The Influence of Algae Patents Funded by the U.S. Department of Energy's Bioenergy 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 algae research funded by the U.S. Department of Energy (DOE)'s Bioenergy Technologies Office (BETO) and its precursor programs, as well as algae 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 main purpose of the backward tracing is to determine the extent to which BETO-funded algae research has formed a foundation for innovations patented by leading algae organizations. Meanwhile, the primary purpose of the forward tracing is to examine the broader influence of BETO-funded algae research upon subsequent technological developments, both within and outside algae technology. In addition to these BETO-based analyses, we also extend many elements of the analysis to other DOE-funded algae patents, in order to gain insights into their influence.

The main finding of this report is:

- Algae research funded by BETO, and by DOE in general, has had a significant influence on subsequent developments, both within and beyond algae technology. This influence can be seen upon innovations associated with the leading algae organizations. It can also be traced in other technologies, notably waste water treatment, power generation and carbon dioxide sequestration.

More detailed findings from this report include:

- In algae technology, in the period 1976-2018, we identified a total of 4,136 patents (1,333 U.S. patents, 988 EPO patents and 1,815 WIPO patents). We grouped these patents into 2,365 patent families, where each family contains all patents resulting from the same initial application (named the priority application).

- 74 algae patents are confirmed to be associated with BETO funding (53 U.S. patents, 6 EPO patents, and 15 WIPO patents). We grouped these BETO-funded algae patents into 42 patent families.

