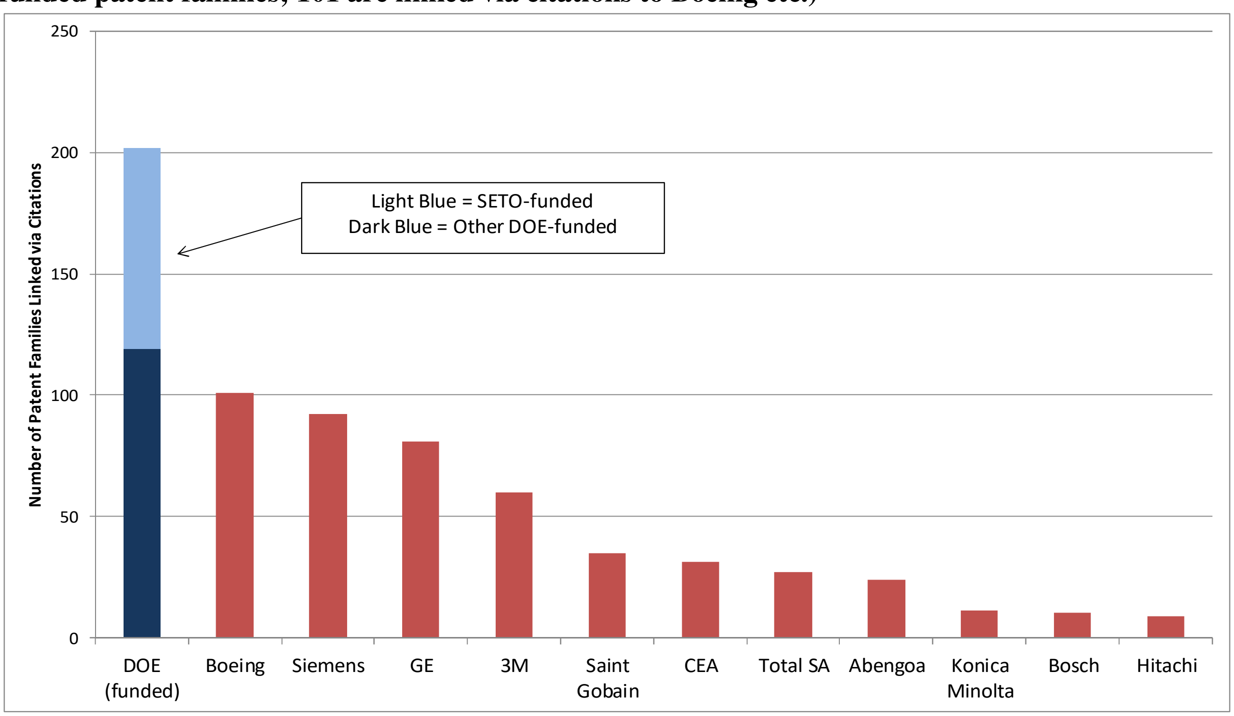
Note: The data collection period for this analysis ended with 2018. Any 2019 patents in the 2015-2019 bar are additional patents that have been included because they are members of the same patent families as pre-2019 patents. No new patent search for 2019 was carried out.

- Based on combined U.S., EPO and WIPO data, the 191 DOE-funded CSP patent families represent the second largest portfolio in CSP technology, behind only Siemens (211 patent families). The remaining organizations in the top eleven (top 10 plus ties) in terms of number of CSP patent families are: Abengoa SA (115); Bosch (101); CEA (Commissariat à l'énergie atomique et aux énergies alternatives - 87); Boeing (75); Compagnie de Saint-Gobain (74); General Electric (69); Konica Minolta (64); Total SA (64); 3M (59) and Hitachi (59).

- SETO-funded CSP patents have a particular focus on larger scale CSP installations, plus technologies designed for these installations (such as solar towers). Meanwhile, Other DOE-funded CSP patents concentrate more on solar heat exchange and building applications. The leading CSP organizations beyond DOE are focused to a greater extent on mountings and tracking for CSP. As such, in the period 1976-2018, SETO funding may have helped fill a research gap (i.e. large scale CSP installations) not addressed extensively by the leading companies.

- Twice as many CSP patent families owned by leading organizations are linked via citations to earlier DOE-funded (i.e. SETO-funded and Other DOE-funded) CSP patents than are linked to the CSP patents assigned to any other leading organization (see Figure E-2). This is an impressive result, and suggests that DOE-funded research has formed an important part of the foundation for CSP research carried out by leading organizations.

Figure E-2 – Number of Leading Organization CSP Patent Families Linked via Citations to Earlier CSP Patents Associated with Each Leading Organization
(e.g. 202 leading organization CSP families are linked via citations to earlier SETO/Other DOE funded patent families; 101 are linked via citations to Boeing etc.)



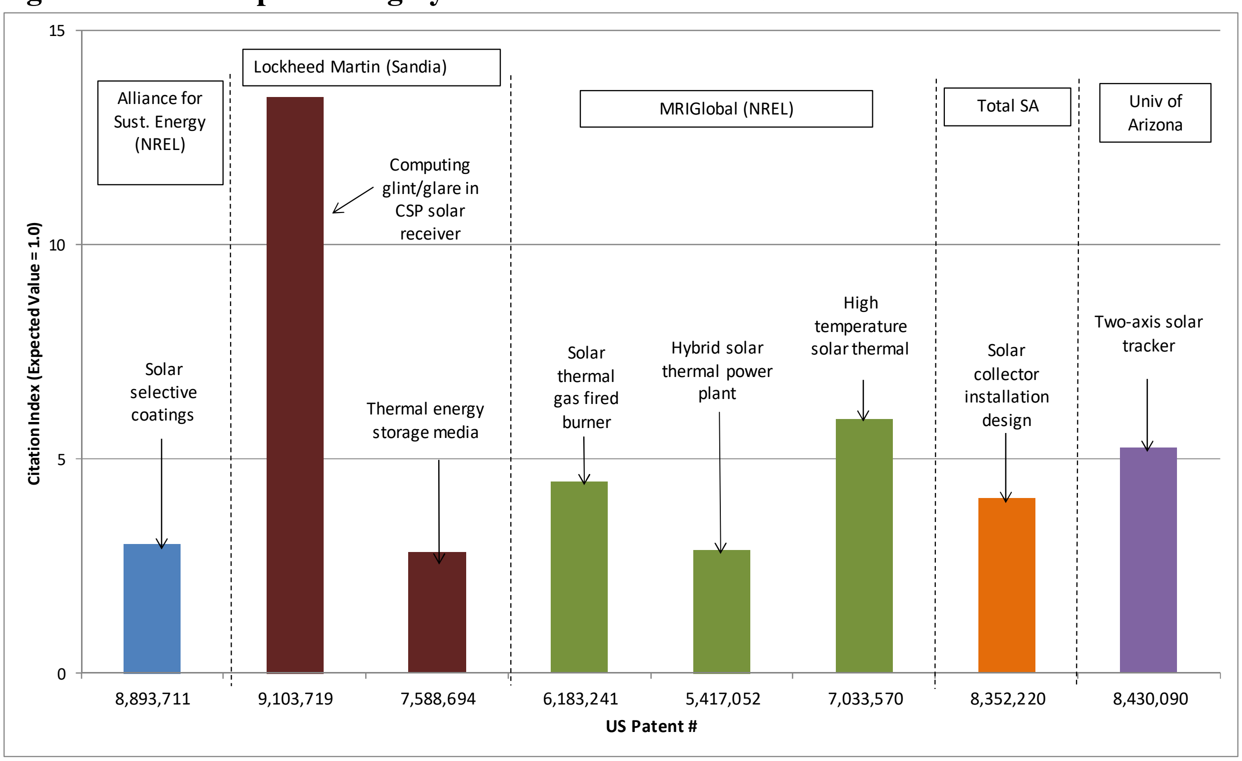
- Among the leading organizations, CSP patent families owned by Boeing, Total SA and 3M are linked particularly extensively via citations to earlier DOE-funded CSP patents. More than 30% of each of these companies' CSP patent families are linked to earlier DOE-funded CSP patents. This suggests that DOE-funded CSP research has had an especially strong influence on innovations developed by these companies.

- SETO-funded CSP patents have an average Citation Index value of 1.58 (the Citation Index is a normalized citation metric with an expected value of 1.0; a value of 1.58 shows that, based on their age and technology, SETO-funded CSP energy patents have been cited as prior art 58% more frequently than expected by subsequent patents). Meanwhile, Other DOE-funded CSP patents have a Citation Index of 1.25, showing that they have been cited 25% more frequently than expected.

- The influence of SETO-funded and Other DOE-funded CSP patents can be seen both within the CSP technology field, and in other technologies, notably photovoltaics, material science, bioenergy and optics.

- There are a number of individual high-impact SETO-funded CSP patents, as shown in Figure E-3. They include a Sandia National Laboratory patent describing computer-based optimization of solar collectors (cited 13 times more frequently than peer patents from the same year and technology); an MRIGlobal (National Renewable Energy Laboratory) patent detailing a high-temperature solar thermal reactor (cited almost six times more frequently than peer patents); and a University of Arizona patent describing a two-axis solar tracker apparatus (cited more than five times as frequently as peer patents).

Figure E-3 – Examples of Highly-Cited SETO-funded CSP Patents



1.0 Introduction

This report focuses on Concentrating Solar-Thermal Power (CSP) technology.[1] Its objective is to trace the influence of CSP research funded by the Solar Energy Technologies Office (SETO) in the Department of Energy's (DOE) Office of Energy Efficiency and Renewable Energy (EERE) – as well as CSP research funded by DOE as a whole – upon subsequent developments both within and outside CSP technology. The purpose of the report is to:

(i) Locate patents awarded for key SETO-funded (and Other DOE-funded) innovations in CSP technology; and

(ii) Determine the extent to which SETO-funded (and Other DOE-funded) CSP research has influenced subsequent technological developments both within and beyond CSP.

The primary focus of the report is on the influence of SETO-funded CSP patents. That said, we also extend many elements of the analysis to DOE-funded CSP patents that could not be definitively linked to SETO funding. There are both evaluative and practical reasons for extending the analysis in this way. From an evaluation perspective, it is interesting to examine the influence of SETO itself upon the development of CSP technology, while also tracing the influence of DOE more generally. Meanwhile, in practical terms, determining which patents were funded by SETO, versus other offices within DOE, is often very difficult.

In the U.S. patent system, applicants are required to acknowledge any government funding they have received related to the invention described in their patent application. Typically, this government support is listed at the level of the agency (e.g. Department of Energy, Department of Defense, etc.). Hence, the only way to determine which office within DOE funded a given patent is via other data resources (e.g. iEdison), or through direct input from offices, program managers and individual inventors. Such information is often unavailable, especially for older patents where records may be less comprehensive, and there is less access to the inventors and program managers involved.

Rather than discard patents confirmed as DOE-funded, but that could not be definitively categorized as SETO-funded, we instead included these patents in the analysis under a separate "Other DOE-funded" category. Some of these Other DOE-funded patents are linked to funding from non-SETO DOE offices but, for a much larger number, the source of funding within DOE is unknown. Many of these "unknown" patents are from the earliest period of the analysis (1976-1984) and may in fact have been funded by SETO, although a definitive link could not be established. Hence, the results reported here may underestimate the influence of SETO-funded CSP research, relative to the influence of CSP research funded by the rest of DOE.

[1] During a large part of SETO's history, its research in this area was referred to as 'solar thermal', with the key element being the use of sunlight to heat a fluid (e.g. water) in order to generate energy. Also, patent classification systems use the term solar thermal rather than CSP. In this report, we refer to CSP in order to match the current name of the SETO Concentrating Solar Power (CSP) R&D subprogram. That said, we recognize that 'solar thermal' may be a more appropriate label for the entire history of work in this area funded by SETO, and thus for the SETO-funded patents included in this analysis.

This report contains three main sections. The first of these sections describes the project design. This section includes a brief overview of patent citation analysis, and outlines its use in the multi-generation tracing employed in this project. The second section outlines the methodology, and includes a description of the various data sets used in the analysis, and the processes through which these data sets were constructed and linked.

The third section presents the results of our analysis. Results are presented at the organizational level for both SETO-funded and Other DOE-funded patents. These results show the distribution of SETO-funded (and Other DOE-funded) patents across CSP technologies (as defined by Cooperative Patent Classifications). They also evaluate the extent of SETO's influence (and DOE's influence in general) on subsequent developments in CSP and other technologies. Patent level results are then presented to highlight individual SETO-funded CSP patents that have been particularly influential, as well as revealing key patents from other organizations that build extensively on SETO-funded CSP research.[2]

2.0 Project Design

This section of the report outlines the project design. It begins with a brief overview of patent citation analysis, which forms the basis for much of the evaluation presented in this report. This overview is followed by a description of the techniques used to link the various patent sets in the analysis, plus a listing and description of the metrics employed in the study.

The analysis described in this report is based largely upon tracing citation links between successive generations of patents. This tracing is carried out both backwards and forwards in time. The primary purpose of the backward tracing is to determine the extent to which technologies developed by leading organizations in the CSP industry used SETO-funded research as a foundation. Meanwhile, the primary purpose of the forward tracing is to examine how SETO-funded CSP patents influenced subsequent technological developments more broadly, both within and outside CSP technology. Many elements of both the backward and forward tracing are also extended to the Other DOE-funded patents, in order to trace their influence, both overall and upon the leading CSP organizations.[3]

Our analysis covers patents filed in three systems: the U.S. Patent & Trademark Office (U.S. patents); the European Patent Office (EPO patents); and the World Intellectual Property Organization (WIPO patents). By covering multiple generations of citations across patent systems, our analysis allows for a wide variety of possible linkages between DOE-funded CSP research and subsequent technological developments. Examining all of these linkage types at the

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[2] This is one of a series of similar reports examining research portfolios across a range of DOE offices. Note that the results are not designed to be compared across portfolios, for example in terms of numbers of patents granted, number of citations received etc. The portfolios have very different profiles with respect to research risks, funding levels and time periods covered, plus there are wide variations in the propensity to patent across technologies. Hence, the results reported in the various reports should not be used for comparative analyses across portfolios.

[3] The analyses described in this report were carried out separately for SETO-funded CSP patents and Other DOE-funded CSP patents. However, referring repeatedly to "SETO-funded/Other DOE-funded patents" or "SETO-funded/Other DOE-funded research" in describing the analyses is lengthy, so we instead use the collective terms "DOE-funded patents" and "DOE-funded research" in the Project Design and Methodology sections of the report.

level of an entire technology involves a significant data processing effort, and requires access to specialist citation databases, such as those maintained at 1790 Analytics. As a result, this project is more ambitious than many previous attempts to trace through multiple generations of research, which have often been based on studying very specific technologies or individual products.

Patent Citation Analysis

In many patent systems, patent documents contain a list of references to prior art. The purpose of these prior art references is to detail the state of the art at the time of the patent application, and to demonstrate how the new invention is original over and above this prior art. Prior art references may include many different types of public documents. A large number of the references are to earlier patents, and these references form the basis for this study. Other references (not covered in this study) may be to scientific papers and other types of documents, such as technical reports, magazines and newspapers.

The responsibility for adding prior art references differs across patent systems. In the U.S. patent system, it is the duty of patent applicants to reference (or "cite") all prior art of which they are aware that may affect the patentability of their invention. Patent examiners may then reference additional prior art that limits the claims of the patent for which an application is being filed. In contrast to this, in patents filed at the European Patent Office (EPO) and World Intellectual Property Organization (WIPO), prior art references are added solely by the examiner, rather than by both the applicant and examiner. The number of prior art references on EPO and WIPO patents thus tends to be much lower than the number on U.S. patents.[4]

Patent citation analysis focuses on the links between generations of patents that are made by these prior art references. In simple terms, this type of analysis is based upon the idea that the prior art referenced by patents has had some influence, however slight, upon the development of these patents. The prior art is thus regarded as part of the foundation for the later inventions.

In assessing the influence of individual patents, citation analysis centers on the idea that highly cited patents (i.e. those cited by many later patents) tend to contain technological information of particular interest or importance. As such, they form the basis for many new innovations and research efforts, and so are cited frequently by later patents. While it is not true to say that every highly cited patent is important, or that every infrequently cited patent is necessarily trivial, many research studies have shown a correlation between patent citations and measures of technological and economic importance. For background on the use of patent citation analysis, including a summary of validation studies supporting its use, see: Breitzman A. & Mogee M. "The many applications of patent analysis", *Journal of Information Science*, 28(3), 2002, 187-205; and Jaffe A. & de Rassenfosse G. "Patent Citation Data in Social Science Research: Overview and Best Practices", NBER Working Paper No. 21868, January 2016.

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[4] Note that this analysis does not cover patents from other systems, notably patents from the Chinese, Japanese and Korean patent offices. This is because patents from these systems do not typically list any prior art. Hence, it is not possible to use citation links to trace the influence of DOE research on patents from these systems. Having said this, Chinese, Japanese and Korean organizations are among the most prolific applicants in the WIPO system. Our analysis thus picks up the role of organizations from these countries via their WIPO filings.

Patent citation analysis has also been used extensively to trace technological developments over time. For example, in the analysis presented in this report, we use citations from patents to earlier patents to trace the influence of DOE-funded CSP research. Specifically, we identify cases where patents cite DOE-funded CSP patents as prior art. These represent first-generation links between DOE-funded patents and subsequent technological developments. We also identify cases where patents cite patents that in turn cite DOE-funded CSP patents. These represent second-generation links between technological developments and DOE-funded research.

The idea behind this analysis is that the later patents have built in some way on the earlier DOE-funded CSP research. By determining how frequently DOE-funded CSP patents have been cited by subsequent patents, it is thus possible to evaluate the extent to which DOE-funded research forms a foundation for various technologies both within and beyond CSP.

Forward and Backward Tracing

As noted above, the purpose of this analysis is to trace the influence of DOE-funded CSP research upon subsequent developments both within and beyond CSP technology. There are two approaches to such a tracing study – backward tracing and forward tracing – each of which has a slightly different objective.

Backward tracing, as the name suggests, looks backwards over time. The idea of backward tracing is to take a particular technology, product, or industry, and to trace back to identify the earlier technologies upon which it has built. In the context of this project, we first identify the leading CSP organizations in terms of patent portfolio size. We then trace backwards from the patents owned by these organizations. This makes it possible to determine the extent to which innovations associated with these leading CSP organizations build on earlier SETO-funded and Other DOE-funded research.

The idea of forward tracing is to take a given body of research, and to trace the influence of this research upon subsequent technological developments. In the context of the current analysis, forward tracing involves identifying all CSP patents resulting from research funded by DOE (i.e. SETO plus Other DOE). The influence of these patents on later generations of technology is then evaluated. This tracing is not restricted to subsequent CSP patents, since the influence of a body of research may extend beyond its immediate technology. Hence, the purpose of the forward tracing element of this project is to determine the influence of DOE-funded CSP patents upon developments both inside and outside this technology.

Tracing Multiple Generations of Citation Links

The simplest form of tracing study is one based on a single generation of citation links between patents. Such a study identifies patents that cite, or are cited by, a given set of patents as prior art.

The analysis described in this report extends the tracing by adding a second generation of citation links.[5]

The backward tracing starts with patents assigned to the leading patenting organizations in CSP technology. The first generation contains the patents that are cited as prior art by these starting patents. The second generation contains patents that are in turn cited as prior art by these first generation patents. In other words, the backward tracing starts with CSP patents owned by leading organizations in this technology, and traces back through two generations of earlier patents to identify the technologies upon which they were built, including those funded by DOE.

The forward tracing starts with DOE-funded patents in CSP technology. The first generation contains the patents that cite these DOE-funded patents as prior art. The second generation contains the patents that in turn cite these first-generation patents. In other words, the analysis starts with DOE-funded CSP patents and traces forward for two generations of subsequent patents.

This means that we trace forward through two generations of citations starting from DOE-funded CSP patents; and backward through two generations starting from the patents owned by leading CSP organizations. Hence there are two types of links between DOE-funded patents and subsequent generations of patents:

1. **Direct Links**: where a patent cites a DOE-funded CSP patent as prior art.

2. **Indirect Links**: where a patent cites an earlier patent, which in turn cites a DOE-funded CSP patent. The DOE patent is thus linked indirectly to the subsequent patent.

The idea behind adding the second generation of citations is that agencies such as DOE often support basic scientific research. It may take time, and numerous generations of research, for this basic research to be used in an applied technology, for example that described in a patent owned by a leading company. Introducing a second generation of citations provides greater access to these indirect links between basic research and applied technology.

One potential problem with adding generations of citations must be acknowledged. Specifically, if one uses enough generations of links, eventually almost every node in the network will be linked. This is a problem common to many networks, whether these networks consist of people, institutions, or scientific documents, as in this case. The most famous example of this is the idea that every person is within six links of any other person in the world. By the same logic, if one takes a starting set of patents, and extends the network of prior art references far enough, almost all patents will be linked to this starting set. Hence, while including a second generation of citations provides insights into indirect links between basic research and applied technologies, adding further generations may bring in too many patents with little connection to the starting patent set.

[5] As noted above, the forward and backward tracing were carried out separately for SETO-funded and Other DOE-funded CSP patents. The references in this section to "DOE patents" are shorthand, and do not mean that the tracing was carried out for all DOE-funded CSP patents as a single portfolio.

Constructing Patent Families

The coverage of a patent is limited to the jurisdiction of its issuing authority. For example, a patent granted by the U.S. Patent & Trademark Office (a 'U.S. patent') provides protection only within the United States. If an organization wishes to protect an invention in multiple countries, it must file patents in each of those countries' systems. For example, a company may file to protect a given invention in the U.S., China, Germany, Japan and many other countries. This would result in multiple patent documents for the same invention.[6] In addition, in some systems – notably the U.S. – inventors may apply for a series of patents based on the same underlying invention.

In the case of this study, one or more U.S., EPO and WIPO patents may result from a single invention. To avoid counting the same inventions multiple times, it is necessary to construct "patent families". A patent family contains all of the patents and patent applications that result from the same original patent application (named the "priority application"). A family may include patents from multiple countries, and also multiple patents from the same country. In this project, we constructed patent families for DOE-funded CSP patents, and also for the patents owned by leading CSP organizations. We also assembled families for all patents linked via citations to DOE-funded CSP patents.

To construct these patent families, we matched the priority documents of the U.S., EPO and WIPO patents, in order to group them into the appropriate families. It should be noted that the priority document need not necessarily be a U.S., EPO or WIPO application. For example, a Japanese patent application may result in U.S., EPO and WIPO patents, which are grouped in the same patent family because they share the same Japanese priority document.

Metrics Used in the Analysis

Table 1 contains a list of the metrics used in the analysis. These metrics are divided into three main groups – technology landscape metrics (trends, assignees, and technology distributions), backward tracing metrics, and forward tracing metrics. Findings for each of these three groups of metrics can be found in the Results section of the report.

[6] It also means that patents from a given country's system are not synonymous with inventions made in that country. Indeed, roughly half of all U.S. patent applications are from overseas inventors.

Table 1 – List of Metrics Used in the Analysis

Metric
Trends
• Number of SETO/Other DOE-funded CSP patent families by year of priority application
• Number of SETO/Other DOE-funded granted U.S. CSP patents by issue year
• Overall number of CSP patent families by priority year
• Percentage of CSP patents families funded by SETO/Other DOE by priority year
Assignee Metrics
• Number of CSP patent families for leading patenting organizations
• Assignees with largest number of CSP patent families funded by SETO/Other DOE
Technology Metrics
• Patent classification (CPC) distribution for SETO-funded CSP patent families (vs Other DOE-funded, leading CSP companies, all CSP)
Backward Tracing Metrics
• Total number of leading company CSP patent families linked via citations to earlier patent families from SETO/Other DOE-funded and other leading companies
• Number of CSP patent families for each leading company linked via citations to earlier SETO/Other DOE-funded patent families
• Total number of citation links from each leading company to SETO/Other DOE-funded patent families
• Percentage of leading company CSP patent families linked via citations to earlier SETO/Other DOE-funded patent families
• SETO/Other DOE-funded CSP patent families linked via citations to largest number of leading company CSP patent families
• Leading company CSP patent families linked via citations to largest number of SETO-funded CSP patent families
• Highly cited leading company CSP patent families linked via citations to earlier SETO-funded CSP patent families
Forward Tracing Metrics
• Citation Index for CSP patent portfolios owned by leading companies, plus portfolios of SETO/Other DOE-funded CSP patents
• Number of patent families linked via citations to SETO/Other DOE-funded CSP patents by patent classification
• Organizations (beyond leading CSP companies) linked via citations to largest number of SETO/Other DOE-funded CSP patent families
• Highly cited SETO-funded CSP U.S. patents
• SETO/Other DOE-funded CSP patent families linked via citations to largest number of subsequent CSP/non-CSP patent families
• Highly cited patents (not owned by leading companies) linked via citations to earlier SETO-funded CSP patents families

3.0 Methodology

The previous section of the report outlines the objective of our analysis – that is, to determine the influence of SETO-funded (and Other DOE-funded) CSP research on subsequent developments both within and outside CSP technology. This section of the report describes the methodology used to implement the analysis. Particular emphasis is placed on the processes employed to construct the various data sets required for the analysis. Specifically, the forward tracing starts from the sets of CSP patents funded by SETO and Other DOE. Meanwhile, the backward tracing starts from the set of all CSP patents owned by leading patenting organizations in CSP technology. We therefore had to define these various data sets – SETO-funded CSP patents; Other DOE-funded CSP patents; and CSP patents assigned to the leading organizations in this technology.

Identifying SETO-funded and Other DOE-funded CSP Patents

The objective of this analysis is to trace the influence of CSP research funded by SETO (plus CSP research funded by the remainder of DOE) upon subsequent developments both within and outside CSP technology. Outlined below are the three steps used to identify SETO-funded and Other DOE-funded CSP patents. These three steps are:

(i) Defining the universe of DOE-funded patents;

(ii) Determining which of these DOE-funded patents are relevant to CSP; and

(iii) Categorizing these DOE-funded CSP patents according to whether or not they can be linked definitively to SETO funding.

Defining the Universe of DOE-Funded Patents

Identifying patents funded by government agencies is often more difficult than locating patents funded by companies. When a company funds internal research, any patented inventions emerging from this research are likely to be assigned to the company itself. In order to construct a patent set for a company, one simply has to identify all patents assigned to the company, along with all of its subsidiaries, acquisitions, etc.

Constructing a patent list for a government agency is more complicated, because the agency may fund research carried out at many different organizations. For example, DOE operates seventeen national laboratories. Patents emerging from these laboratories may be assigned to DOE. However, they may also be assigned to the organization that manages a given laboratory. For example, many patents from Sandia National Laboratory are assigned to Lockheed Martin (Sandia's former lab manager), while many Lawrence Livermore National Laboratory patents are assigned to the University of California. Lockheed Martin and the University of California are large organizations with many interests beyond managing DOE labs, so one cannot simply take all of their patents and define them as DOE-funded.

A further complication is that DOE does not only fund research in its own labs and research centers, it also funds extramural research carried out by other organizations. If this research results in patented inventions, these patents are likely to be assigned to the organizations carrying out the research, rather than to DOE.

We therefore constructed a database containing all DOE-funded patents. These include patents assigned to DOE itself, and also patents assigned to individual labs, lab managers, and other organizations and companies funded by DOE. This "All DOE" patent database was constructed using a number of sources:

1. ***DOEPatents Database*** – The first source is a database of DOE-funded patents put together by DOE's Office of Scientific & Technical Information (OSTI), and available on the web at www.osti.gov/doepatents/. This database contains information on research grants provided by DOE. It also links these grants to the organizations or DOE labs that carried out the research, the sponsor organization within DOE, and the patents that resulted from these DOE grants.

2. ***iEdison Database*** – EERE staff provided us with an output from the iEdison database, which is used by government grantees and contractors to report government-funded subject inventions, patents, and utilization data to the government agency that issued the funding award.

3. ***Visual Patent Finder Database*** – EERE also provided us with an output from its Visual Patent Finder tool. This tool takes DOE-funded patents and clusters them based on word occurrence patterns. In our case, the output was a flat file containing DOE-funded patents.

4. ***Patents assigned to DOE*** – in the USPTO database, we identified a small number of U.S. patents assigned to DOE itself that were not in the any of the sources above. These patents were added to the list of DOE patents.

5. ***Patents with DOE Government Interest*** – A U.S. patent has on its front page a section entitled 'Government Interest', which details the rights that the government has in a particular invention. For example, if a government agency funds research at a private company, the government may have certain rights to patents granted based on this research. We identified all patents that refer to 'Department of Energy' or 'DOE' in their Government Interest field, including different variants of these strings. We also identified patents that refer to government contracts beginning with 'DE-' or containing the string '-ENG-'. The former string typically denotes DOE contracts and financial assistance projects, while the latter string is a legacy DOE lab code listed on numerous older DOE-funded patents. We manually checked all of the patents containing these strings that were not already in any of the sources above, to make sure that they are indeed DOE-funded (e.g. '-ENG-' is also used in a small number of NSF contracts). We then included the additional DOE funded patents in the database.

The "All DOE" patent database constructed from these five sources contains more than 31,000 DOE-funded U.S. patents issued between January 1976 and December 2018 (the end-point of the primary data collection for this analysis).

Identifying DOE-Funded CSP Patents

Having defined the universe of DOE-funded patents, the next step was to determine which of these patents are relevant to CSP technology. We designed a custom patent filter to identify CSP patents, consisting of a combination of Cooperative Patent Classifications (CPCs) and keywords. Details of the patent filter are shown in Table 2.

Table 2 – Filter used to Identify DOE-funded CSP Patents

Patent Classification	Description
Y02B 10/20-24	Solar thermal – collectors, air conditioning, refrigeration
Y02E 10/40-47	Solar thermal – collectors, concentrators, mountings
Y02P 80/24	Solar thermal – applications
Y02P 60/124	Solar thermal – in greenhouses
F24S	Solar thermal – collectors, heating systems
F03G 6/003-068	Solar thermal – use in generating mechanical power
F03G 2006/006	Solar thermal – use in generating mechanical power
F03G 2006/008	Solar thermal – use in generating mechanical power
F03G 2006/061	Solar thermal – parabolic linear concentrators
F03G 2006/062	Solar thermal – parabolic point concentrators
OR	
Title/Abstract	
Solar* +/- 2 words (thermal* or concentrat* or collect* or transpir* or heat* or fluid* or steam* or pond* or receiver*) Where * is a wildcard representing unlimited characters (e.g. collect* includes collector, collectors, collection etc.)	

In addition to this patent filter, we also searched a number of specific technical terms provided to us by SETO (e.g. heliostat; Fresnel; enclosed parabolic trough; power tower; solar air heating).

We then manually checked the resulting list of patents to determine which of them appear relevant to CSP. For example, there are a number of patents that could be defined as CSP and also photovoltaics. We read these patents individually in order to define them as CSP, photovoltaics, or both.

Having constructed this draft patent list, we then sent it to SETO for review (including the patents that had been classified as CSP, photovoltaics or both). Following this review, and based on feedback from SETO, the initial list of CSP patents funded by DOE contained a total of 208 granted U.S. patents.

Defining SETO-funded vs. Other DOE-funded CSP Patents

As noted above, linking DOE-funded patents to individual offices is often a difficult task. For this analysis, EERE staff undertook an exhaustive process to determine which of the 208 DOE-funded CSP patents in the initial list could be linked definitively to SETO funding. This process involved a number of steps, which are listed below:

(i) Linking contract numbers listed in patents to EERE project contract numbers, for financial assistance projects,
(ii) Linking contract numbers listed in patents to EERE SBIR project agreement numbers,
(iii) Asking SETO technology managers to verify individual patents,
(iv) Asking SETO technology managers to send lab patents to lab POCs to get direct verification of these patents,
(v) Contacting individual inventors listed on patents to ask them to confirm whether individual patents were funded by SETO, and
(vi) Locating references to patents in available office annual project progress reports or patent disclosure documents with accomplishments reported by PIs.

Final List of SETO-funded and Other DOE-funded CSP Patents

Based on the process described above, we divided the initial list of 208 DOE-funded CSP U.S. patents into two categories – SETO-funded and Other DOE-funded. We then searched for equivalents of each of these patents in the EPO and WIPO systems. An equivalent is a patent filed in a different patent system covering essentially the same invention. We also searched for U.S. patents that are continuations, continuations-in-part, or divisional applications of each of the patents in the final set. We then grouped the patents into families by matching priority documents (see earlier discussion of patent families). Table 3 contains a summary of the final number of SETO-funded and Other DOE-funded CSP patents and patent families.

Table 3 – Number of SETO-funded and Other DOE-funded CSP Patents and Patent Families

	# Patent Families	# U.S. Patents	# EPO Patents	# WIPO Patents
SETO-funded	56	70	17	25
Other DOE-funded	135	150	8	18
Total DOE-funded	191	220	25	43

Table 3 shows that we identified a total of 56 SETO-funded CSP patent families, containing 70 U.S. patents, 17 EPO patents, and 25 WIPO patents (see Appendix A for patent list). We also identified 135 Other DOE-funded CSP patent families, containing 150 U.S. patents, 8 EPO patents, and 18 WIPO patents (see Appendix B for patent list).

As noted throughout this report, the approach used to define patents as SETO-funded was very stringent. Hence, a number of the Other DOE-funded patents may in fact have been funded by SETO, but are not categorized as such because a definite link could not be established. To get a better sense of how many of these Other DOE-funded patents (and patent families) may in fact be SETO-funded, we divided them into two groups.

The first group contains DOE-funded patent families that are definitely not linked to SETO. These include families linked specifically to funding from an office other than SETO, or that the inventor or SETO technology manager said were not funded by SETO (but without specifying funding from a different office). There are 29 such patent families. Out of these 29 families, three were funded by ARPA-E, two by the Office of Science, two by the Hydrogen and Fuel Cell Technologies Office, and one (very old) family by the Atomic Energy Commission. No funding source could be established for the remaining 21 families, but they are confirmed to be not connected to SETO funding.

The second group contains DOE-funded patent families where the funding source within DOE could not be established, and inventors and SETO technology managers could not state categorically whether or not they were funded by SETO. There are 106 such patent families. Many of them are from the earliest time periods in the analysis, between 1976 and 1984, so institutional knowledge associated with them is relatively scarce. Hence, up to 80% (106 out of 135) of the Other DOE-funded patent families included in this analysis may in fact be SETO-funded. As a result, the findings in this analysis may understate the influence of SETO funded CSP patents, relative to the influence of the remainder of DOE patents.

Identifying CSP Patents Assigned to Leading Organizations

The purpose of the backward tracing element of our analysis is to evaluate the influence of SETO-funded (and Other DOE-funded) research upon CSP innovations produced by leading organizations in this technology. To identify such organizations, we first defined the universe of CSP patents in the period 1976-2018 using a modified version of the patent filter detailed earlier in Table 2.[7] Based on this filter, we identified a total of 19,477 CSP patents (7,983 U.S. patents; 6,466 WIPO patents; and 5,028 EPO patents). We grouped these patents into 14,582 patent families by matching priority documents.

We then located the most prolific patenting organizations in this overall CSP patent universe, based on number of patent families.[8] The eleven organizations (i.e. top ten plus ties) with the largest number of CSP patent families are shown in Table 4. This includes patent families associated with all variant names under which the organizations have patents, plus all subsidiaries and acquisitions. The CSP patent families of these eleven organizations form the starting point for the backward tracing element of the analysis.

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[7] We modified the filter to remove patents that use the terms photovoltaic, PV, solar cell, solar module, solar panel (including variants of these terms) in their titles and abstracts. The modification was necessary because, while the process of delineating between CSP and PV patents was carried out manually for DOE-funded patents, a manual approach was not possible at the scale of the universe of potential CSP patents.

[8] These organizations are sometimes referred to hereafter as the leading CSP organizations. This is based on patent portfolio size, and is not a reflection of number of units sold or revenues, profits etc. A fuller description would be the leading patenting CSP organizations, but this is a cumbersome description to use throughout the results section of the report.

Table 4 - Leading Patenting CSP Organizations

Organization	# CSP Patent Families
Siemens	211
Abengoa	115
Bosch	101
CEA	87
Boeing	75
Saint Gobain	74
GE	69
Konica Minolta	64
Total SA	64
3M	59
Hitachi	59

The organizations in Table 4 include a number of large companies for which CSP technology forms only a small part of their operations, for example Siemens, Bosch and Boeing. There are also companies with a stronger focus on renewable energy, notably Abengoa. It is also worth noting the presence of Total SA in the table, which is largely due to its majority ownership of SunPower Corporation. SunPower is a photovoltaics company, but some of its patents cover both photovoltaics and CSP technology, hence its inclusion in the list.

Constructing Citation Links

Through the processes described above, we constructed starting patent sets for both the backward forward tracing elements of the analysis. The patent set for the backward tracing consisted of patent families assigned to the leading patenting organizations in CSP technology. The patent sets for the forward tracing consisted of SETO-funded (and, separately, Other DOE-funded) CSP patent families.

Having defined these patent sets, we then traced backward through two generations of citations from the leading organizations' CSP patents, and forward through two generations of citations from the SETO/Other DOE-funded CSP patents. These included citations listed on U.S., EPO and WIPO patents, and required extensive data cleaning to account for differences in referencing formats across these systems. The citation linkages identified, along with characteristics of the starting patent sets, form the basis for the results described in the next section of this report.

4.0 Results

This section of the report outlines the results of our analysis tracing the influence of SETO-funded and Other DOE-funded CSP research on subsequent developments both within and beyond CSP technology. The results are divided into three main sections. In the first section, we examine trends in patenting over time in CSP technology, and assess the distribution of SETO-funded and Other DOE-funded patents across CSP technologies. The second section then reports the results of an analysis tracing backwards from CSP patents owned by the leading organizations in this technology. The purpose of this analysis is to determine the extent to which CSP innovations developed by leading organizations build upon earlier CSP research funded by

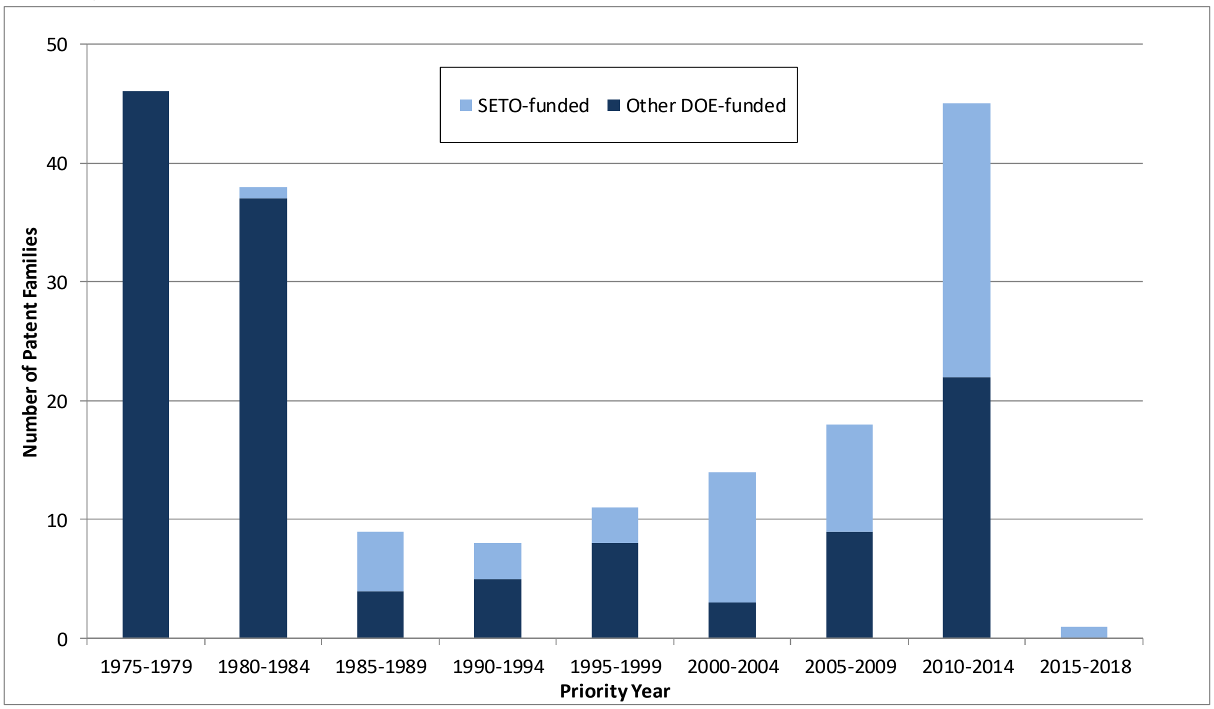
SETO (plus CSP research funded by the remainder of DOE). In the third section, we report the results of an analysis tracing forwards from SETO-funded (and Other DOE-funded) CSP patents. The purpose of this analysis is to assess the broader influence of SETO-funded (and other DOE-funded) research upon subsequent developments within and beyond CSP technology.

Overall Trends in CSP Patenting

Trends in CSP Patenting over Time

Figure 1 shows the number of DOE-funded CSP patent families by priority year – i.e. the year of the first application in each patent family. This figure separates SETO-funded and Other DOE-funded patent families, and reveals an interesting pattern in terms of DOE's patent activity in CSP technology.

Figure 1 - Number of CSP Patent Families funded by SETO and Other DOE Sources by Priority Year (5-Year Totals)

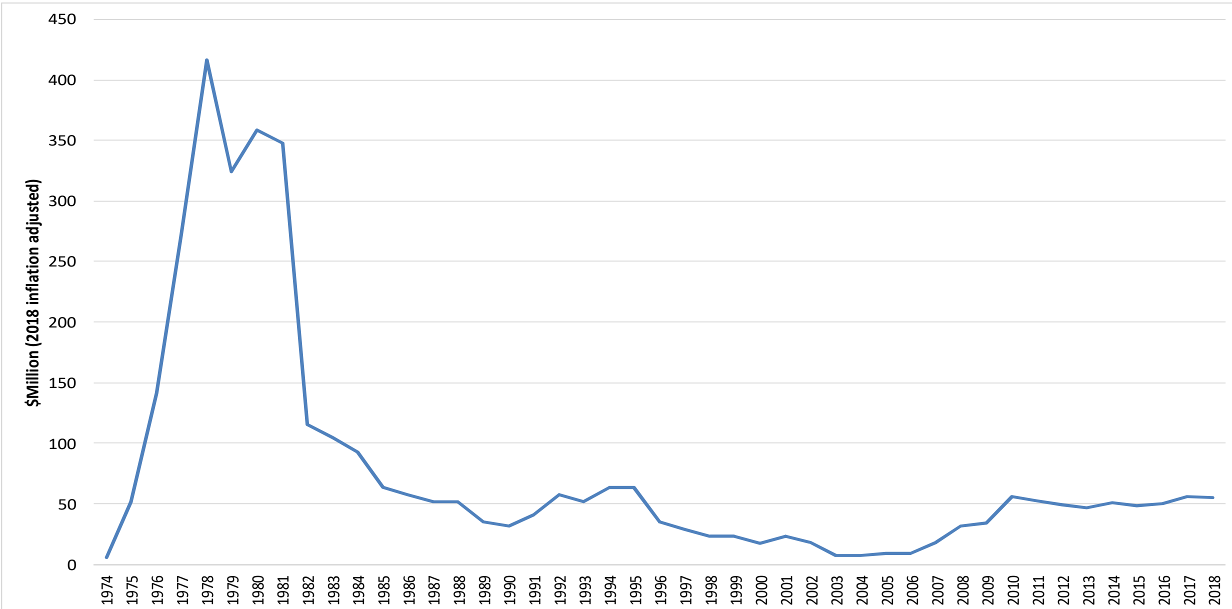


Note: The final time period in this figure is 2015-2018, and is shown for completeness, although data for this time period are incomplete. Due to time lags associated with the patenting process, only a fraction of the patent families from this time period will be included.

Figure 1 reveals that the earliest years in the study were an active period of CSP patenting for recipients of DOE funding. Forty-six CSP patent families funded by DOE were filed in 1975-79, followed by 38 patent families in 1980-84. Out of all these patent families, only one was confirmed as being funded by SETO. However, this may be largely due to the age of these patent families, which reduces the amount of institutional knowledge associated with them (for example program managers and inventors connected to these research efforts). Almost all of the patent families from these time periods were marked as "unknown" in terms of whether they were funded by SETO (rather than being marked specifically as being not funded by SETO, or as being funded by a non-SETO office).

Figure 2 shows the pattern of SETO funding of CSP research from 1974 through 2018. This figure reveals that SETO CSP funding was at its peak in the late 1970s and early 1980s, which coincides with the early burst of DOE-funded CSP patent applications.[9]

Figure 2 - SETO CSP Funding (in $Million, 2018 inflation adjusted)



Source: Funding data is EERE historical appropriations provided by DOE that was obtained from Congressional Budgets. A secondary source for historical data is "History of Solar Energy at DOE", a 2011 presentation by Frank (Tex) Wilkins. Funding data in nominal dollars is inflation-adjusted using the 2018 GDP deflator index from U.S. Department of Commerce, Bureau of Economic Analysis.

Hence, many of the early DOE-funded CSP patents marked as "unknown" for funding source may in fact have been funded by SETO, although records to confirm this are not available. This should be kept in mind in assessing the results presented below, especially in terms of evaluating the balance of SETO's influence in CSP versus the influence of the remainder of DOE.

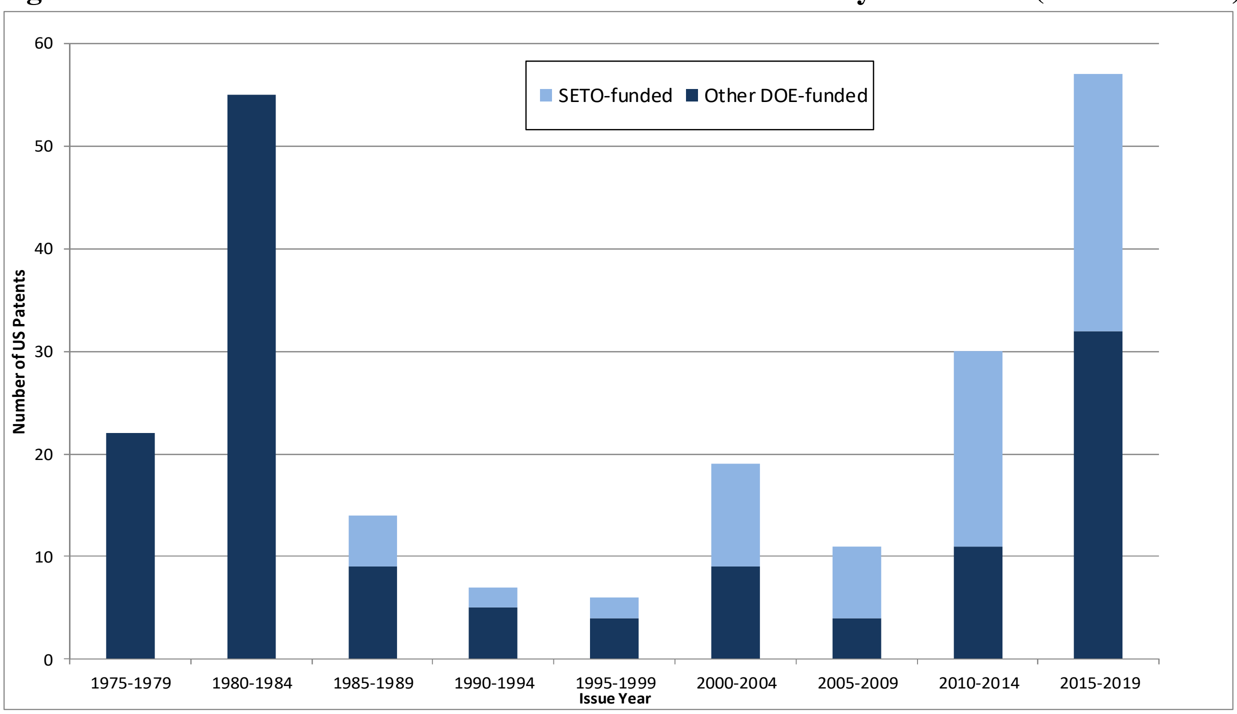
Following the initial spike in CSP patent activity associated with DOE funding, there was then a relatively quiet period from 1985 through 1994, with only 17 patent families filed during that 10-year period. Almost half of these patent families are associated with SETO funding. The number of patent families then increased steadily from 1995 through 2009, with an almost even split between patent families funded by SETO and those classified as Other DOE-funded.

[9] Note that this funding chart is not included in order to facilitate a longitudinal analysis of funding vs. patenting, which is a highly complex relationship beyond the scope of this study. The chart is merely an additional data point showing how SETO was active in CSP in the early years of the analysis, thus adding credence to the suggestion that SETO may have funded many of the "unknown" DOE-funded CSP patents .

In the time period 2010-14, the number of DOE-funded CSP patents then increased rapidly, with a total of 45 patent families filed during this time period. Twenty-three of these families were SETO-funded, and 22 were Other DOE-funded. Overall, Figure 1 thus suggests that there have been two particularly active periods in DOE-funded CSP patent activity, one from 1975-1984, and one from 2010 onwards.

These two distinct time periods where DOE-funded CSP patenting was particularly active are also reflected in Figure 3. This chart shows the number of CSP granted U.S. patents funded by DOE. Again, there was an initial period from 1975-1984 where patent activity was relatively high, especially in 1980-84, when 55 U.S. patents were granted. None of these patents are defined as being associated with SETO funding. However, as noted above, many of them may in fact be SETO-funded, but we were not able to confirm this. There then followed a relatively quiet period in patenting that lasted until 2010, after which the number of patents increased rapidly, peaking at 57 U.S. patents granted in 2015-19.

Figure 3-Number of DOE-Funded CSP Granted U.S. Patents by Issue Year (5-Year Totals)



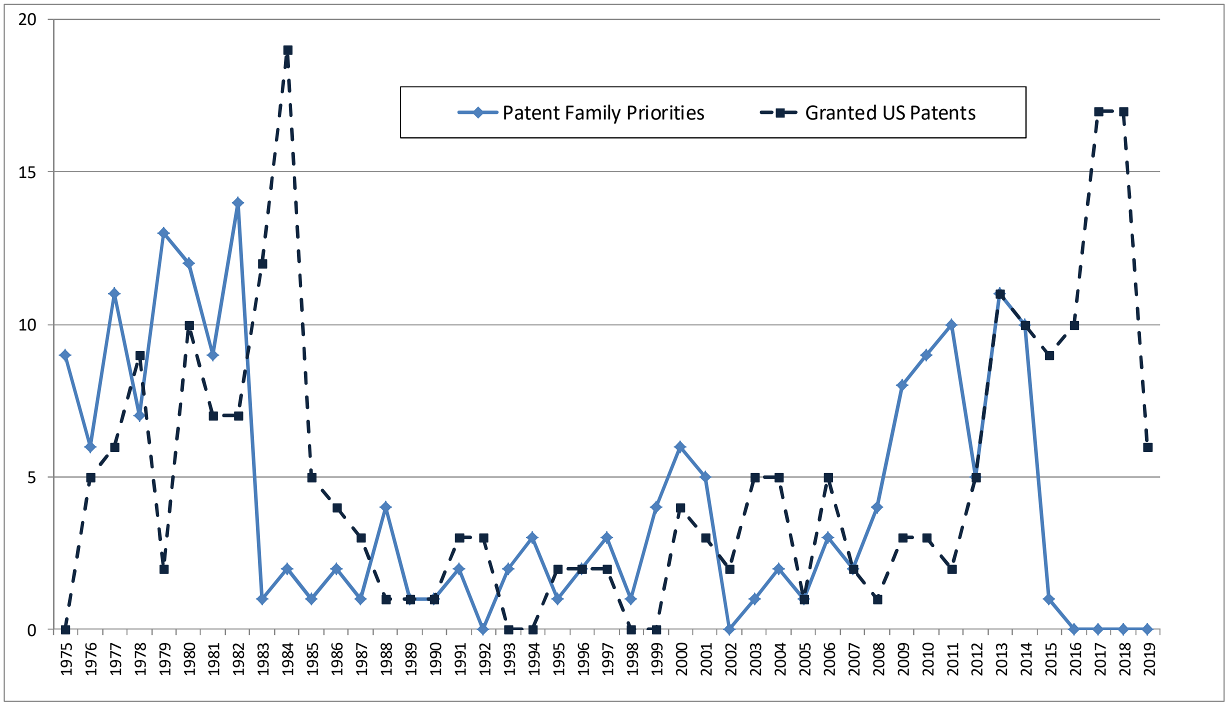
Note: The data collection period for this analysis ended with 2018. The 2019 patents in the 2015-2019 column are additional patents that have been included because they are members of the same patent families as pre-2019 patents. No new patent search for 2019 was carried out.

Comparing Figures 1 and 3 shows the effect of time lags in the patenting process, with many of the patent families with priority dates in 2010-14 (Figure 1) resulting in granted U.S. patents in 2015-19 (Figure 3). These time lags can also be seen in Figure 4, which shows CSP patent family priority years, and issue years for granted U.S. CSP patents (in this figure, SETO and Other DOE are combined, in order to simplify the presentation).

In this figure, the initial peak in patent family priorities is in 1982, with the peak in granted U.S. patents occurring two years later in 1984. More recently, patent family priorities peaked in 2013-

2014, followed by a peak in granted U.S. patents in 2017-18 (note that, due to the primary data collection for this analysis ending in 2018, the number of patent families and granted U.S. patents declines in the most recent years).

Figure 4 - Number DOE-funded CSP Patent Families (by Priority Year) and Granted U.S. Patents (by Issue Year)

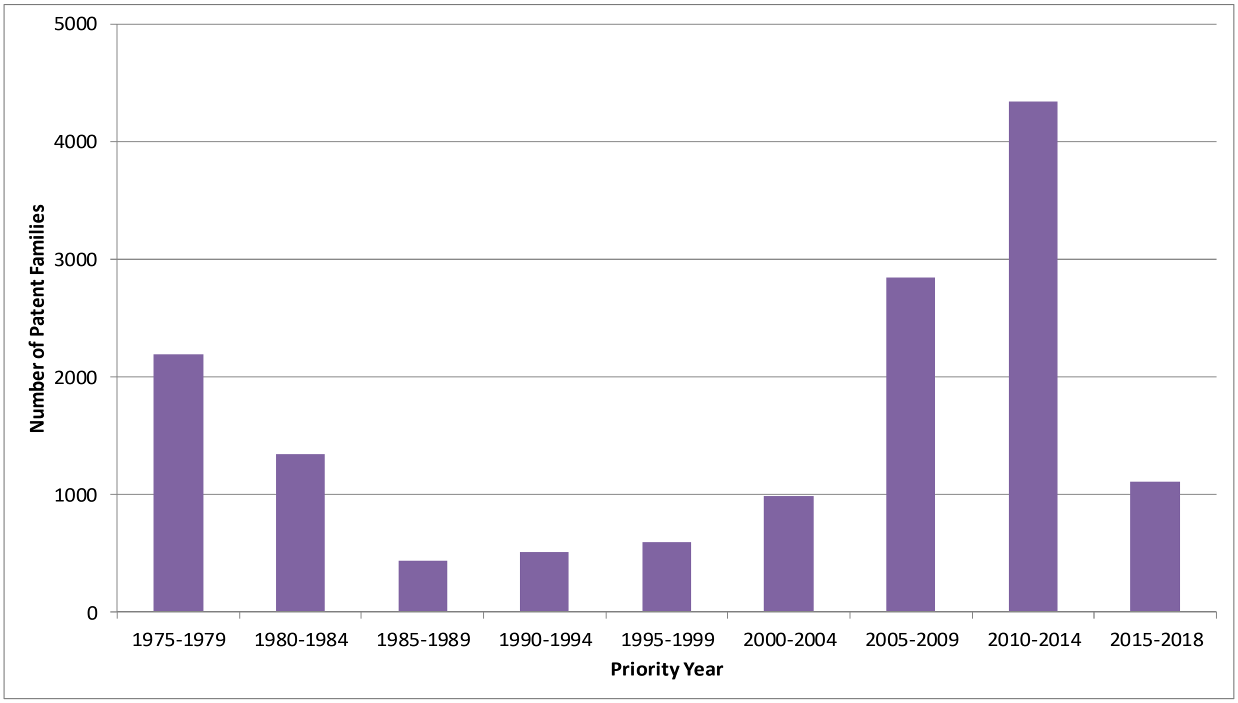


Note: The data collection period for this analysis ended with 2018. The 2019 patents are additional patents that have been included because they are members of the same patent families as pre-2019 patents. No new patent search for 2019 was carried out.

Figure 5 shows the total number of CSP patent families by priority year (based on the universe of USPTO, EPO, and WIPO filings). There is a cumulative total of 14,582 CSP patent families over the entire period. This chart follows a similar pattern to the earlier DOE-based figures, with an initial period of high patent activity from 1975-84, followed by a relatively quiet period from 1985-2004 with few patent families. The number of patent families then increased sharply from 2005 onwards, peaking in the period 2010-14 (the data for 2015-18 are again incomplete). This suggests two distinct periods where overall interest in CSP was particularly strong, one in the late 1970s and early 1980s, and one from 2005 onwards.

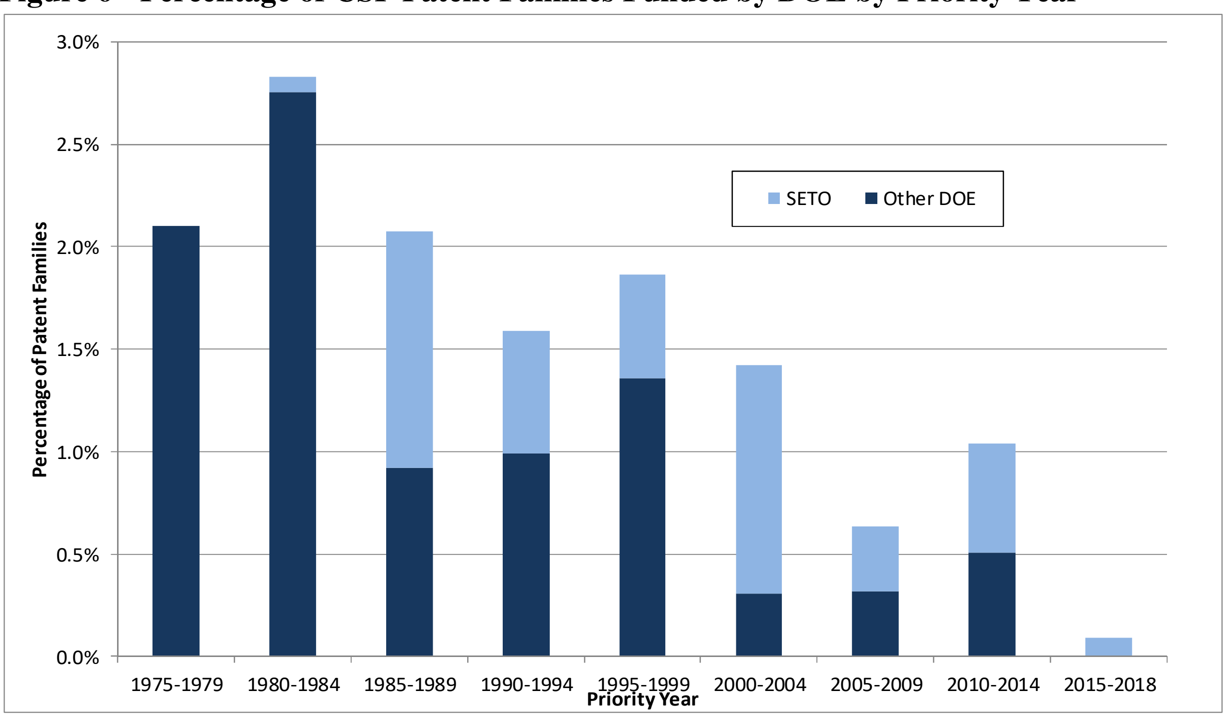
Figure 6 shows the percentage of total CSP patent families funded by DOE. This peaked in the earliest time periods, with 2.75% of all CSP patent families funded by DOE in 1980-84, but has fallen steadily since then. In 2010-2014, just over 1% of all CSP patent families were funded by DOE, although this is in the context of a sharp overall increase in CSP patenting. Overall, 1.3% of CSP patent families in the period 1976-2018 were funded by DOE.

Figure 5 - Total Number of CSP Patent Families by Priority Year (5-Year Totals)



Note: The final time period in this figure is 2015-2018, and is shown for completeness, although data for this time period are incomplete. Due to time lags associated with the patenting process, only a fraction of the patent families from this time period will be included.

Figure 6 - Percentage of CSP Patent Families Funded by DOE by Priority Year

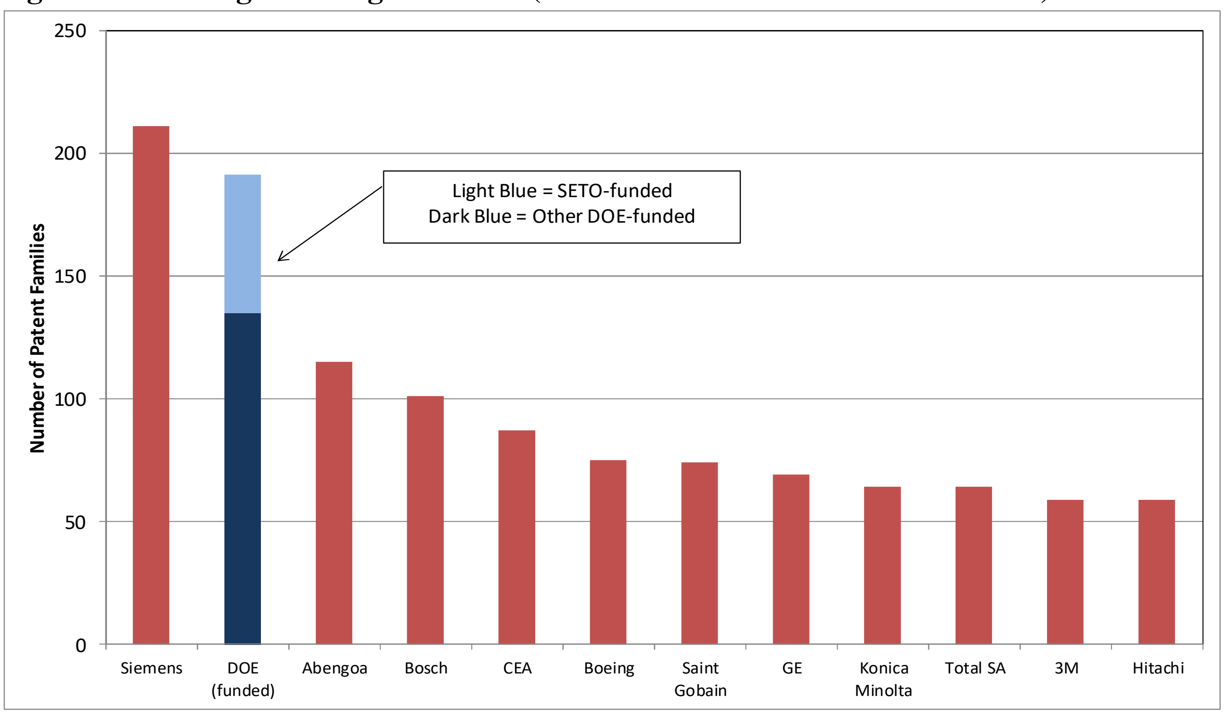


Note: The final time period in this figure is 2015-2018, and is shown for completeness, although data for this time period are incomplete. Due to time lags associated with the patenting process, only a fraction of the patent families from this time period will be included.

Leading CSP Assignees

The eleven leading patenting organizations (i.e. top ten plus ties) in CSP technology are listed above in Table 4, along with their number of CSP patent families. The CSP patent portfolios for these leading organizations are the basis for the backward tracing element of the analysis, as outlined below. Figure 7 shows the same information in graphical form, while also including DOE-funded patent families. This figure reveals that, while the percentage of CSP patent families funded by DOE is less than 3% over all time periods (see Figure 6), DOE-funded CSP patents in fact represent one of the most significant portfolios in the technology. DOE (SETO plus Other DOE) funded families rank second in this figure, behind only Siemens.

Figure 7 - Leading CSP Organizations (Based on Number of Patent Families)



It should be noted that there is a small amount of double-counting patent families in Figure 7. Specifically, there are four patent families assigned to the leading CSP companies – two to Total SA, one each to 3M and Boeing – that were partially or fully funded by SETO. There are also two General Electric patent families that were funded by Other DOE. These six patent families appear in both the DOE column and the respective company columns in Figure 7. This is appropriate, since these patent families are both funded by DOE and assigned to a leading CSP company. Also, note that DOE would remain in second place in Figure 7, even if these patent families were not counted in its total.

Assignees of SETO/Other DOE CSP Patents

The DOE-funded CSP patent portfolios are constructed somewhat differently from the portfolios of the leading organizations listed in Figure 7. Specifically, DOE's 191 patent families are those funded by DOE, but are not necessarily assigned to the agency. For example, SETO (or another DOE office) may have partially or fully funded research projects at companies or DOE national laboratories that produced patents. In such cases, the assignees of the patents may be the respective companies or DOE laboratory managers.

Figure 8 shows the leading assignees on SETO-funded CSP patent families. This chart is headed by Lockheed Martin with 13 CSP patent families, all of which result from its management of Sandia National Labs from 1993 until 2017. MRIGlobal (formerly Midwest Research Institute) is second in Figure 8, with seven SETO-funded CSP patent families, all of which result from its management of the National Renewable Energy Laboratory (NREL). There are also a further five patent families assigned to the Alliance for Sustainable Energy (co-owned by MRIGlobal and Battelle), again for its management of NREL. This suggests that Sandia and NREL have been particularly active in SETO-funded CSP research.

Figure 8 - Assignees with Largest Number of SETO-Funded CSP Patent Families

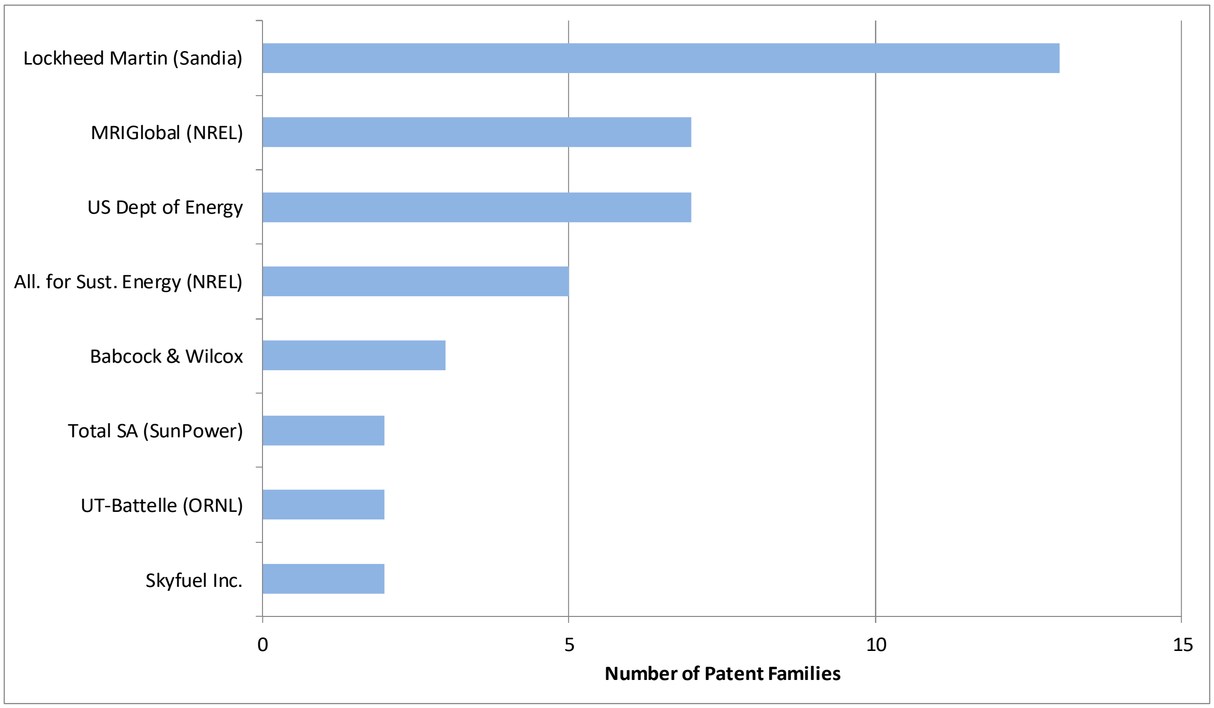
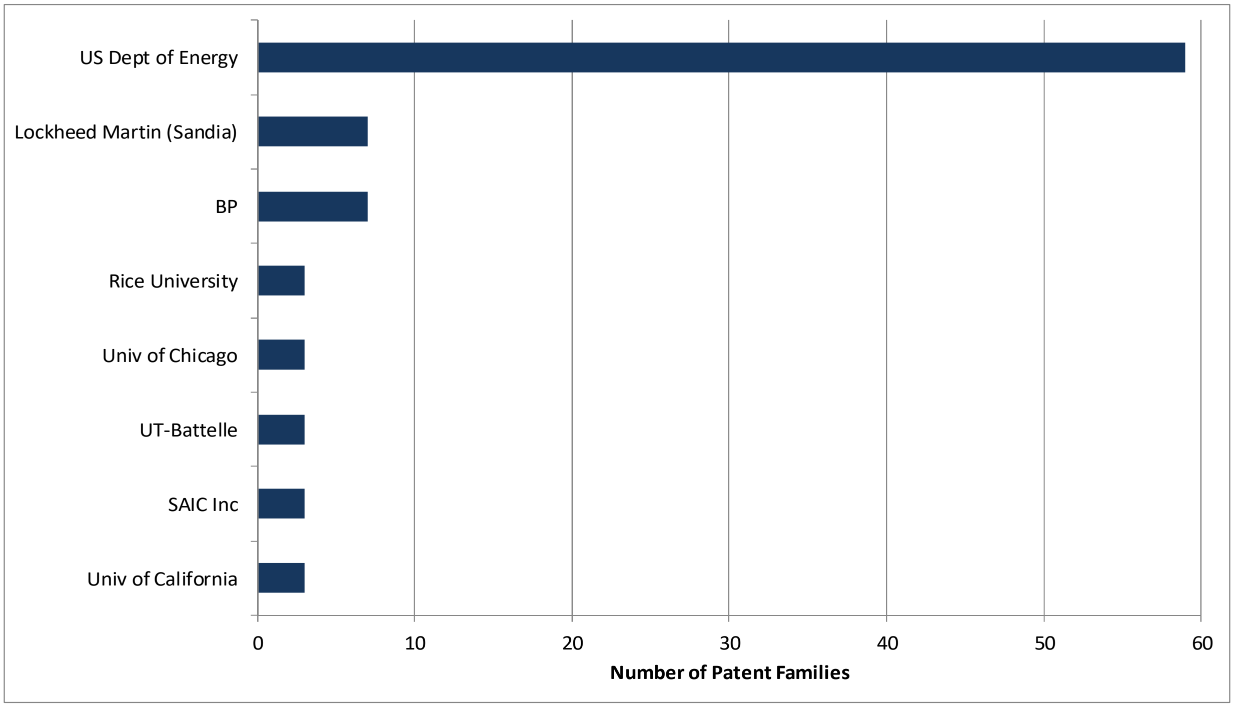


Figure 9 shows the leading assignees on Other DOE-funded CSP patent families. Most of the patent families in this chart are assigned to DOE itself (59 patent families), many from the earliest years in this analysis. BP and Lockheed Martin are second in this figure with seven patent families each, the latter again through its former management of Sandia.

Comparing Figures 8 and 9 reveals some overlap between the assignees on SETO-funded and Other DOE-funded CSP patent families (e.g. the prominence of Lockheed Martin/Sandia in each figure). There are also a number of differences, notably the more prominent role of NREL-related assignees among SETO-funded patent families.

Figure 9 - Assignees with Largest Number of Other DOE-funded CSP Patent Families



Distribution of CSP Patents across Patent Classifications

We analyzed the distribution of SETO-funded CSP U.S. patents across Cooperative Patent Classifications (CPCs).[10] We then compared this distribution to those associated with Other DOE-funded CSP patents; CSP patents assigned to the leading organizations; and the universe of CSP patents. This provides insights into the technological focus of SETO funding in CSP, versus the focus of the remainder of DOE, leading CSP organizations, and CSP technology in general.

The results from this CPC analysis are shown in two separate charts, each from a different perspective. Figure 10 is based on the six CPCs that are most prevalent among SETO-funded CSP patents. The purpose of this chart is thus to show the main focus areas of SETO-funded CSP research, and the extent to which these areas translate to other portfolios (Other DOE-funded; leading CSP organizations; all CSP). This figure shows that SETO-funded research includes relatively balanced coverage across the six CPC groups (which is not surprising, since the SETO-funded patent portfolio forms the basis for the CPCs included in the chart). The CPC Y02E 10/41, which covers solar tower concentrators, is the most common CPC among SETO-funded CSP U.S. patents. Over 30% of SETO-funded CSP U.S. patents include this CPC, suggesting that solar towers are a significant research focus for recipients of SETO funding. Solar collectors (CPC F24S 20/20) are also a major research area, with 25% of SETO-funded CSP U.S. patents including this CPC. Meanwhile, Other DOE-funded patents are more concerned with solar heat exchangers (CPC Y02E 10/44), as are CSP patents in general. Leading organizations, on the other hand, focus more on mountings and tracking (CPC Y02E 10/47).

[10] The CPC is a patent classification system. Patent offices give each patent numerous CPC classifications covering different aspects of the claimed invention. In this analysis, all CPCs attached to patents are included.

Figure 10 - Percentage of CSP U.S. Patents in Most Common Cooperative Patent Classifications (Among SETO-Funded CSP Patents)

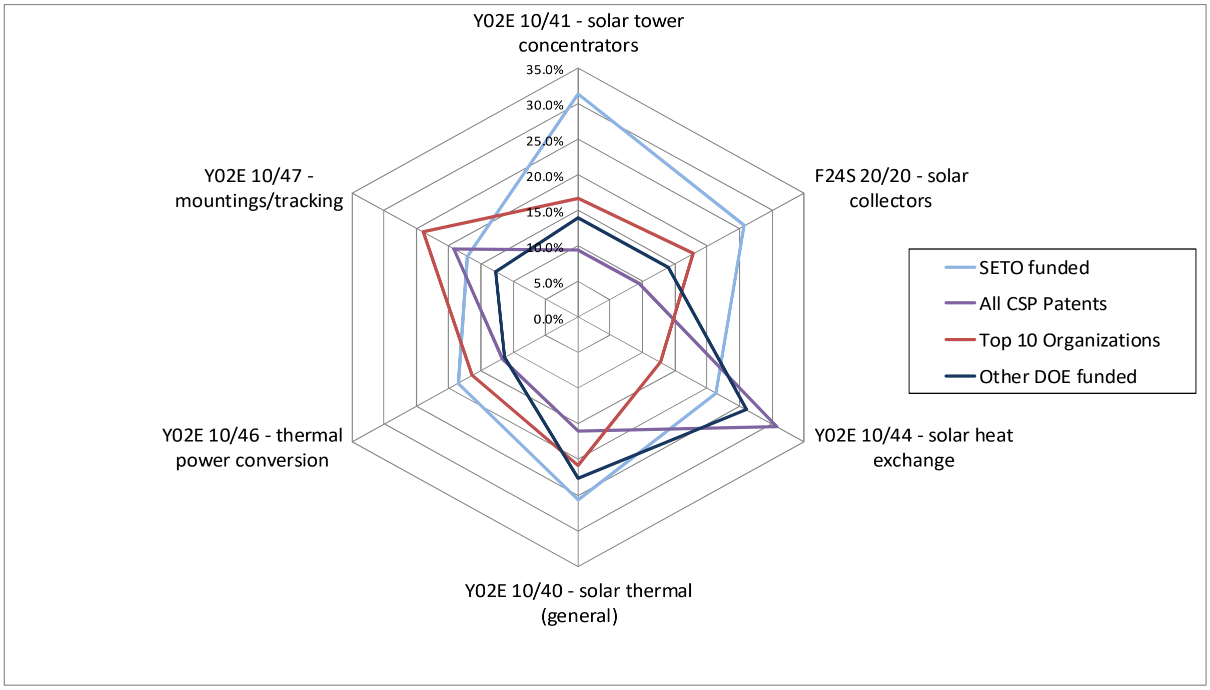
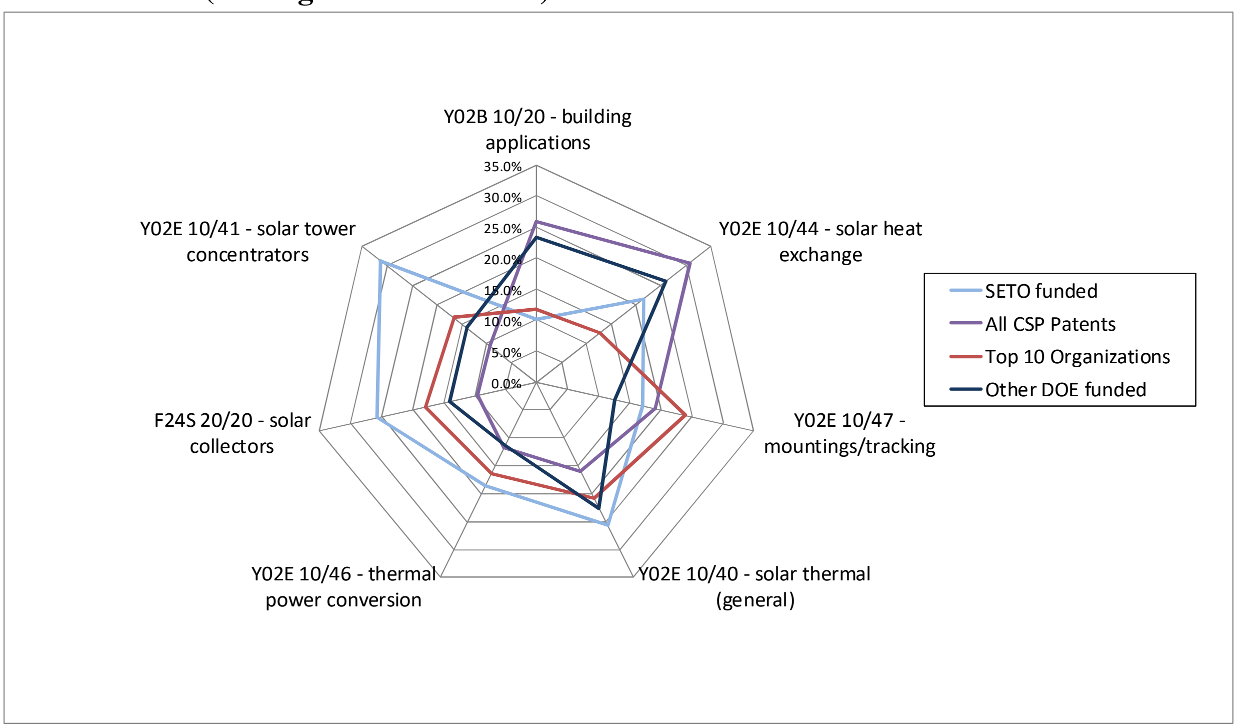


Figure 11 is similar to Figure 10, except from the perspective of the most common CPCs among all CSP patents. Hence, it shows the main CSP research areas, and how they are represented in various CSP portfolios (SETO-funded; Other DOE-funded; leading CSP organizations).

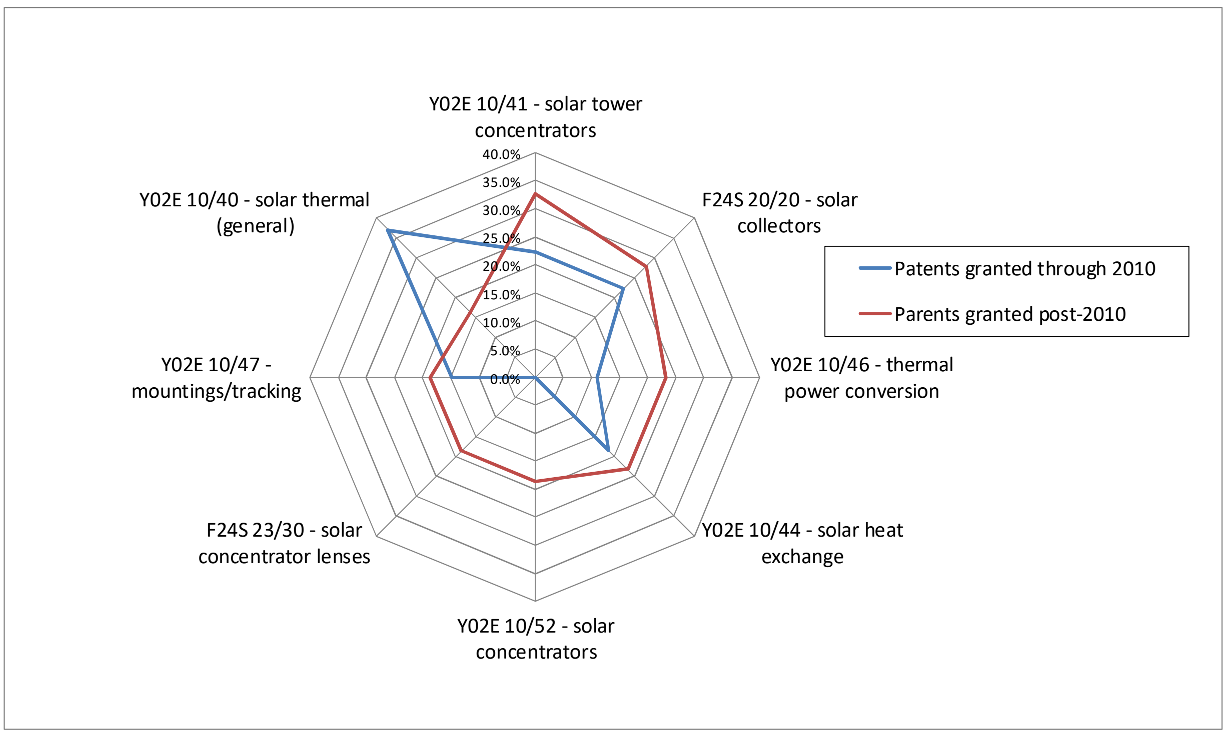
Figure 11 - Percentage of CSP U.S. Patents in Most Common Cooperative Patent Classifications (Among All CSP Patents)



The biggest difference between the CPCs in the two figures is the presence of CPC Y02B 10/20 in Figure 11. This CPC is concerned with the application of solar thermal technology in buildings. Other DOE-funded patents, and CSP patents owned by the leading organizations, both have a significant presence in this CPC. Meanwhile, SETO-funded patents has less presence in this building-related CPC, suggesting that recipients of SETO CSP funding have focused on other areas, notably larger scale installations, plus technologies designed for these installations (such as solar towers). As such, in the period 1976-2018, SETO funding may have helped fill a research gap not addressed extensively by the leading companies.

Figure 12 compares the CPC distribution of SETO-funded CSP U.S. patents across two time periods – patents issued through the end of 2010, and patents issued from 2011 onwards. This figure reveals that, in the earlier time period, 37% of SETO-funded patents have CPC Y02E 10/40 attached, which is related to generic solar thermal technology. In the more recent time period, this CPC is less prominent. A higher percentage of patents are in CPCs related to solar concentrators, such as Y02E 10/41 (33%) and Y02E 10/52 (18%). There is also an increased percentage of patents in a CPC related to solar concentrator lenses - F24S 23/30 (19%). This suggests that these became areas of increasing focus for recipients of SETO funding in the post-2010 period.

Figure 12 - Percentage of SETO-funded CSP U.S. Patents in Most Common Cooperative Patent Classifications Across Two Time Periods



Tracing Backwards from CSP Patents Owned by Leading Organizations

This section reports the results of an analysis tracing backwards from CSP patents owned by leading organizations in this technology to earlier research, including that funded by SETO (plus DOE in general). The results in this section are examined at two levels. First, we report results at the organizational level. These results reveal the extent to which SETO-funded and Other DOE-funded research forms a foundation for subsequent innovations associated with leading CSP organizations. Second, we drill down to the level of individual patents, with a particular focus on SETO-funded CSP patents. These patent-level results highlight specific SETO-funded patents that have had a particularly strong influence on subsequent patents owned by leading organizations in CSP technology. They also highlight which CSP patents owned by these leading organizations are linked particularly extensively to earlier SETO-funded research.

Organizational Level Results

In the organizational level results, we first compare the influence of SETO-funded and Other DOE-funded CSP research against the influence of leading organizations in CSP technology. We then look at which of these leading organizations build particularly extensively on DOE-funded CSP research.

Figure 13 compares the influence of DOE-funded CSP research to the influence of research carried out by the eleven leading CSP organizations listed above. Specifically, this figure shows the number of CSP patent families owned by the leading organizations that are linked via citations to earlier CSP patent families assigned to each of these leading organizations (plus patent families funded by DOE). In other words, this figure shows the organizations whose patents have had the strongest influence upon subsequent developments made by leading organizations in CSP technology.[11]

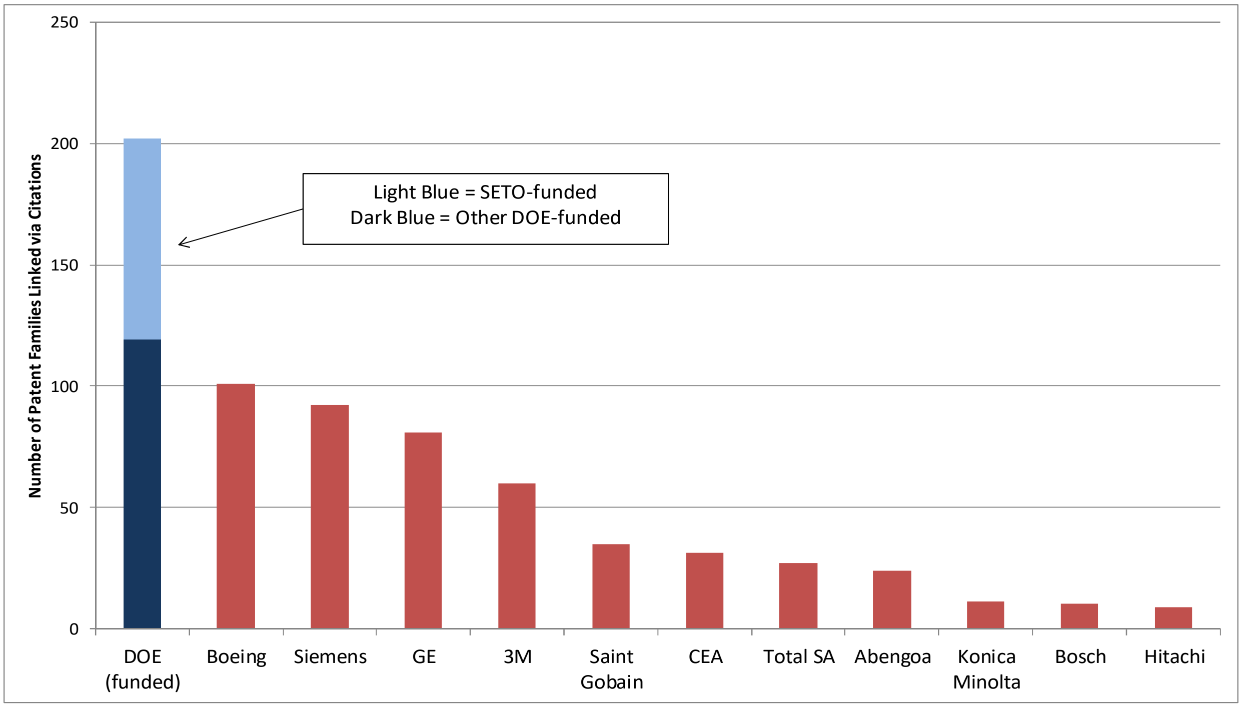
In total, 202 CSP patent families from leading organizations (i.e. 20.7% of their 978 families) are linked via citations to earlier DOE-funded CSP patents, out of which 83 are linked to SETO-funded CSP patents. This puts DOE-funded patents at the head of Figure 13 by a wide margin, ahead of Boeing in second place with 101 linked patent families. It means that twice as many CSP patent families owned by leading organizations are linked via citations to DOE-funded CSP patents than are linked to the CSP patents assigned to any other leading organization.

Figure 13 thus suggests that DOE-funded research has helped form an important part of the foundation for CSP research carried out by leading organizations. Indeed, this figure may

[11] This figure compares the influence of patents *funded* by SETO/DOE against patents *owned* by (i.e. assigned to) organizations. Such a comparison is reasonable, since patents funded by organizations through their R&D budgets will be assigned to those organizations. Also, organizations cannot choose to reference the patents of a non-competitor (such as DOE) rather than the patents of a competitor in order to reduce the "credit" given to that competitor. Such an omission could lead to the invalidation of their patents. Note that, as in Figure 7, there is a small amount of double-counting in Figure 13, since six of the 978 patent families assigned to the leading CSP organizations were also funded by DOE. Also, in Figures 13-16, leading company patent families linked to both VTO-funded and Other DOE-funded patents are allocated to the VTO-funded segment of the DOE column, in order to avoid double-counting these families.

underestimate the influence of SETO-funded CSP research (relative to Other DOE-funded research), since many of the early Other DOE-funded CSP patent families may in fact have been funded by SETO, as discussed earlier.

Figure 13 - Number of Leading Organization CSP Patent Families Linked via Citations to Earlier CSP Patents Assigned to Each Leading Organization
e.g. 202 leading organization CSP families are linked to earlier SETO/Other DOE-funded patents



Figures 14 through 16 examine which of the leading organizations build particularly extensively on earlier SETO-funded and Other DOE-funded patents. Figure 14 shows how many CSP patent families owned by each of the leading organizations are linked via citations to at least one earlier DOE-funded CSP patent. Siemens heads this list, with 37 patent families linked via citations to DOE-funded patents, 19 of which are linked to SETO. Boeing is second in Figure 14, with 36 patent families linked to DOE-funded patents (13 linked to SETO), followed by Abengoa (27 linked to DOE; 14 to SETO) and Total SA (24 linked to DOE; 10 to SETO).

Figure 15 counts the total number of citation links from leading organizations to earlier DOE-funded patents. This differs slightly from the count of linked families in Figure 14, since a single patent family can be linked to multiple earlier DOE-funded patents. Boeing is at the head of this chart, with a total of 59 citation links to DOE-funded CSP patents, 17 of which are links to SETO-funded patents. 3M is in second place, with 55 CSP patent families linked to DOE, nine of which are linked to SETO, followed by Abengoa (53 links to DOE; 23 to SETO) and Siemens (47 links to DOE; 23 to SETO).

Figure 14 - Number of Patent Families Assigned to Leading CSP Companies Linked via Citations to Earlier SETO/Other DOE-Funded CSP Patents

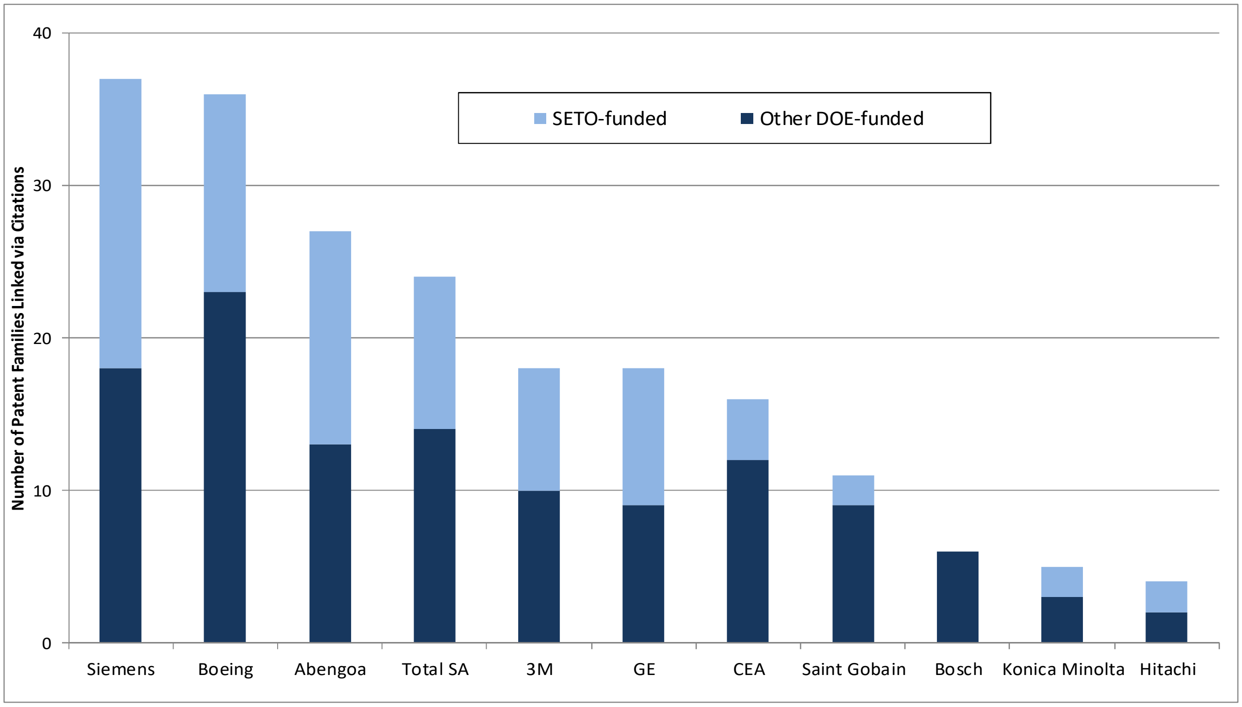
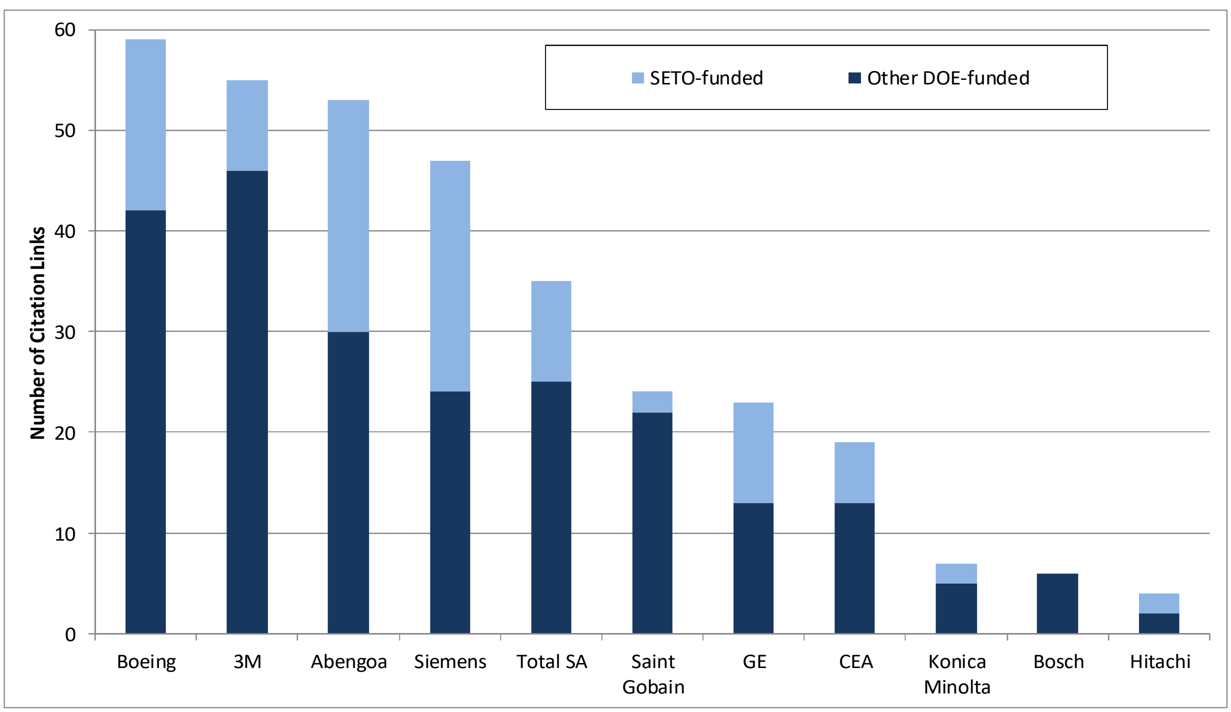


Figure 15 - Total Number of Citation Links from Leading CSP Company Patent Families to Earlier SETO/Other DOE-Funded CSP Patents



There is an element of portfolio size bias in the patent family counts in Figures 14 and 15. Organizations with larger CSP patent portfolios are likely to have more patent families linked to

DOE, simply because they have more families overall. Figure 16 accounts for this portfolio size bias by calculating the percentage of each leading company's CSP patent families that are linked via citations to earlier DOE-funded CSP patents, rather than their absolute number. This is a measure of how extensively each company builds on DOE-funded research, relative to their overall patent output.

Figure 16 - Percentage of Leading CSP Company Patent Families Linked via Citations to Earlier DOE/SETO funded CSP Patents

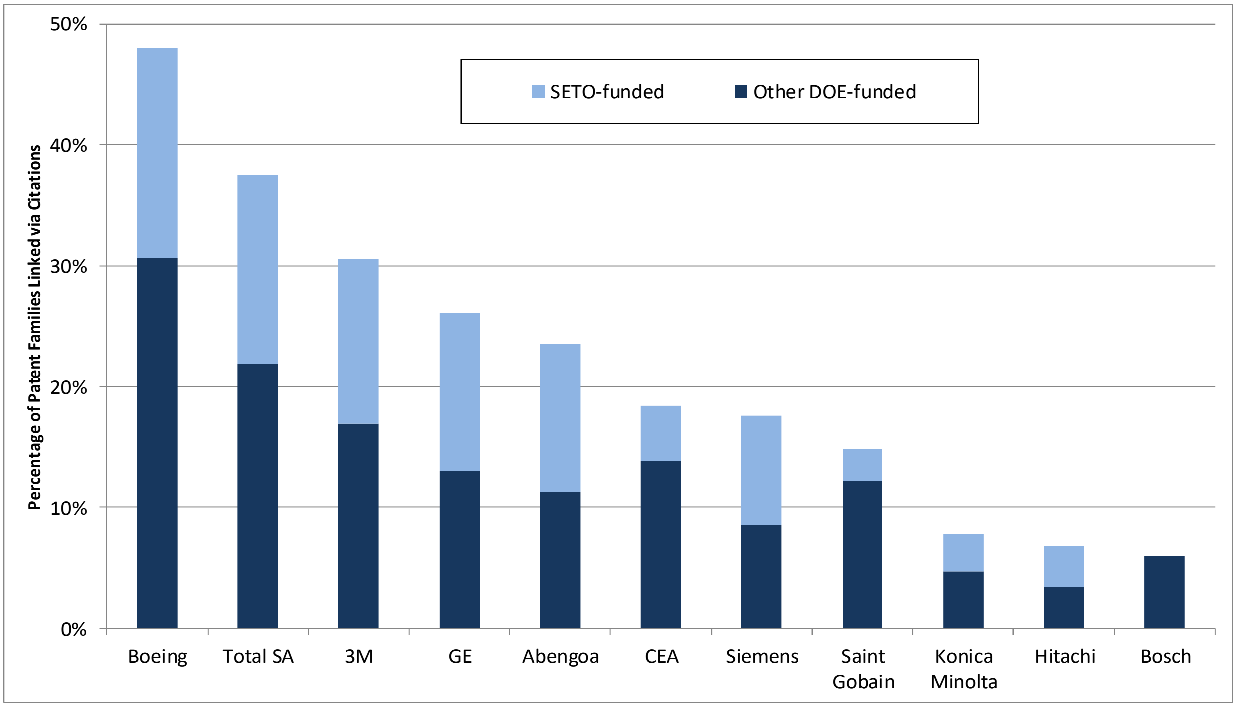


Figure 16 reveals that three leading organizations have more than 30% of their CSP patent families linked to earlier DOE-funded CSP patents – Boeing (48.0% in total; 17.3% to SETO), Total/SunPower (33.5% total; 15.6% to SETO) and 3M (30.5% total; 13.6% to SETO). In addition, two other organizations have more than 10% of their CSP patent families linked to earlier SETO-funded patents – General Electric (13.0%) and Abengoa (12.2%).

Patent Level Results

The previous section of the report examined results at the level of entire patent portfolios. The purpose of this section is to drill down to identify individual DOE-funded CSP patent families (in particular SETO-funded families) that have had a particularly strong influence on subsequent CSP patents owned by leading organizations in this technology. It also identifies individual CSP patents owned by leading organizations that have extensive links to earlier SETO-funded research.

Table 5 shows the SETO-funded CSP patent families linked via citations to the largest number of subsequent patent families owned by leading organizations in this technology. Many of the SETO-funded patent families in this table are relatively old. This is not surprising, since older patents have had a longer time period to become connected to subsequent generations of technology. As such, most of the patent families in Table 5 represent older foundational technologies that are linked to subsequent innovations associated with leading organizations in the CSP industry.

Table 5 – SETO-Funded CSP Patent Families Linked via Citations to Most Subsequent Leading Organization CSP Patent Families

Patent Family #	Representative Patent #	Priority Year	# Linked Families	Assignee	Title
22522277	5417052	1993	29	MRIGlobal (NREL)	Hybrid solar central receiver for combined cycle power plant
24734669	5128115	1991	13	US Dept of Energy	Manufacture of silicon carbide using solar energy
40567662	8893711	2007	7	MRIGlobal (NREL)	High temperature solar selective coatings
26917242	6487859	2000	7	MRIGlobal (NREL)	Dish/stirling hybrid-receiver
41058768	7588694	2008	7	Lockheed Martin (Sandia)	Low-melting point inorganic nitrate salt heat transfer fluid
35734310	6989924	1998	7	MRIGlobal (NREL)	Durable corrosion and ultraviolet-resistant silver mirror
24726588	6597709	2000	6	US Dept of Energy	Method and apparatus for aligning a solar concentrator using two lasers
38218767	7612937	2001	6	Alliance for Sust. Energy (NREL)	Advanced ultraviolet-resistant silver mirrors for use in solar reflectors

Among these older SETO-funded patent families, there are two that stand out in terms of the number of leading organization patent families linked to them. The first (whose representative patent[12] is US #5,417,052) is assigned to MRIGlobal (formerly Midwest Research Institute), through its management of NREL. It describes a solar thermal power plant and is linked to 29 CSP patent families assigned to leading organizations. These include patent families owned by five of the ten leading organizations (Abengoa, Boeing, General Electric, Hitachi and Siemens). Examples include solar receiver patents assigned to Abengoa, solar thermal power plant patents assigned to General Electric, and similar power plant patents assigned to Siemens. Many of these leading organization patents are relatively new, thus showing how an early innovation funded by SETO has fed through into recent developments in CSP technology.

The second noteworthy SETO-funded patent family in Table 5 has representative patent US #5,128,115. This patent family is assigned to DOE[13] and describes the use of solar thermal energy in the production of silicon carbide, an abrasive material used in grinding and polishing applications. This patent family is linked to thirteen subsequent CSP patent families assigned to the leading organizations in this technology. Eight of these thirteen patent families are assigned to Total/SunPower, with the remaining five patent families assigned to Abengoa. The SunPower patents describe various components of solar concentrators and collectors, while the Abengoa

[12] The representative patent is a single patent from a family, but it is not necessarily the priority filing.
[13] Patents may be assigned to DOE itself for various reasons, including where the inventors are federal employees; where the funding recipient elects not to pursue patent protection for, or take title to, the invention; or where the funding recipient does not have the right to take title to the invention.

patents describe solar tower plants. Again, many of these linked patents are relatively new, reflecting the influence of early SETO funded innovations on recent CSP technologies.

Table 5 also contains two newer SETO-funded patent families. The first of these is a Lockheed Martin (Sandia) patent family describing molten salts for thermal energy storage (representative patent #7,588,694). This family is linked to seven leading organization CSP patent families, six of them assigned to Siemens and describing thermal storage media for CSP systems. The second is an MRIGlobal (NREL) patent family (representative patent #8,893,711) related to coatings for solar concentrators. This family is linked to seven patent families owned by leading organizations – including Abengoa, CEA, and Siemens – describing solar concentrators and solar power plants.

Tables 5 lists SETO-funded patents linked to large numbers of subsequent CSP patent families owned by leading organizations in this industry. Table 6 looks in the opposite direction, and lists CSP patent families owned by leading organizations that are linked via citations to the most earlier patents funded by SETO.

Table 6 - Leading Organization CSP Patent Families Linked via Citations to Largest Number of SETO Funded CSP Patent Families

Patent Family #	Representative Patent #	Priority Year	# SETO Fams	Assignee	Title
43297302	9151518	2009	7	Abengoa	Solar concentrator plant using natural-draught tower technology and operating method
45833414	9322576	2011	3	CEA	Receiver module for solar power station with in-built thermal monitoring
43355918	9086058	2009	3	Abengoa	Method for the natural-draught cooling of a solar concentration plant

Abengoa has the patent family with the most citation links to SETO-funded CSP patents. This Abengoa family (representative patent US #9,151,518) describes solar concentrator plants that use natural-draught tower technology. It is linked to seven earlier SETO-funded patent families related to solar thermal power plants, and also solar absorbent coatings for solar collectors and concentrators. Abengoa also has a second patent family in Table 6 (representative patent US #9,086,058) describing similar natural-draught technology. It is linked to three earlier SETO-funded CSP patents. CEA has the other patent family in this table. This family (representative patent US #9,322,576) describes a receiver module for a solar power station, and is also linked to three SETO-funded CSP patent families.

We also identified high-impact CSP patents owned by leading organizations that have citation links back to SETO-funded patents.[14] The idea is to highlight key technologies owned by these organizations that are linked to earlier SETO-funded CSP research.

[14] High-impact patents are identified using 1790's Citation Index metric. This metric is derived by first counting the number of times a patent is cited as prior art by subsequent patents. This number is then divided by the mean number of citations received by peer patents from the same issue year and technology (as defined by their first listed Cooperative Patent Classification). For example, the number of citations received by a 2010 patent in CPC F02S 20/20 (solar collectors) is divided by the mean number of citations received by all patents in that CPC issued in 2010. The expected Citation Index for an individual patent is one. The extent to which a patent's Citation Index is

Table 7 - Highly Cited Leading Company CSP Patents Linked to Earlier SETO-funded CSP Patents

US Patent #	Issue Year	# Cites Received	Citation Index	Assignee	Title
9322963	2016	11	7.37	Total SA (SunPower)	Opposing row linear concentrator architecture
9035168	2015	18	6.19	Total SA (SunPower)	Support for solar energy collectors
6957536	2005	47	3.30	Boeing Co	Systems and methods for generating electrical power from solar energy
8839784	2014	13	3.01	Total SA (SunPower)	Locating connectors and methods for mounting solar hardware
5862800	1999	39	3.00	Boeing Co	Molten nitrate salt solar central receiver of low cycle fatigue 625 alloy
6701711	2004	45	2.74	Boeing Co	Molten salt receiver cooling system
6668555	2003	35	2.12	Boeing Co	Solar receiver-based power generation system
6532953	2003	20	2.10	Boeing Co	Geometric dome stowable tower reflector

Table 7 lists CSP patents owned by leading organizations that have Citation Index values over two (i.e. they have been cited at least twice as frequently as expected), and that are linked to earlier SETO-funded CSP patents. The patents in this table are listed in descending order according to their Citation Index values. The list is dominated by two companies – Total SA (SunPower) and Boeing. The three Total patents (e.g. US #9,322,963) are from the mid-2010s, and focus on solar collectors. Meanwhile, the five Boeing patents (e.g. US #6,957,536) are older, dating from the mid-2000s, and describe solar energy power generation systems.

While the patent-level results focus on SETO-funded CSP patent families, we also identified Other DOE-funded CSP families linked via citations to the largest number of subsequent patent families owned by leading organizations in this technology. These families, listed in Table 8, are all from the initial period of significant DOE-funded patent activity in 1975-84 (and some may in fact have been SETO-funded, as discussed earlier).

The two Other DOE-funded families at the head of Table 8 (representative patent numbers US #4,225,781 and #4,466,423) are assigned to DOE and describe solar collectors. Eight of the leading organizations have at least one CSP patent family linked to one of these Other DOE-funded patent families. Table 8 also contains DOE-funded patent families (e.g. representative patent US #4,373,383) assigned to Atlantic Richfield describing heliostats. These families are also linked to subsequent CSP patent families assigned to eight of the leading organizations. This shows the breadth of influence of early DOE-funded solar collector research.

greater or less than one reveals whether it has been cited more or less frequently than expected, and by how much. For example, a Citation Index of 1.5 shows that a patent has been cited 50% more frequently than expected. Meanwhile a Citation Index of 0.7 reveals that a patent has been cited 30% less frequently than expected. By extension, the expected Citation Index for a portfolio of patents is also one, with values above one showing that a portfolio has been cited more than expected, and values below one showing that a portfolio has not been cited as frequently as expected. Note that the Citation Index is calculated for U.S. patents only, since citation rates differ across patent systems.

Table 8 - Other DOE-Funded CSP Patent Families Linked via Citations to Most Subsequent Leading Organization CSP Families

Patent Family #	Representative Patent #	Priority Year	# Linked Families	Assignee	Title
21770379	4225781	1979	22	US Dept of Energy	SOLAR TRACKING APPARATUS
23705281	4466423	1982	19	US Dept of Energy	RIM-DRIVE CABLE-ALIGNED HELIOSTAT COLLECTOR SYSTEM
22480949	4373783	1980	19	Atlantic Richfield	THERMALLY STABILIZED HELIOSTAT
23224224	4394859	1981	18	US Dept of Energy	CENTRAL SOLAR ENERGY RECEIVER
24397682	3994279	1975	17	US Dept of Energy	SOLAR COLLECTOR WITH IMPROVED THERMAL CONCENTRATION
26835966	4456332	1980	15	Atlantic Richfield	METHOD OF FORMING STRUCTURAL HELIOSTAT
24871756	4114592	1976	14	US Dept of Energy	CYLINDRICAL RADIANT ENERGY DIRECTION DEVICE WITH REFRACTIVE MEDIUM
25206306	4099515	1977	13	US Dept of Energy	FABRICATION OF TROUGH-SHAPED SOLAR COLLECTORS

Overall, the backward tracing element of the analysis suggests that SETO-funded and Other DOE-funded CSP patents have had a strong influence on subsequent innovations associated with the leading CSP organizations. This influence can be seen both over time, and across these leading organizations.

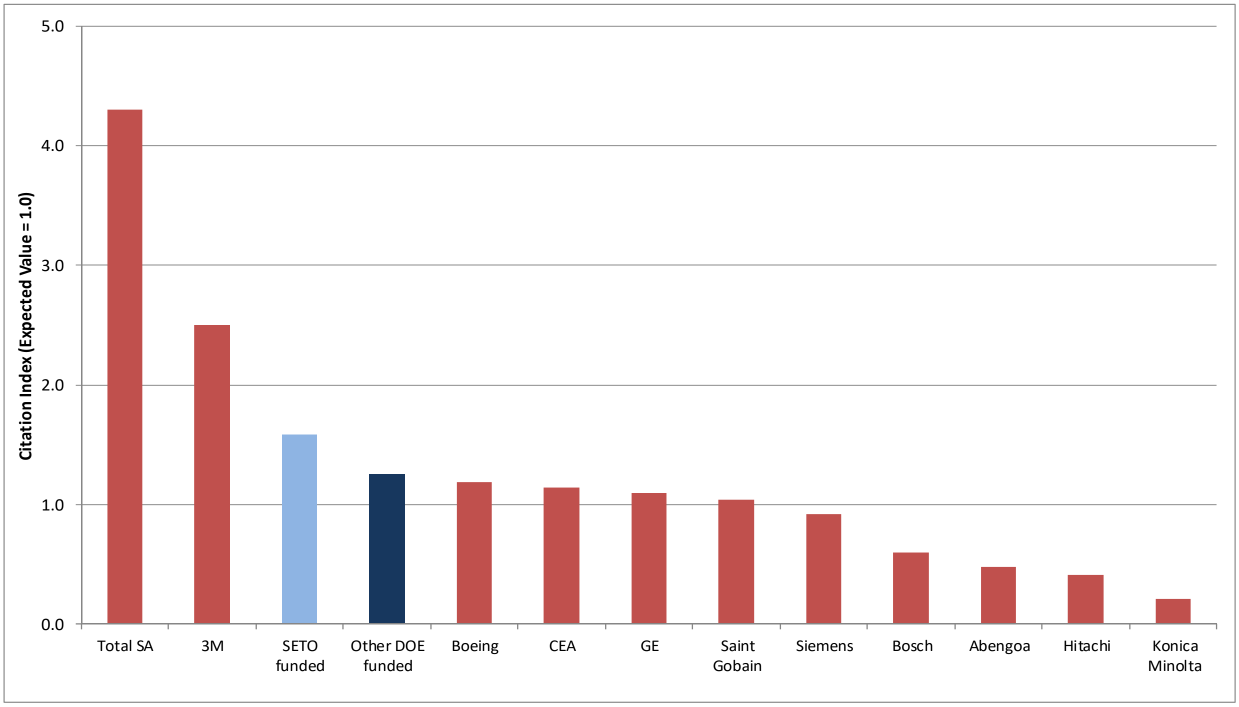
Tracing Forwards from DOE-funded CSP Patents

The previous section of the report examines the influence of DOE-funded CSP research upon technological developments associated with leading CSP organizations. That analysis was based on tracing backwards from the patents of leading organizations to previous generations of research. This section reports the results of an analysis tracing in the opposite direction – starting with SETO-funded (and Other DOE-funded) CSP patents, and tracing forwards in time through two generations of citations. Hence, while the previous section of the report focuses on DOE's influence upon a specific patent set (i.e. patents owned by leading CSP organizations), this section of the report focuses on the broader influence of DOE-funded CSP research, both within and beyond the CSP industry. Also, in order to avoid repeating earlier results, the forward tracing concentrates primarily on patents that are linked to DOE-funded CSP research, but are not owned by leading CSP organizations.

Organizational Level Results

We first generated Citation Index values for the portfolios of SETO-funded and Other DOE-funded CSP patents. For context, we then compared these Citation Indexes against those of the leading CSP organizations. The results are shown in Figure 17.

Figure 17 - Citation Index for Leading Companies' CSP Patent Portfolios, plus SETO-funded and Other DOE-funded CSP Patents



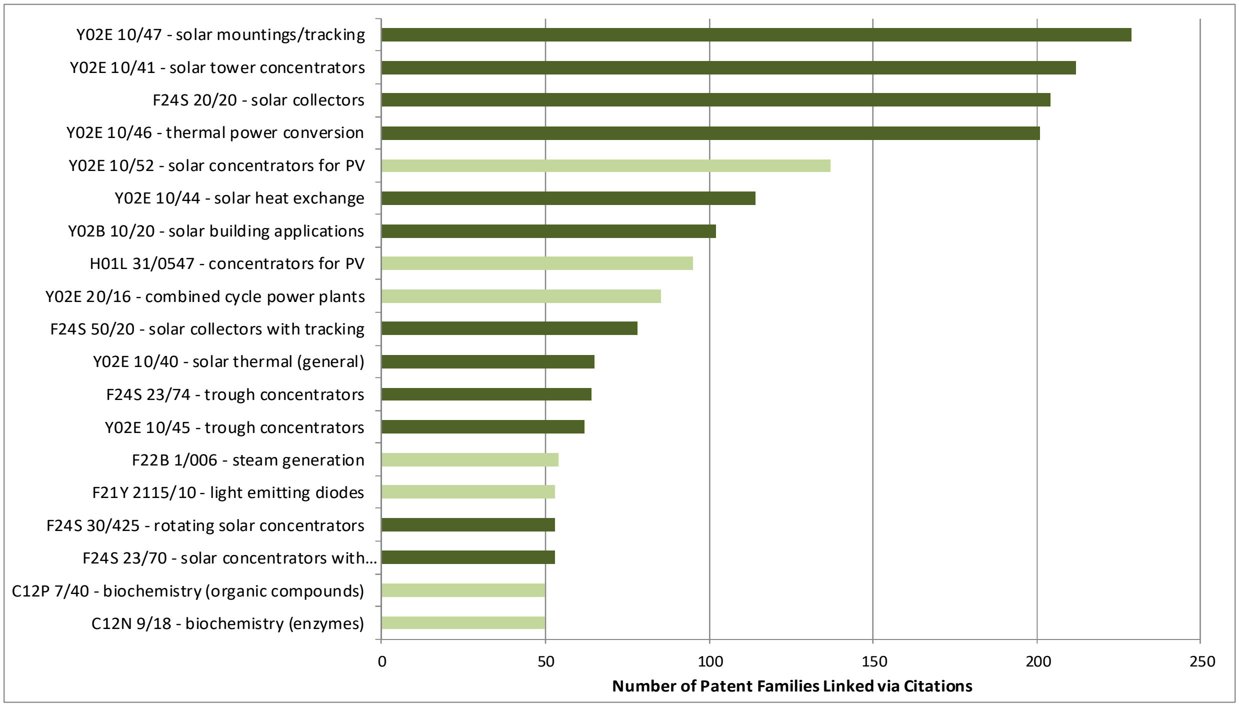
This figure reveals that SETO-funded CSP patents have a Citation Index of 1.58, showing they have been cited almost 60% more frequently than expected. The Citation Index for Other DOE-funded CSP patents is somewhat lower at 1.25, but this means that these patents have still been cited 25% more frequently than expected. Overall, SETO ranks third in Figure 17, behind Total SA and 3M, while Other DOE is fourth.

The Citation Index measures the overall influence of the DOE-funded CSP patent portfolios, but does not address the breadth of this influence across technologies. To analyze this question, we therefore identified the Cooperative Patent Classifications (CPCs) of the patent families linked via citations to earlier DOE-funded CSP patent families.[15] These CPCs reflect the influence of DOE-funded research across technologies.

Figure 18 shows the CPCs with the largest number of patent families linked via citations to SETO-funded CSP patents. The CPCs in this figure are divided into two groups – those related to CSP technology (shown in dark green) and those beyond CSP technology (shown in light green). The former represent the influence of SETO-funded patents on CSP technology itself, while the latter represent spillovers of the influence of SETO-funded CSP research into other technology areas.

[15] Patents typically have numerous CPCs attached to them, reflecting different aspects of the invention they describe. In this analysis, we include all CPCs attached to the patents linked to earlier DOE-funded CSP patent families.

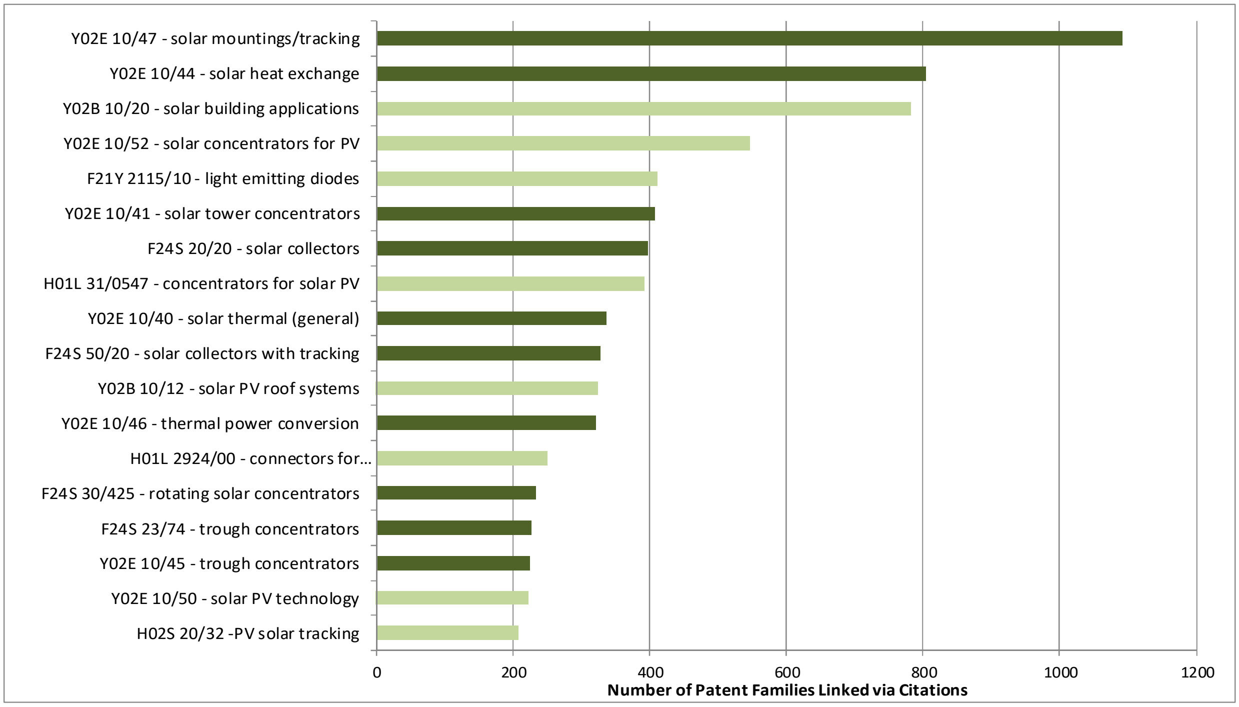
Figure 18 - Number of Patent Families Linked to Earlier SETO-Funded CSP Patents by CPC (Dark Green = CSP technology; Light Green = Other technology)



Not surprisingly, Figure 18 is dominated by CPCs related to CSP, showing the influence of SETO-funded research in this technology. The four CPCs with the largest number of patent families linked via citations to SETO-funded CSP patents are: Y02E 10/47 (solar mountings/tracking), Y02E 10/41 (solar tower concentrators); F24S 20/20 (solar collectors); and Y02E 10/46 (thermal power conversion). There are also a number of CPCs in Figure 21 related to technologies beyond CSP. These include CPCs connected to photovoltaics (Y02E 10/52 and H01L 31/0547); power plants (Y02E 20/16 and F02B 1/006); optical devices (F21Y 2115/10); and biochemistry (C12P 7/40 and C12N 9/18). This reflects how SETO-funded CSP research has influenced developments in related technologies (i.e. photovoltaics and power generation), and also other applications for elements of CSP technology (e.g. the use of coatings in optical devices).

Figure 19 is similar to Figure 18, but is based on patent families linked via citations to Other DOE-funded CSP patents, rather than SETO-funded CSP patents. This figure is again dominated by CPCs related to CSP technology, which is to be expected. One notable difference between this figure and the previous one is the greater presence of CPCs related to photovoltaics. Specifically, Figure 19 contains CPCs covering solar concentrators for photovoltaic applications (Y02E 10/52 and H01L 31/0547); roof systems for photovoltaic installations (Y02B 10/12 and H02S 20/23); and solar tracking for photovoltaics (H02S 20/32). This suggests that Other DOE-funded CSP research has stronger links to photovoltaics than SETO-funded CSP research (with the caveat that some of this Other DOE-funded research may in fact be funded by SETO).

Figure 19 - Number of Patent Families Linked to Earlier Other DOE-Funded CSP Patents by CPC (Dark Green = CSP technology; Light Green = Other technology)



The organizations with the largest number of patent families linked to earlier SETO-funded CSP patents are shown in Figure 20. To avoid repeating the results from earlier, this figure excludes the leading CSP organizations used in the backward tracing element of the analysis. Also, note that Figure 20 includes all patent families assigned to the organizations listed within it, not just their patent families describing CSP technology. A wide range of organizations appear in this figure. These include specialist CSP companies such as GlassPoint and BrightSource. They also include other energy companies – ExxonMobil, Exelon, Ener-Core – plus large multinationals such as IBM, DuPont and Xerox.

Figure 21 shows the organizations with the largest number of patent families linked via citations to earlier Other DOE-funded CSP patents. This figure is headed by United Technologies, which has 106 patent families linked to earlier DOE-funded CSP patents, followed by Magna International (84 families) and Emerson Electric (72 families). In general, the companies in Figure 21 are multinationals, rather than specialist CSP or energy companies.

Figure 20 - Organizations with Largest Number of Patent Families Linked via Citations to SETO-funded CSP Patents (excluding leading CSP organizations)

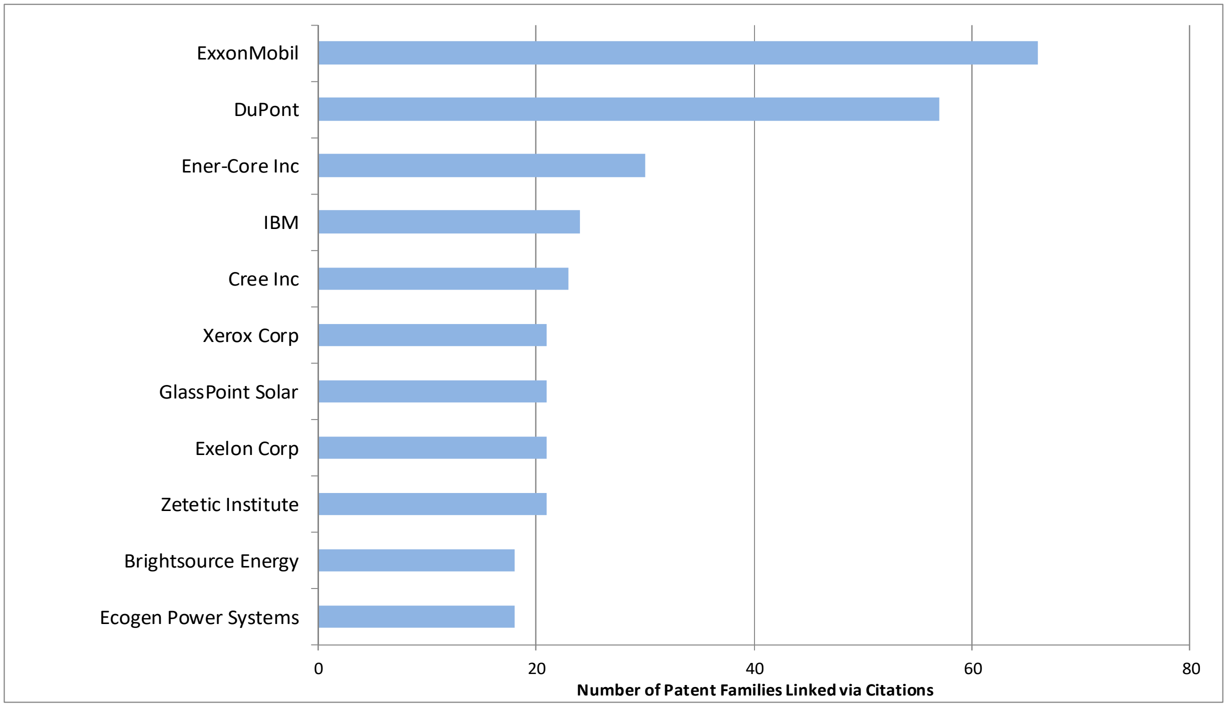
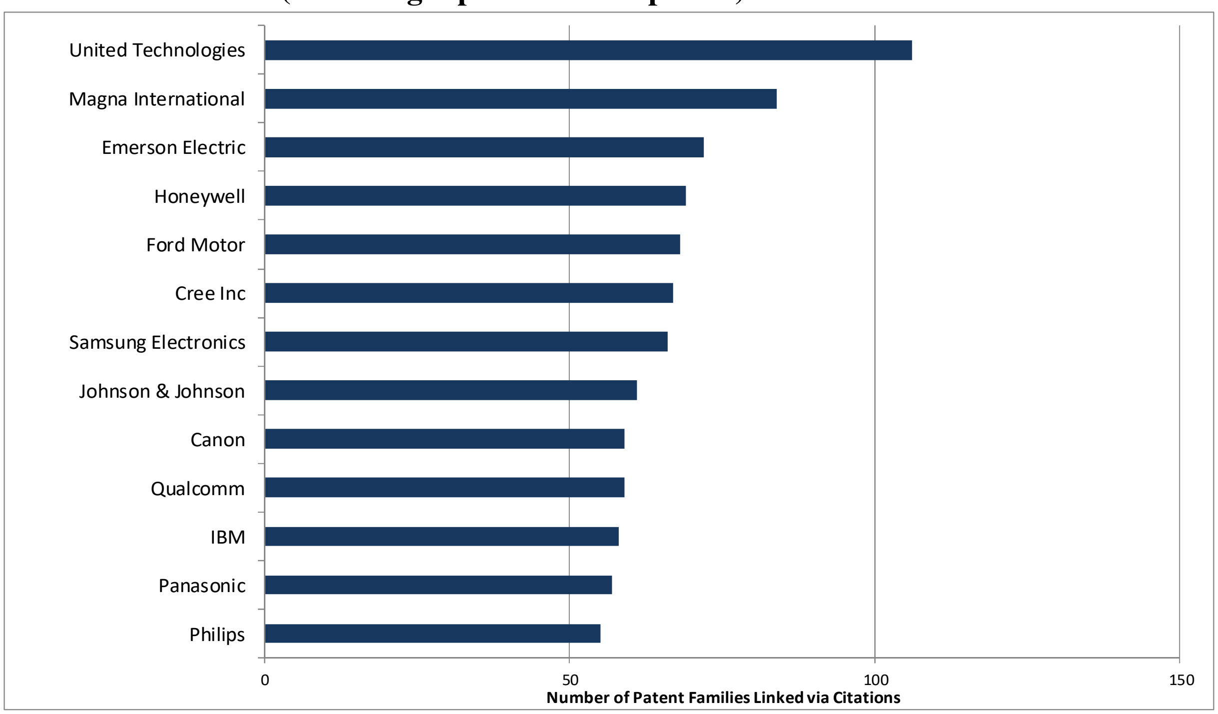


Figure 21 - Organizations with Largest Number of Patent Families Linked to Other DOE-funded CSP Patents (excluding top 10 CSP companies)



Patent Level Results

This section of the report drills down to identify individual DOE-funded (and particularly SETO-funded) CSP patents whose influence on subsequent technological developments has been particularly strong. It also highlights patents that have extensive citation links to earlier SETO-funded CSP research. The simplest way of identifying high-impact SETO-funded CSP patents is through overall Citation Indexes. The SETO-funded patents with the highest Citation Index values are shown in Table 9, with selected patents also presented in Figure 22.

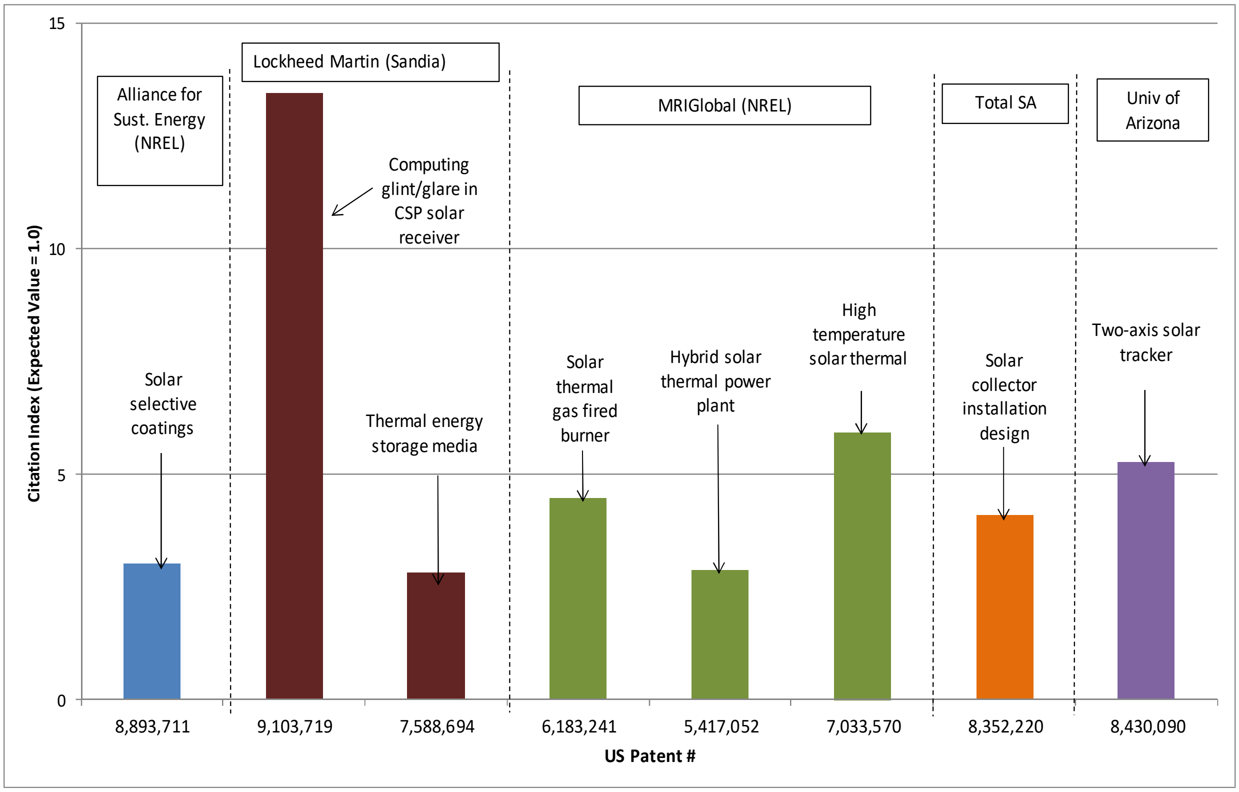
Table 9 – List of Highly Cited SETO-Funded CSP Patents

US Patent #	Issue Year	# Cites Received	Citation Index	Assignee	Title
9103719	2015	20	13.45	Lockheed Martin (Sandia)	Computation of glint, glare, and solar irradiance distribution
7033570	2006	66	5.93	MRIGlobal/Univ Colorado	Solar-thermal fluid-wall reaction processing
8604333	2013	19	5.43	Univ of Arizona	Method of manufacturing reflectors for a solar concentrator apparatus
8430090	2013	18	5.27	Univ of Arizona	Solar concentrator apparatus with large, multiple, co-axial dish reflectors
6183241	2001	72	4.48	MRIGlobal (NREL)	Uniform-burning matrix burner
8352220	2013	17	4.08	Total SA	Automated solar collector installation design including ability to define heterogeneous design preferences
8818924	2014	16	3.47	Total SA	Automated solar collector installation design
8893711	2014	13	3.01	Alliance for Sust. Energy (NREL)	High temperature solar selective coatings
5417052	1995	65	2.88	MRIGlobal (NREL)	Hybrid solar central receiver for combined cycle power plant
7588694	2009	14	2.82	Lockheed Martin (Sandia)	Low-melting point inorganic nitrate salt heat transfer fluid
7667833	2010	11	2.01	Lockheed Martin (Sandia)	Alignment method for parabolic trough solar concentrators
6597709	2003	25	2.01	US Dept of Energy	Method and apparatus for aligning a solar concentrator using two lasers

The patents in Table 9 are a mix of older patents that have received large numbers of citations from subsequent generations of patents, and more recent patents that have attracted more citations than expected. One advantage of using Citation Indexes is that these two groups of patents can be compared directly, since each is benchmarked against peer patents of the same age and technology.

The patent at the head of Table 9 (US #9,103,719) is a 2015 Sandia National Lab patent describing computer-based optimization of solar collectors. It has been cited by a series of subsequent patents, notably Clean Power Research patents describing computer modeling of energy consumption for various renewable energy technologies, including solar. Table 9 also contains highly-cited patents assigned to MRIGlobal describing solar thermal methods to produce hydrogen (US #7,033,570, co-assigned with the University of Colorado) and solar dish/Stirling engine power generation (US #6,183,241). In addition, the University of Arizona has two patents near the head of the list describing solar concentrators (e.g. US #8,604,333).

Figure 22 – Examples of Highly-Cited SETO-funded CSP Patents



The Citation Indexes in Table 9 are based on a single generation of citations to SETO-funded CSP patents. Tables 10 and 11 extend this by examining a second generation of citations – i.e. they show the SETO-funded CSP patents linked via citations to the largest number of subsequent patent families.[16] These subsequent families are divided into two groups, according to whether they are within or beyond CSP technology. This provides insights into which SETO-funded patent families have been particularly influential within CSP technology, and which have had a broader impact beyond CSP.

Table 10 contains older SETO-funded CSP patent families (i.e. with priority dates prior to 2000) linked via citations to the largest number of subsequent patent families. The patent family at the head of this table (representative patent US #5,417,052) is assigned to MRIGlobal (NREL) and describes a hybrid solar thermal and natural gas power generation system. It is linked to 475 subsequent patent families, just under half of which are within CSP technology. This patent was highlighted earlier in the backward tracing analysis.

There are two other SETO-funded patent families linked to more than 300 subsequent families. The first (representative patent US #5,005,958) describes solar concentrators, especially for laser pumping applications, and is assigned to the University of Chicago. The second (representative

[16] The SETO-funded patent families are divided into two tables based on their age, since older patents tend to be connected to larger numbers of subsequent patents, simply because there has been more time for them to become linked to future generations of technology.

patent US #4,702,853) is assigned to DOE, and describes thermal energy storage materials. This second patent family is interesting, in that almost all of the subsequent families linked to it are from outside CSP, and focus more on material science. As such, this is an example of SETO-funded CSP research influencing technology developments beyond CSP.

Table 10 - Pre-2000 SETO-funded CSP Patent Families Linked via Citations to Largest Number of Subsequent CSP/Other Patent Families

Family #	Priority Year	Rep. Patent #	# Linked Families	# Linked CSP Families	Assignee	Title
22522277	1993	5417052	475	219	MRIGlobal (NREL)	Hybrid solar central receiver for combined cycle power plant
26860228	1988	5005958	311	104	University of Chicago	High flux solar energy transformation
25436335	1986	4702853	305	7	US Dept of Energy	Phase change thermal energy storage material
22937529	1999	6183241	119	22	MRIGlobal (NREL)	Uniform-burning matrix burner
24734669	1991	5128115	114	60	US Dept of Energy	Manufacture of silicon carbide using solar energy
23116459	1994	6077401	93	40	MRIGlobal (NREL)	Production of fullerenes using concentrated solar flux
24274046	1984	4552438	74	25	US Dept of Energy	Cable tensioned membrane solar collector module with variable tension control
21846305	1987	4762298	72	16	US Dept of Energy	Support and maneuvering device
35734310	1998	6989924	52	18	MRIGlobal (NREL)	Durable corrosion and ultraviolet-resistant silver mirror
24565826	1996	5692491	41	24	MRIGlobal (NREL)	Unglazed transpired solar collector having a low thermal-conductance absorber

Table 11 contains newer SETO-funded patent families, with priority dates from 2000 onwards. That said, most of these families are still relatively old, dating from the very start of this century. There are two families that stand out in terms of the number of subsequent patent families linked to them. The first (representative patent US #6,603,069) is assigned to UT-Battelle through its management of ORNL. It describes a solar thermal system in which the solar concentrator is connected to a bioreactor for power generation. This patent family is connected to 225 subsequent families, 62 of which are related to CSP. The second patent family (representative patent US #7,033,570) is co-assigned to the University of Colorado and MRIGlobal, and describes solar thermal systems for producing hydrogen and carbon black. It is linked to 181 subsequent families, less than a third of which are related to CSP, many of the remainder describing gasification and bioenergy applications. Again, this is another example of SETO-funded CSP research influencing technology developments beyond CSP.

Table 11 - Post-1999 SETO-funded CSP Patent Families Linked via Citations to Largest Number of Subsequent CSP/Other Patent Families

Family #	Priority Year	Rep. Patent #	# Linked Families	# Linked CSP Families	Assignee	Title
25494610	2001	6603069	225	62	UT-Battelle (ORNL)	Adaptive, full-spectrum solar energy system
46282100	2000	7033570	181	56	MRIGlobal / Univ Colorado	Solar-thermal fluid-wall reaction processing
22752871	2000	6872378	97	47	MRIGlobal (NREL)	Solar thermal aerosol flow reaction process
24726588	2000	6597709	78	46	US Dept of Energy	Method and apparatus for aligning a solar concentrator using two lasers
32681039	2003	6814070	74	5	Gas Technology Inst	Molded polymer solar water heater
26917242	2000	6487859	72	54	MRIGlobal (NREL)	Dish/stirling hybrid-receiver
38218767	2001	7612937	45	27	Alliance for Sustainable Energy (NREL)	Advanced ultraviolet-resistant silver mirrors for use in solar reflectors
27789291	2000	6632542	43	23	Lockheed Martin (Sandia)	Solar selective absorption coatings
36659019	2000	7077532	40	27	Lockheed Martin (Sandia)	Solar reflection panels
40937567	2008	8082755	38	17	University of Arizona	Method of manufacturing large dish reflectors for a solar concentrator apparatus
40567662	2007	8893711	36	4	MRIGlobal (NREL)	High temperature solar selective coatings
41058768	2008	7588694	29	18	Lockheed Martin (Sandia)	Low-melting point inorganic nitrate salt heat transfer fluid
21694983	2001	6722358	27	19	FAFCO Inc	Integral collector storage system with heat exchange apparatus

The tables above identify SETO-funded patent families linked particularly strongly to subsequent technological developments. Table 12 looks in the opposite direction, and identifies highly-cited patents linked via citations to earlier SETO-funded CSP patents. As such, these are examples where SETO-funded CSP research has formed part of the foundation for subsequent high-impact technologies, many of them outside CSP. This table focuses on patent families not owned by the leading CSP organizations, since those families were examined in the backward tracing element of the analysis.

Table 12 - Highly Cited Patents (not from leading CSP companies) Linked via Citations to Earlier SETO-funded CSP Patents

US Patent #	Issue Year	# Cites Received	Citation Index	Assignee	Title
7976631	2011	145	15.37	Applied Materials	Multi-gas straight channel showerhead
8938932	2015	44	14.24	Quality Product LLC	Rail-less roof mounting system
9422957	2016	13	10.33	ABB Ltd	Panel clamp
7723083	2010	58	9.60	DuPont	Production of peracids using an enzyme having perhydrolysis activity
6560038	2003	156	8.30	Teledyne Technologies	Light extraction from LEDs with light pipes
5396350	1995	358	8.21	Honeywell	Backlighting apparatus employing an array of microprisms
8701773	2014	23	7.84	Glasspoint Solar	Oilfield application of solar energy collection
7153015	2006	169	7.79	Innovations in Optics	LED white light optical system
7902094	2011	44	7.52	Eastman Chemical	Water-dispersible and multicomponent fibers from sulfopolyesters
6390626	2002	143	6.69	Duke University	Image projection system engine assembly
6703328	2004	106	6.68	Innovative Network Corp of Japan	Semiconductor device manufacturing method
6185051	2001	169	6.32	Western Digital	High numerical aperture optical focusing device for use in data storage systems
7160612	2007	57	6.01	Hills Inc	Multi-component fibers having enhanced reversible thermal properties and methods of manufacturing thereof

The highly-cited patents in Table 12 cover a wide range of technologies. They include patents for lighting applications assigned to Teledyne and Honeywell, and semiconductor manufacturing patents assigned to Applied Materials and the Innovation Network Corporation of Japan (INCJ). There are also patents for roof mounting systems, especially for solar panels, assigned to ABB and Quality Products LLC. Closer to CSP, there is a highly-cited patent assigned to GlassPoint Solar (US #8,701,773) that describes the use of solar thermal technology in oilfield applications.

As with the backward tracing element of the analysis, the patent-level results from forward tracing focus on SETO-funded CSP patents. However, within the forward tracing we did also identify Other DOE-funded CSP patent families linked via citations to the largest number of subsequent patent families within and beyond CSP technology. These Other DOE-funded CSP families are shown in Table 13 (the families are not divided into two tables based on age, since they are primarily from the same early time period).

The patent family at the head of Table 13 (representative patent US #4,114,592) is assigned to DOE and describes a solar concentrator. It is linked to almost 1,700 subsequent patent families, only 156 of which are within CSP. Another interesting patent family in this figure (representative patent US #4,929,278) describes a sol-gel coating for plastics, such as for solar collectors. It is linked to 730 subsequent patent families, only four of which are related to CSP, with many of the other linked families describing coatings for various applications. There is also another patent family (representative patent #5,161,057) that describes a Fresnel lens for solar concentrators. This family is linked to over 600 subsequent families, almost all concerned with optical elements and lenses rather than CSP. These are examples of spillovers in the influence of Other DOE-funded CSP research.

Table 13 - Other DOE-funded CSP Patent Families Linked via Citations to Largest Number of Subsequent CSP/Other Patent Families

Family #	Priority Year	Rep. Patent #	# Linked Families	# Linked CSP Families	Assignee	Title
24871756	1976	4114592	1692	156	US Dept of Energy	CYLINDRICAL RADIANT ENERGY DIRECTION DEVICE WITH REFRACTIVE MEDIUM
23954835	1974	4002499	1247	234	US Dept of Energy	RADIANT ENERGY COLLECTOR
24325876	1975	3957031	983	176	US Dept of Energy	LIGHT COLLECTORS IN CYLINDRICAL GEOMETRY
22525869	1988	4929278	730	4	US Dept of Energy	SOL-GEL ANTIREFLECTIVE COATING ON PLASTICS
24662482	1976	4130107	724	91	US Dept of Energy	SOLAR CONCENTRATOR WITH RESTRICTED EXIT ANGLES
25427946	1978	4230095	723	95	US Dept of Energy	IDEAL LIGHT CONCENTRATORS WITH REFLECTOR GAPS
26935843	1988	5161057	603	11	Unassigned	DISPERSION-COMPENSATED FRESNEL LENS
22347866	1980	4359265	599	26	University Patents Inc	CONTROLLED DIRECTIONAL SCATTERING CAVITY FOR TUBULAR ABSORBERS
21770379	1979	4225781	590	205	US Dept of Energy	SOLAR TRACKING APPARATUS

Overall, the forward tracing element of the analysis shows that SETO-funded and Other DOE-funded CSP research has had a strong influence on subsequent technologies. This influence can be seen both within CSP technology, and in other technologies such as photovoltaics, material science, bioenergy and optics.

5.0 Conclusions

This report describes the results of an analysis tracing links between CSP research funded by DOE (SETO plus Other DOE) and subsequent developments both within and beyond CSP technology. This tracing is carried out both backwards and forwards in time. The purpose of the backward tracing is to determine the extent to which DOE-funded research forms a foundation for the technologies developed by leading CSP organizations. The purpose of the forward tracing is to examine the broader influence of DOE-funded CSP patents upon subsequent developments, both within and outside CSP technology.

The backward tracing element of the analysis shows that SETO-funded and Other DOE-funded CSP patents have had a strong influence on subsequent innovations associated with the leading CSP organizations. This influence can be seen both over time, and across these leading organizations. Meanwhile, the forward tracing shows that, although DOE-funded patents were a small percentage of all patents over the time period from 1976 to 2018, they have had a strong influence on subsequent technologies. This influence can be seen both within CSP technology, and in other technologies such as photovoltaics, material science, bioenergy and optics.

Overall, the analysis presented in this report reveals that CSP research funded by SETO, and by DOE in general, has had a significant influence on subsequent developments, both within and beyond CSP technology. This influence can be seen on innovations associated with the leading CSP organizations, plus innovations associated with large companies across a range of other technologies.

Appendix A. SETO-funded CSP Patents Used in the Analysis

Patent #	Application Year	Issue / Publication Year	Assignee	Title
4552438	1984	1985	UNITED STATES DEPARTMENT OF ENERGY	CABLE TENSIONED MEMBRANE SOLAR COLLECTOR MODULE WITH VARIABLE TENSION CONTROL
4643168	1985	1987	UNITED STATES DEPARTMENT OF ENERGY	LIQUID COOLED FIBER THERMAL RADIATION RECEIVER
4702853	1986	1987	UNITED STATES DEPARTMENT OF ENERGY	PHASE CHANGE THERMAL ENERGY STORAGE MATERIAL
4762298	1987	1988	UNITED STATES DEPARTMENT OF ENERGY	SUPPORT AND MANEUVERING DEVICE
4875467	1988	1989	UNITED STATES DEPARTMENT OF ENERGY	SUPPORT AND MANEUVERING APPARATUS FOR SOLAR ENERGY RECEIVERS
5005958	1989	1991	ARCH DEVELOPMENT CORP	HIGH FLUX SOLAR ENERGY TRANSFORMATION
5128115	1991	1992	UNITED STATES DEPARTMENT OF ENERGY	MANUFACTURE OF SILICON CARBIDE USING SOLAR ENERGY
5417052	1993	1995	MIDWEST RESEARCH INSTITUTE	HYBRID SOLAR CENTRAL RECEIVER FOR COMBINED CYCLE POWER PLANT
5692491	1996	1997	MIDWEST RESEARCH INSTITUTE	UNGLAZED TRANSPIRED SOLAR COLLECTOR HAVING A LOW THERMAL-CONDUCTANCE ABSORBER
6077401	1994	2000	MIDWEST RESEARCH INSTITUTE	PRODUCTION OF FULLERENES USING CONCENTRATED SOLAR FLUX
6183241	1999	2001	MIDWEST RESEARCH INSTITUTE	UNIFORM-BURNING MATRIX BURNER
6487859	2001	2002	MIDWEST RESEARCH INSTITUTE	DISH/STIRLING HYBRID-RECEIVER
6597709	2000	2003	UNITED STATES DEPARTMENT OF ENERGY	METHOD AND APPARATUS FOR ALIGNING A SOLAR CONCENTRATOR USING TWO LASERS
6603069	2001	2003	UT-BATTELLE LLC	ADAPTIVE, FULL-SPECTRUM SOLAR ENERGY SYSTEM
6632542	2000	2003	SANDIA CORP	SOLAR SELECTIVE ABSORPTION COATINGS
6722358	2001	2004	FAFCO INC	INTEGRAL COLLECTOR STORAGE SYSTEM WITH HEAT EXCHANGE

				APPARATUS
6739136	2002	2004	MIDWEST RESEARCH INSTITUTE	COMBUSTION SYSTEM FOR HYBRID SOLAR FOSSIL FUEL RECEIVER
6783653	2002	2004	SANDIA CORP	SOLAR SELECTIVE ABSORPTION COATINGS
6814070	2003	2004	DAVIS ENERGY GROUP INC	MOLDED POLYMER SOLAR WATER HEATER
6872378	2003	2005	MIDWEST RESEARCH INSTITUTE	SOLAR THERMAL AEROSOL FLOW REACTION PROCESS
6989924	1999	2006	MIDWEST RESEARCH INSTITUTE	DURABLE CORROSION AND ULTRAVIOLET-RESISTANT SILVER MIRROR
7033570	2003	2006	UNIVERSITY OF COLORADO/MID WEST RES INST	SOLAR-THERMAL FLUID-WALL REACTION PROCESSING
7077532	2000	2006	SANDIA CORP	SOLAR REFLECTION PANELS
7231128	2003	2007	UT-BATTELLE LLC	HYBRID SOLAR LIGHTING SYSTEMS AND COMPONENTS
7588694	2008	2009	SANDIA CORP	LOW-MELTING POINT INORGANIC NITRATE SALT HEAT TRANSFER FLUID
7612937	2005	2009	ALLIANCE FOR SUSTAINABLE ENERGY LLC	ADVANCED ULTRAVIOLET-RESISTANT SILVER MIRRORS FOR USE IN SOLAR REFLECTORS
7667833	2007	2010	SANDIA CORP	ALIGNMENT METHOD FOR PARABOLIC TROUGH SOLAR CONCENTRATORS
7973235	2004	2011	UT-BATTELLE LLC	HYBRID SOLAR LIGHTING DISTRIBUTION SYSTEMS AND COMPONENTS
8082755	2009	2011	UNIVERSITY OF ARIZONA	METHOD OF MANUFACTURING LARGE DISH REFLECTORS FOR A SOLAR CONCENTRATOR APPARATUS
8109265	2009	2012	SANDIA CORP	SUCTION-RECIRCULATION DEVICE FOR STABILIZING PARTICLE FLOWS WITHIN A SOLAR POWERED SOLID PARTICLE RECEIVER
8294886	2010	2012	SANDIA CORP	ALIGNMENT METHOD FOR SOLAR COLLECTOR ARRAYS
8350145	2009	2013	UNIVERSITY OF ARIZONA	PHOTOVOLTAIC GENERATOR WITH A SPHERICAL IMAGING LENS FOR USE WITH A PARABOLOIDAL SOLAR REFLECTOR
8352220	2010	2013	SUNPOWER CORP	AUTOMATED SOLAR COLLECTOR INSTALLATION DESIGN INCLUDING ABILITY TO DEFINE HETEROGENEOUS DESIGN PREFERENCES
8430090	2009	2013	UNIVERSITY OF	SOLAR CONCENTRATOR

			ARIZONA	APPARATUS WITH LARGE, MULTIPLE, CO-AXIAL DISH REFLECTORS
8459865	2010	2013	SANDIA CORP	TRACKING HEAT FLUX SENSORS FOR CONCENTRATING SOLAR APPLICATIONS
8557099	2010	2013	PPG INDUSTRIES OHIO INC	ELECTROCURTAIN COATING PROCESS FOR COATING SOLAR MIRRORS
8582092	2011	2013	SANDIA CORP	ALIGNMENT AND FOCUS OF MIRRORED FACETS OF A HELIOSTAT
8604333	2011	2013	UNIVERSITY OF ARIZONA	METHOD OF MANUFACTURING REFLECTORS FOR A SOLAR CONCENTRATOR APPARATUS
8664577	2011	2014	SANDIA CORP	LONG RANGE HELIOSTAT TARGET USING ARRAY OF NORMAL INCIDENCE PYRANOMETERS TO EVALUATE A BEAM OF SOLAR RADIATION
8669509	2011	2014	SANDIA CORP	MOBILE COMPUTING DEVICE CONFIGURED TO COMPUTE IRRADIANCE, GLINT, AND GLARE OF THE SUN
8673035	2011	2014	UNIVERSITY OF COLORADO	SOLAR-THERMAL REACTION PROCESSING
8674280	2010	2014	SANDIA CORP	CONCENTRATION SOLAR POWER OPTIMIZATION SYSTEM AND METHOD OF USING SAME
8712745	2012	2014	SUNPOWER CORP	AUTOMATED SOLAR COLLECTOR INSTALLATION DESIGN INCLUDING ABILITY TO DEFINE HETEROGENEOUS DESIGN PREFERENCES
8818924	2010	2014	SUNPOWER CORP	AUTOMATED SOLAR COLLECTOR INSTALLATION DESIGN
8893711	2007	2014	ALLIANCE FOR SUSTAINABLE ENERGY LLC	HIGH TEMPERATURE SOLAR SELECTIVE COATINGS
8978642	2013	2015	NORWICH TECHNOLOGIES INC	CAVITY RECEIVERS FOR PARABOLIC SOLAR TROUGHS
9103719	2011	2015	SANDIA CORP	COMPUTATION OF GLINT, GLARE, AND SOLAR IRRADIANCE DISTRIBUTION
9175882	2010	2015	THE BOEING CO	SOLAR ENERGY SYSTEM WITH WIND VANE
9279188	2013	2016	SANDIA CORP	HYBRID METAL OXIDE CYCLE WATER SPLITTING
9297554	2013	2016	NORWICH TECHNOLOGIES	CAVITY RECEIVERS FOR PARABOLIC SOLAR TROUGHS

			INC	
9347690	2013	2016	ALLIANCE FOR SUSTAINABLE ENERGY LLC	METHODS AND SYSTEMS FOR CONCENTRATED SOLAR POWER
9404675	2013	2016	NORWICH TECHNOLOGIES INC	CAVITY RECEIVERS FOR PARABOLIC SOLAR TROUGHS
9458838	2014	2016	THE BABCOCK & WILCOX CO	POWER GENERATION PLANT INTEGRATING CONCENTRATED SOLAR POWER RECEIVER AND PRESSURIZED HEAT EXCHANGER
9493695	2014	2016	UNIVERSITY OF SOUTH FLORIDA	METHOD OF ENCAPSULATING A PHASE CHANGE MATERIAL WITH A METAL OXIDE
9556528	2016	2017	SANDIA CORP	HYBRID METAL OXIDE CYCLE WATER SPLITTING
9568653	2013	2017	3M INNOVATIVE PROPERTIES CO	DURABLE SOLAR MIRROR FILMS
9638842	2013	2017	SKYFUEL INC	MODIFICATION OF UV ABSORPTION PROFILE OF POLYMER FILM REFLECTORS TO INCREASE SOLAR-WEIGHTED REFLECTANCE
9702348	2014	2017	ALLIANCE FOR SUSTAINABLE ENERGY LLC	CHEMICAL LOOPING FLUIDIZED-BED CONCENTRATING SOLAR POWER SYSTEM AND METHOD
9719697	2014	2017	UNIVERSITY OF HOUSTON	GRADIENT SINO ANTI-REFLECTIVE LAYERS IN SOLAR SELECTIVE COATINGS
9722534	2015	2017	SANDIA CORP	COMPUTATION OF GLINT, GLARE, AND SOLAR IRRADIANCE DISTRIBUTION
9726155	2011	2017	WILSON SOLARPOWER CORP	CONCENTRATED SOLAR POWER GENERATION USING SOLAR RECEIVERS
9917221	2013	2018	MASSACHUSETTS INSTITUTE OF TECHNOLOGY	SOLAR POWER CONVERSION SYSTEM WITH DIRECTIONALLY- AND SPECTRALLY-SELECTIVE PROPERTIES BASED ON A REFLECTIVE CAVITY
9920955	2015	2018	THE BABCOCK & WILCOX CO	WATER JACKET FOR SOLID PARTICLE SOLAR RECEIVER
9939178	2014	2018	THE BABCOCK & WILCOX CO	SOLIDS-BASED CONCENTRATED SOLAR POWER RECEIVER
9945585	2015	2018	ALLIANCE FOR SUSTAINABLE ENERGY LLC	SYSTEMS AND METHODS FOR DIRECT THERMAL RECEIVERS USING NEAR BLACKBODY CONFIGURATIONS

9950305	2012	2018	BATTELLE MEMORIAL INSTITUTE	SOLAR THERMOCHEMICAL PROCESSING SYSTEM AND METHOD
9998070	2016	2018	3M INNOVATIVE PROPERTIES CO	DURABLE SOLAR MIRROR FILMS
10042094	2011	2018	SKYFUEL INC	WEATHERABLE SOLAR REFLECTOR WITH HIGH ABRASION RESISTANCE
10060681	2016	2018	UNIVERSITY OF LOUISVILLE	HEAT PIPE AUGMENTED PASSIVE SOLAR HEATING SYSTEM
10280903	2017	2019	WILSON SOLARPOWER CORP	CONCENTRATED SOLAR POWER GENERATION USING SOLAR RECEIVERS
EP0452323	1989	1991	UNITED STATES DEPARTMENT OF ENERGY	SUPPORT AND MANEUVERING APPARATUS FOR SOLAR ENERGY RECEIVER.
EP1341604	2001	2003	MIDWEST RESEARCH INSTITUTE	SOLAR THERMAL AEROSOL FLOW REACTION PROCESS
EP1969283	2006	2008	MIDWEST RESEARCH INSTITUTE	ADVANCED ULTRAVIOLET-RESISTANT SILVER MIRRORS FOR USE IN SOLAR REFLECTORS
EP2217865	2007	2010	MIDWEST RESEARCH INSTITUTE	HIGH TEMPERATURE SOLAR SELECTIVE COATINGS
EP2282976	2009	2011	UNIVERSITY OF ARIZONA	METHOD OF MANUFACTURING LARGE DISH REFLECTORS FOR A SOLAR CONCENTRATOR APPARATUS
EP2286466	2009	2011	UNIVERSITY OF ARIZONA	SOLAR CONCENTRATOR APPARATUS WITH LARGE MULTIPLE CO-AXIAL DISH REFLECTORS
EP2286467	2009	2011	UNIVERSITY OF ARIZONA	PHOTOVOLTAIC GENERATOR WITH A SPHERICAL IMAGING LENS FOR USE WITH A PARABOLOIDAL SOLAR REFLECTOR
EP2366965	2011	2011	THE BOEING CO	SOLAR ENERGY SYSTEM WITH WIND VANE
EP2399211	2010	2011	SUNPOWER CORP	AUTOMATED SOLAR COLLECTOR INSTALLATION DESIGN
EP2399213	2010	2011	SUNPOWER CORP	AUTOMATED SOLAR COLLECTOR INSTALLATION DESIGN INCLUDING ABILITY TO DEFINE HETEROGENEOUS DESIGN PREFERENCES
EP2616679	2011	2013	WILSON SOLARPOWER CORP	CONCENTRATED SOLAR POWER GENERATION USING SOLAR RECEIVERS
EP2633101	2011	2013	PPG INDUSTRIES	ELECTROCURTAIN COATING

			OHIO INC	PROCESS FOR COATING SOLAR MIRRORS
EP2834574	2013	2015	NORWICH TECHNOLOGIES INC	LINEAR SOLAR RECEIVER FOR CONCENTRATING SOLAR POWER SYSTEMS
EP2844464	2013	2015	3M INNOVATIVE PROPERTIES CO	DURABLE SOLAR MIRROR FILMS
EP2964952	2014	2016	SKYFUEL INC	HIGH SOLAR-WEIGHTED REFLECTANCE POLYMER FILM REFLECTORS
EP2975263	2015	2016	THE BABCOCK & WILCOX CO	POWER GENERATION PLANT INTEGRATING CONCENTRATED SOLAR POWER RECEIVER AND PRESSURIZED HEAT EXCHANGER
EP3146275	2015	2017	THE BABCOCK & WILCOX CO	SOLAR RECEIVER COMPRISING LIGHT APERTURES AND A WATER JACKET FOR COOLING THE LIGHT APERTURES
WO1990001134	1989	1990	UNITED STATES DEPARTMENT OF ENERGY	SUPPORT AND MANEUVERING APPARATUS FOR SOLAR ENERGY RECEIVER
WO1995012757	1994	1995	MIDWEST RESEARCH INSTITUTE	HYBRID CENTRAL RECEIVER
WO2003038348	2002	2003	UT-BATTELLE LLC	ADAPTIVE, FULL-SPECTRUM SOLAR ENERGY SYSTEM
WO2003049853	2001	2003	MIDWEST RESEARCH INSTITUTE	SOLAR THERMAL AEROSOL FLOW REACTION PROCESS
WO2007076282	2006	2007	MIDWEST RESEARCH INSTITUTE	ADVANCED ULTRAVIOLET-RESISTANT SILVER MIRRORS FOR USE IN SOLAR REFLECTORS
WO2009051595	2007	2009	ALLIANCE FOR SUSTAINABLE ENERGY LLC	HIGH TEMPERATURE SOLAR SELECTIVE COATINGS
WO2009140174	2009	2009	UNIVERSITY OF ARIZONA	SOLAR CONCENTRATOR APPARATUS WITH LARGE, MULTIPLE, CO-AXIAL DISH REFLECTORS
WO2009140175	2009	2009	UNIVERSITY OF ARIZONA	PHOTOVOLTAIC GENERATOR WITH A SPHERICAL IMAGING LENS FOR USE WITH A PARABOLOIDAL SOLAR REFLECTOR
WO2009140176	2009	2009	UNIVERSITY OF ARIZONA	METHOD OF MANUFACTURING LARGE DISH REFLECTORS FOR A SOLAR CONCENTRATOR APPARATUS
WO2010096268	2010	2010	SUNPOWER CORP	AUTOMATED SOLAR COLLECTOR INSTALLATION

				DESIGN
WO2010096270	2010	2010	SUNPOWER CORP	AUTOMATED SOLAR COLLECTOR INSTALLATION DESIGN INCLUDING ABILITY TO DEFINE HETEROGENEOUS DESIGN PREFERENCES
WO2012037532	2011	2012	WILSON SOLARPOWER CORP	CONCENTRATED SOLAR POWER GENERATION USING SOLAR RECEIVERS
WO2012060914	2011	2012	PPG INDUSTRIES OHIO INC	ELECTROCURTAIN COATING PROCESS FOR COATING SOLAR MIRRORS
WO2013012907	2012	2013	UNIVERSITY OF SOUTH FLORIDA	METHOD OF ENCAPSULATING A PHASE CHANGE MATERIAL WITH A METAL OXIDE
WO2013019167	2011	2013	SANDIA CORP	HYBRID METAL OXIDE CYCLE WATER SPLITTING
WO2013019199	2011	2013	SANDIA CORP	HYBRID METAL OXIDE CYCLE WATER SPLITTING
WO2013036220	2011	2013	SKYFUEL INC	WEATHERABLE SOLAR REFLECTOR WITH ABRASION RESISTANCE
WO2013151601	2013	2013	NORWICH TECHNOLOGIES INC	CAVITY RECEIVERS FOR PARABOLIC SOLAR TROUGHS
WO2013165726	2013	2013	3M INNOVATIVE PROPERTIES CO	DURABLE SOLAR MIRROR FILMS
WO2014018878	2013	2014	BATTELLE MEMORIAL INSTITUTE	SOLAR THERMOCHEMICAL PROCESSING SYSTEM AND METHOD
WO2014039289	2013	2014	MASSACHUSETTS INSTITUTE OF TECHNOLOGY	SOLAR POWER CONVERSION SYSTEM WITH DIRECTIONALLY- AND SPECTRALLY- SELECTIVE PROPERTIES BASED ON A REFLECTIVE CAVITY
WO2014138434	2014	2014	SKYFUEL INC	HIGH SOLAR-WEIGHTED REFLECTANCE POLYMER FILM REFLECTORS
WO2014204671	2014	2014	UNIVERSITY OF HOUSTON	GRADIENT SINO ANTI-REFLECTIVE LAYERS IN SOLAR SELECTIVE COATINGS
WO2015179203	2015	2015	THE BABCOCK & WILCOX CO	WATER JACKET FOR SOLID PARTICLE SOLAR RECEIVER
WO2016057283	2015	2016	THE BABCOCK & WILCOX CO	SOLIDS-BASED CONCENTRATED SOLAR POWER RECEIVER

Appendix B. Other DOE-Funded CSP Patents Used in the Analysis

Patent #	Application Year	Issue / Publication Year	Assignee	Title
3957031	1975	1976	UNITED STATES DEPARTMENT OF ENERGY	LIGHT COLLECTORS IN CYLINDRICAL GEOMETRY
3982526	1975	1976	UNITED STATES DEPARTMENT OF ENERGY	TURNING COLLECTORS FOR SOLAR RADIATION
3986490	1975	1976	UNITED STATES DEPARTMENT OF ENERGY	REDUCING HEAT LOSS FROM THE ENERGY ABSORBER OF A SOLAR COLLECTOR
3991740	1975	1976	UNITED STATES DEPARTMENT OF ENERGY	SEA SHELL SOLAR COLLECTOR
3994279	1975	1976	UNITED STATES DEPARTMENT OF ENERGY	SOLAR COLLECTOR WITH IMPROVED THERMAL CONCENTRATION
4002499	1974	1977	UNITED STATES DEPARTMENT OF ENERGY	RADIANT ENERGY COLLECTOR
4007729	1975	1977	UNITED STATES DEPARTMENT OF ENERGY	MEANS OF INCREASING EFFICIENCY OF CPC SOLAR ENERGY COLLECTOR
4010733	1975	1977	UNITED STATES DEPARTMENT OF ENERGY	STRUCTURALLY INTEGRATED STEEL SOLAR COLLECTOR
4044752	1975	1977	UNITED STATES DEPARTMENT OF ENERGY	SOLAR COLLECTOR WITH ALTITUDE TRACKING
4048980	1976	1977	UNITED STATES DEPARTMENT OF ENERGY	SOLAR RADIATION ABSORBING MATERIAL
4052976	1976	1977	UNITED STATES DEPARTMENT OF ENERGY	NON-TRACKING SOLAR CONCENTRATOR WITH A HIGH CONCENTRATION RATIO
4067316	1976	1978	UNITED STATES DEPARTMENT OF ENERGY	SOLAR ENERGY COLLECTOR
4071659	1975	1978	TEXAS INSTRUMENTS INC	SOLAR ABSORPTION SURFACE PANEL
4078544	1976	1978	UNITED STATES DEPARTMENT OF ENERGY	CORRUGATED COVER PLATE FOR FLAT PLATE COLLECTOR
4099515	1977	1978	UNITED STATES DEPARTMENT OF ENERGY	FABRICATION OF TROUGH-SHAPED SOLAR COLLECTORS
4114592	1976	1978	UNITED STATES DEPARTMENT OF ENERGY	CYLINDRICAL RADIANT ENERGY DIRECTION DEVICE WITH REFRACTIVE MEDIUM
4120565	1977	1978	UNITED STATES DEPARTMENT OF ENERGY	PRISMS WITH TOTAL INTERNAL REFLECTION AS SOLAR REFLECTORS

4121564	1977	1978	SANDERS ASSOCIATES INC	SOLAR ENERGY RECEIVER
4126123	1977	1978	UNASSIGNED	SOLAR ENERGY COLLECTOR INCLUDING A WEIGHTLESS BALLOON WITH SUN TRACKING MEANS
4130107	1977	1978	UNITED STATES DEPARTMENT OF ENERGY	SOLAR CONCENTRATOR WITH RESTRICTED EXIT ANGLES
4141626	1977	1979	FMC CORP	METHOD OF AND APPARATUS FOR COLLECTING SOLAR RADIATION UTILIZING VARIABLE CURVATURE CYLINDRICAL REFLECTORS
4150659	1977	1979	CHEVRON RESEARCH COMPANY	APPARATUS FOR PREVENTING HIGH TEMPERATURES IN A GLAZED SOLAR COLLECTOR
4192583	1977	1980	UNITED STATES DEPARTMENT OF ENERGY	SOLAR RECEIVER HELIOSTAT REFLECTOR HAVING A LINEAR DRIVE AND POSITION INFORMATION SYSTEM
4209236	1977	1980	UNITED STATES DEPARTMENT OF ENERGY	SOLAR CENTRAL RECEIVER HELIOSTAT REFLECTOR ASSEMBLY
4212287	1978	1980	GENERAL ELECTRIC CO	INSOLATION INTEGRATOR
4224803	1978	1980	UNASSIGNED	CHEMICAL HEAT PUMP
4225781	1979	1980	UNITED STATES DEPARTMENT OF ENERGY	SOLAR TRACKING APPARATUS
4226657	1978	1980	UNITED STATES DEPARTMENT OF ENERGY	METHOD OF MAKING REFLECTING FILM REFLECTOR
4229184	1979	1980	UNITED STATES DEPARTMENT OF ENERGY	APPARATUS AND METHOD FOR SOLAR COAL GASIFICATION
4230095	1978	1980	UNITED STATES DEPARTMENT OF ENERGY	IDEAL LIGHT CONCENTRATORS WITH REFLECTOR GAPS
4237332	1978	1980	UNITED STATES DEPARTMENT OF ENERGY	NONIMAGING RADIANT ENERGY DIRECTION DEVICE
4242112	1979	1980	RCA CORP	SOLAR POWERED DEHUMIDIFIER APPARATUS
4262739	1979	1981	UNITED STATES DEPARTMENT OF ENERGY	SYSTEM FOR THERMAL ENERGY STORAGE, SPACE HEATING AND COOLING AND POWER CONVERSION
4272268	1977	1981	UNASSIGNED	CHEMICAL HEAT PUMP
4274394	1979	1981	UNITED STATES DEPARTMENT OF ENERGY	ELECTROMECHANICAL SOLAR TRACKING APPARATUS
4280333	1979	1981	UNITED STATES DEPARTMENT	PASSIVE ENVIRONMENTAL TEMPERATURE CONTROL

			OF ENERGY	SYSTEM
4286576	1979	1981	UNITED STATES DEPARTMENT OF ENERGY	SOLAR ENERGY THERMALIZATION AND STORAGE DEVICE
4307709	1980	1981	UNASSIGNED	INTERNAL ABSORBER SOLAR COLLECTOR
4308042	1980	1981	ATLANTIC RICHFIELD CO	HEAT PUMP WITH FREEZE-UP PREVENTION
4308723	1979	1982	ATLANTIC RICHFIELD CO	HEAT PUMP EMPLOYING OPTIMAL REFRIGERANT COMPRESSOR FOR LOW PRESSURE RATIO APPLICATIONS
4313304	1979	1982	UNITED STATES DEPARTMENT OF ENERGY	RADIANT ENERGY COLLECTION AND CONVERSION APPARATUS AND METHOD
4313424	1980	1982	UNITED STATES DEPARTMENT OF ENERGY	SOLAR HEATING SYSTEM
4327707	1979	1982	UNITED STATES DEPARTMENT OF ENERGY	SOLAR COLLECTOR
4336692	1980	1982	ATLANTIC RICHFIELD CO	DUAL SOURCE HEAT PUMP
4359265	1980	1982	UNIVERSITY PATENTS INC	CONTROLLED DIRECTIONAL SCATTERING CAVITY FOR TUBULAR ABSORBERS
4361135	1981	1982	UNITED STATES DEPARTMENT OF ENERGY	COOPERATIVE HEAT TRANSFER AND GROUND COUPLED STORAGE SYSTEM
4373783	1980	1983	ATLANTIC RICHFIELD CO	THERMALLY STABILIZED HELIOSTAT
4376755	1982	1983	UNITED STATES DEPARTMENT OF ENERGY	PRODUCTION OF CRYSTALLINE REFRACTORY METAL OXIDES CONTAINING COLLOIDAL METAL PRECIPITATES AND USEFUL AS SOLAR-EFFECTIVE ABSORBERS
4380156	1981	1983	ATLANTIC RICHFIELD CO	MULTIPLE SOURCE HEAT PUMP
4380229	1980	1983	UNITED STATES DEPARTMENT OF ENERGY	SOLAR RECEIVER PROTECTION MEANS AND METHOD FOR LOSS OF COOLANT FLOW
4387961	1981	1983	UNASSIGNED	COMPOUND PARABOLIC CONCENTRATOR WITH CAVITY FOR TUBULAR ABSORBERS
4390008	1980	1983	UNITED STATES DEPARTMENT OF ENERGY	HOT WATER TANK FOR USE WITH A COMBINATION OF SOLAR ENERGY AND HEAT-PUMP DESUPERHEATING
4392481	1981	1983	UNITED STATES DEPARTMENT	SOLAR COLLECTOR APPARATUS HAVING

			OF ENERGY	INCREASED ENERGY REJECTION DURING STAGNATION
4394859	1981	1983	UNITED STATES DEPARTMENT OF ENERGY	CENTRAL SOLAR ENERGY RECEIVER
4403601	1981	1983	UNASSIGNED	RADIATION RECEIVER
4416916	1982	1983	ENGELHARD CORP	THIN FILM SOLAR ENERGY COLLECTOR
4418684	1981	1983	BUTLER-MANUFACTURI NG CO	ROOF APERTURE SYSTEM FOR SELECTIVE COLLECTION AND CONTROL OF SOLAR ENERGY FOR BUILDING HEATING, COOLING AND DAYLIGHTING
4419984	1980	1983	UNIVERSITY PATENTS INC	RADIANT ENERGY COLLECTOR
4424800	1981	1984	UNITED STATES DEPARTMENT OF ENERGY	THERMAL CONTROL SYSTEM AND METHOD FOR A PASSIVE SOLAR STORAGE WALL
4425903	1981	1984	UNASSIGNED	CHEMICAL HEAT PUMP
4425904	1980	1984	UNITED STATES DEPARTMENT OF ENERGY	TRACKING SYSTEM FOR SOLAR COLLECTORS
4428358	1981	1984	UNASSIGNED	SOLAR SKYLIGHT
4429683	1982	1984	UNITED STATES DEPARTMENT OF ENERGY	GRADIENT ZONE BOUNDARY CONTROL IN SALT GRADIENT SOLAR PONDS
4429684	1981	1984	UNASSIGNED	CHEMICAL HEAT PUMP
4431499	1982	1984	UNITED STATES DEPARTMENT OF ENERGY	METHOD OF SPUTTER ETCHING A SURFACE
4432345	1981	1984	UNITED STATES DEPARTMENT OF ENERGY	RECEIVER FOR SOLAR ENERGY COLLECTOR HAVING IMPROVED APERTURE ASPECT
4437455	1982	1984	ENGELHARD CORP	STABILIZATION OF SOLAR FILMS AGAINST HI TEMPERATURE DEACTIVATION
4437456	1981	1984	UNITED STATES DEPARTMENT OF ENERGY	HEAT COLLECTOR
4440150	1982	1984	ATLANTIC RICHFIELD CO	HELIOSTAT CONTROL
4441484	1981	1984	UNASSIGNED	CHEMICAL HEAT PUMP
4443186	1982	1984	UNITED STATES DEPARTMENT OF ENERGY	SOLAR HEATED ROTARY KILN
4456332	1981	1984	ATLANTIC RICHFIELD CO	METHOD OF FORMING STRUCTURAL HELIOSTAT
4466423	1982	1984	UNITED STATES DEPARTMENT OF ENERGY	RIM-DRIVE CABLE-ALIGNED HELIOSTAT COLLECTOR SYSTEM
4474170	1981	1984	UNITED STATES DEPARTMENT	GLASS HEAT PIPE EVACUATED TUBE SOLAR

			OF ENERGY	COLLECTOR
4479485	1982	1984	UNITED STATES DEPARTMENT OF ENERGY	POWER EFFICIENCY FOR VERY HIGH TEMPERATURE SOLAR THERMAL CAVITY RECEIVERS
4483323	1982	1984	UNITED STATES DEPARTMENT OF ENERGY	TENSIONING DEVICE FOR A STRETCHED MEMBRANE COLLECTOR
4487196	1982	1984	UNITED STATES DEPARTMENT OF ENERGY	FOCUSING SOLAR COLLECTOR AND METHOD FOR MANUFACTURING SAME
4499893	1982	1985	UNITED STATES DEPARTMENT OF ENERGY	SOLAR HEAT RECEIVER
4511215	1983	1985	UNITED STATES DEPARTMENT OF ENERGY	LIGHTWEIGHT DIAPHRAGM MIRROR MODULE SYSTEM FOR SOLAR COLLECTORS
4523577	1982	1985	IOWA STATE UNIVERSITY	SEMI-TRANSPARENT SOLAR ENERGY THERMAL STORAGE DEVICE
4556049	1981	1985	UNASSIGNED	INTEGRATED SOLAR COLLECTOR
4580571	1984	1986	IOWA STATE UNIVERSITY	SEMI-TRANSPARENT SOLAR ENERGY THERMAL STORAGE DEVICE
4584842	1979	1986	UNASSIGNED	SOLAR REFRIGERATION
4615381	1984	1986	ONE DESIGN INC	SOLAR HEATING AND COOLING DIODE MODULE
4620382	1984	1986	UNASSIGNED	APPARATUS FOR TENSIONING A HELIOSTAT MEMBRANE
4706651	1986	1987	UNITED STATES DEPARTMENT OF ENERGY	SOLAR SOLIDS REACTOR
4929278	1988	1990	UNITED STATES DEPARTMENT OF ENERGY	SOL-GEL ANTIREFLECTIVE COATING ON PLASTICS
5016998	1989	1991	SCIENCE APPLICATIONS INTERNATIONA L CORP	FOCUS CONTROL SYSTEM FOR STRETCHED-MEMBRANE MIRROR MODULE
5074283	1990	1991	UNITED STATES DEPARTMENT OF ENERGY	THERMAL STORAGE MODULE FOR SOLAR DYNAMIC RECEIVERS
5161057	1990	1992	UNASSIGNED	DISPERSION-COMPENSATED FRESNEL LENS
5169456	1991	1992	UNASSIGNED	TWO-AXIS TRACKING SOLAR COLLECTOR MECHANISM
5431148	1994	1995	UNITED STATES DEPARTMENT OF ENERGY	IMMERSIBLE SOLAR HEATER FOR FLUIDS
5501268	1993	1996	MARTIN MARIETTA ENERGY SYSTEMS INC	METHOD OF ENERGY LOAD MANAGEMENT USING PCM FOR HEATING AND COOLING OF BUILDINGS
5511537	1994	1996	MARTIN	SMART, PASSIVE SUN FACING

			MARIETTA ENERGY SYSTEMS INC	SURFACES
5646792	1995	1997	SCIENCE APPLICATIONS INTERNATIONAL CORP	LONG-LIFE SELF-RENEWING SOLAR REFLECTOR STACK
6066187	1998	2000	UNITED STATES DEPARTMENT OF ENERGY	SOLAR REDUCTION OF CO.SUB.2
6097556	1996	2000	SCIENCE APPLICATIONS INTERNATIONAL CORP	IRRADIANCE REDISTRIBUTION GUIDE
6116330	1999	2000	THE UNIVERSITY OF DAYTON	HEAT STORAGE SYSTEM UTILIZING PHASE CHANGE MATERIALS GOVERNMENT RIGHTS
6225551	2000	2001	MIDWEST RESEARCH INSTITUTE	MULTI-FACET CONCENTRATOR OF SOLAR SETUP FOR IRRADIATING THE OBJECTS PLACED IN A TARGET PLANE WITH SOLAR LIGHT
6331061	1999	2001	SCIENCE APPLICATIONS INTERNATIONAL CORP	IRRADIANCE REDISTRIBUTION GUIDE
6467916	2001	2002	ARCH DEVELOPMENT CORP	LIGHT TRANSMISSION DEVICE
6541694	2001	2003	DUKE SOLAR ENERGY LLC	NONIMAGING LIGHT CONCENTRATOR WITH UNIFORM IRRADIANCE
6676263	2002	2004	THE UNIVERSITY OF CHICAGO	PERFORMANCE IMPROVEMENTS OF SYMMETRY-BREAKING REFLECTOR STRUCTURES IN NONIMAGING DEVICES
7062913	2000	2006	THE OHIO STATE UNIVERSITY	HEAT ENGINE
7270295	2004	2007	UNIVERSITY OF CALIFORNIA	SOLAR THERMAL AIRCRAFT
7398779	2005	2008	FAFCO INC	THERMOSIPHONING SYSTEM WITH SIDE MOUNTED STORAGE TANKS
7637457	2007	2009	LAWRENCE LIVERMORE NATIONAL SECURITY LLC	RANKINE-BRAYTON ENGINE POWERED SOLAR THERMAL AIRCRAFT
7735323	2008	2010	LAWRENCE LIVERMORE NATIONAL SECURITY LLC	SOLAR THERMAL POWER SYSTEM
7810325	2007	2010	LAWRENCE	SELF-PRESSURIZING

			LIVERMORE NATIONAL SECURITY LLC	STIRLING ENGINE
8132412	2009	2012	LAWRENCE LIVERMORE NATIONAL SECURITY LLC	RANKLINE-BRAYTON ENGINE POWERED SOLAR THERMAL AIRCRAFT
8187731	2010	2012	UNIVERSITY OF COLORADO	METAL FERRITE SPINEL ENERGY STORAGE DEVICES AND METHODS FOR MAKING AND USING SAME
8322092	2009	2012	GS RESEARCH LLC	GEOSOLAR TEMPERATURE CONTROL CONSTRUCTION AND METHOD THEREOF
8344305	2010	2013	UNASSIGNED	SYSTEM AND METHOD FOR ALIGNING HELIOSTATS OF A SOLAR POWER TOWER
8397508	2008	2013	UNIVERSITY OF COLORADO	METAL FERRITE SPINEL ENERGY STORAGE DEVICES AND METHODS FOR MAKING AND USING SAME
8420032	2011	2013	SANDIA CORP	MOVING BED REACTOR FOR SOLAR THERMOCHEMICAL FUEL PRODUCTION
8613204	2010	2013	LAWRENCE LIVERMORE NATIONAL SECURITY LLC	SOLAR-POWERED COOLING SYSTEM
8841548	2011	2014	UCHICAGO ARGONNE LLC	RESONANCE-SHIFTING LUMINESCENT SOLAR CONCENTRATORS
8899044	2011	2014	UNIVERSITY OF CALIFORNIA	SURFACE TENSION MEDIATED CONVERSION OF LIGHT TO WORK
8950392	2009	2015	UNIVERSITY OF CALIFORNIA	SYSTEMS AND METHODS FOR SOLAR ENERGY STORAGE, TRANSPORTATION, AND CONVERSION UTILIZING PHOTOCHEMICALLY ACTIVE ORGANOMETALLIC ISOMERIC COMPOUNDS AND SOLID-STATE CATALYSTS
9025249	2013	2015	UT-BATTELLE LLC	SOLAR CONCENTRATOR WITH INTEGRATED TRACKING AND LIGHT DELIVERY SYSTEM WITH SUMMATION
9032731	2011	2015	WILLIAM MARSH RICE UNIVERSITY	COOLING SYSTEMS AND HYBRID A/C SYSTEMS USING AN ELECTROMAGNETIC RADIATION-ABSORBING COMPLEX
9052452	2013	2015	UT-BATTELLE LLC	SOLAR CONCENTRATOR WITH INTEGRATED TRACKING AND LIGHT DELIVERY SYSTEM WITH

				COLLIMATION
9091466	2013	2015	LAWRENCE LIVERMORE NATIONAL SECURITY LLC	SOLAR-POWERED COOLING SYSTEM
9222665	2011	2015	WILLIAM MARSH RICE UNIVERSITY	WASTE REMEDIATION
9331258	2014	2016	COLORADO SCHOOL OF MINES	SOLAR THERMOELECTRIC GENERATOR
9383120	2015	2016	UNASSIGNED	SOLAR THERMAL CONCENTRATOR APPARATUS, SYSTEM, AND METHOD
9459024	2014	2016	MASSACHUSETTS INSTITUTE OF TECHNOLOGY	LOCALIZED SOLAR COLLECTORS
9499699	2015	2016	SANDIA CORP	HIGH DURABILITY SOLAR ABSORPTIVE COATING AND METHODS FOR MAKING SAME
9545458	2015	2017	WILLIAM MARSH RICE UNIVERSITY	WASTE REMEDIATION
9586190	2014	2017	SANDIA CORP	THERMAL SWING REACTOR INCLUDING A MULTI-FLIGHT AUGER
9624911	2013	2017	SUNFOLDING LLC	FLUIDIC SOLAR ACTUATOR
9650556	2013	2017	SOUTHWEST RESEARCH INSTITUTE	ENCAPSULATION OF HIGH TEMPERATURE MOLTEN SALTS
9657966	2009	2017	SOLARRESERVE	SINGLE BI-TEMPERATURE THERMAL STORAGE TANK FOR APPLICATION IN SOLAR THERMAL PLANT
9669379	2012	2017	UNIVERSITY OF FLORIDA	SOLAR THERMOCHEMICAL REACTOR, METHODS OF MANUFACTURE AND USE THEREOF AND THERMOGRAVIMETER
9739473	2010	2017	WILLIAM MARSH RICE UNIVERSITY	ELECTRICITY GENERATION USING ELECTROMAGNETIC RADIATION
9787247	2014	2017	SHARP LABORATORIES OF AMERICA INC	SOLAR CONCENTRATOR WITH ASYMMETRIC TRACKING-INTEGRATED OPTICS
9821475	2013	2017	OTHER LAB LLC	ROBOTIC ACTUATOR
9874735	2014	2018	UCHICAGO ARGONNE LLC	RESONANCE-SHIFTING LUMINESCENT SOLAR CONCENTRATORS
9879884	2015	2018	UT-BATTELLE LLC	SELF-CALIBRATING SOLAR POSITION SENSOR

9929690	2014	2018	MASSACHUSETTS INSTITUTE OF TECHNOLOGY	SPECTRALLY-ENGINEERED SOLAR THERMAL PHOTOVOLTAIC DEVICES
10001298	2015	2018	NATIONAL TECHNOLOGY & ENGINEERING SOLUTIONS OF SANDIA LLC	METHODS FOR OPERATING SOLAR-THERMOCHEMICAL PROCESSES
10035121	2017	2018	NATIONAL TECHNOLOGY & ENGINEERING SOLUTIONS OF SANDIA LLC	THERMAL SWING REACTOR INCLUDING A MULTI-FLIGHT AUGER
10036878	2015	2018	L'GARDE INC	LIGHTWEIGHT, LOW-COST HELIOSTAT MIRROR FOR CONCENTRATING SOLAR POWER
10072224	2014	2018	UNIVERSITY OF FLORIDA	SOLAR THERMOCHEMICAL REACTOR AND METHODS OF MANUFACTURE AND USE THEREOF
10107268	2015	2018	NATIONAL TECHNOLOGY & ENGINEERING SOLUTIONS OF SANDIA LLC	THERMAL ENERGY STORAGE AND POWER GENERATION SYSTEMS AND METHODS
10239035	2016	2019	UNIVERSITY OF FLORIDA	SOLAR THERMOCHEMICAL REACTOR, METHODS OF MANUFACTURE AND USE THEREOF AND THERMOGRAVIMETER
10345008	2016	2019	UNASSIGNED	SOLAR THERMAL CONCENTRATOR APPARATUS, SYSTEM, AND METHOD
10352589	2015	2019	UNASSIGNED	SOLAR THERMAL CONCENTRATOR APPARATUS, SYSTEM, AND METHOD
10384354	2017	2019	SUNFOLDING LLC	FLUIDIC SOLAR ACTUATOR
10505496	2017	2019	SHARP LABORATORIES OF AMERICA INC	ASYMMETRIC TRACKING-INTEGRATED OPTICS FOR SOLAR CONCENTRATION
EP0030553	1980	1981	ATLANTIC RICHFIELD CO	HEAT PUMP INCLUDING COMPRESSOR HAVING LOW PRESSURE RATIO APPLICATION.
EP1007890	1998	2000	ARCH DEVELOPMENT CORP	SOLAR COLLECTOR
EP2139766	2008	2010	LAWRENCE LIVERMORE NATIONAL	RANKINE-BRAYTON ENGINE POWERED SOLAR THERMAL AIRCRAFT

			SECURITY LLC	
EP2212662	2008	2010	UNIVERSITY OF COLORADO	METAL FERRITE SPINEL ENERGY STORAGE DEVICES AND METHODS FOR MAKING AND USING SAME
EP2513571	2010	2012	WILLIAM MARSH RICE UNIVERSITY	ELECTRICITY GENERATION USING ELECTROMAGNETIC RADIATION
EP2619512	2011	2013	UNASSIGNED	SOLAR THERMAL CONCENTRATOR APPARATUS, SYSTEM, AND METHOD
EP2794086	2012	2014	UNIVERSITY OF FLORIDA	SOLAR THERMOCHEMICAL REACTOR, METHODS OF MANUFACTURE AND USE THEREOF AND THERMOGRAVIMETER
EP3129725	2015	2017	L'GARDE INC	LIGHTWEIGHT, LOW COST HELIOSTAT MIRROR FOR CONCENTRATING SOLAR POWER
WO1980002870	1980	1980	ATLANTIC RICHFIELD CO	HEAT PUMP INCLUDING COMPRESSOR HAVING LOW PRESSURE RATIO APPLICATIONS
WO1999005462	1998	1999	ARCH DEVELOPMENT CORP	NONTRACKING SOLAR CONCENTRATORS
WO2000079203	2000	2000	THE UNIVERSITY OF DAYTON	HEAT STORAGE SYSTEM UTILIZING PHASE CHANGE MATERIALS
WO2001044658	2000	2001	THE OHIO STATE UNIVERSITY	HEAT ENGINE
WO2002075225	2002	2002	DUKE SOLAR ENERGY LLC	NONIMAGING SOLAR CONCENTRATOR WITH UNIFORM IRRADIANCE
WO2006105430	2006	2006	FAFCO INC	SOLAR WATER HEATER
WO2008121774	2008	2008	LAWRENCE LIVERMORE NATIONAL SECURITY LLC	RANKINE-BRAYTON ENGINE POWERED SOLAR THERMAL AIRCRAFT
WO2009061795	2008	2009	UNIVERSITY OF COLORADO	METAL FERRITE SPINEL ENERGY STORAGE DEVICES AND METHODS FOR MAKING AND USING SAME
WO2009102510	2009	2009	LAWRENCE LIVERMORE NATIONAL SECURITY LLC	SOLAR THERMAL POWER SYSTEM
WO2010009052	2009	2010	UNIVERSITY OF CALIFORNIA	SYSTEMS AND METHODS FOR SOLAR ENERGY STORAGE, TRANSPORTATION, AND CONVERSION
WO2011059681	2010	2011	GS RESEARCH LLC	GEOSOLAR TEMPERATURE CONTROL CONSTRUCTION

				AND METHOD THEREOF
WO2011146093	2010	2011	WILLIAM MARSH RICE UNIVERSITY	ELECTRICITY GENERATION
WO2012040663	2011	2012	UNASSIGNED	SOLAR THERMAL CONCENTRATOR APPARATUS, SYSTEM, AND METHOD
WO2013096813	2012	2013	UNIVERSITY OF FLORIDA	SOLAR THERMOCHEMICAL REACTOR, METHODS OF MANUFACTURE AND USE THEREOF AND THERMOGRAVIMETER
WO2014200975	2014	2014	UNIVERSITY OF FLORIDA	SOLAR THERMOCHEMICAL REACTOR AND METHODS OF MANUFACTURE AND USE THEREOF
WO2015035271	2014	2015	MASSACHUSETTS INSTITUTE OF TECHNOLOGY	LOCALIZED SOLAR COLLECTORS
WO2015116268	2014	2015	MASSACHUSETTS INSTITUTE OF TECHNOLOGY	SPECTRALLY-ENGINEERED SOLAR THERMAL PHOTOVOLTAIC DEVICES
WO2015156941	2015	2015	L'GARDE INC	LIGHTWEIGHT, LOW COST HELIOSTAT MIRROR FOR CONCENTRATING SOLAR POWER

An Analysis of the Influence of SETO-funded Concentrating Solar Power Patents

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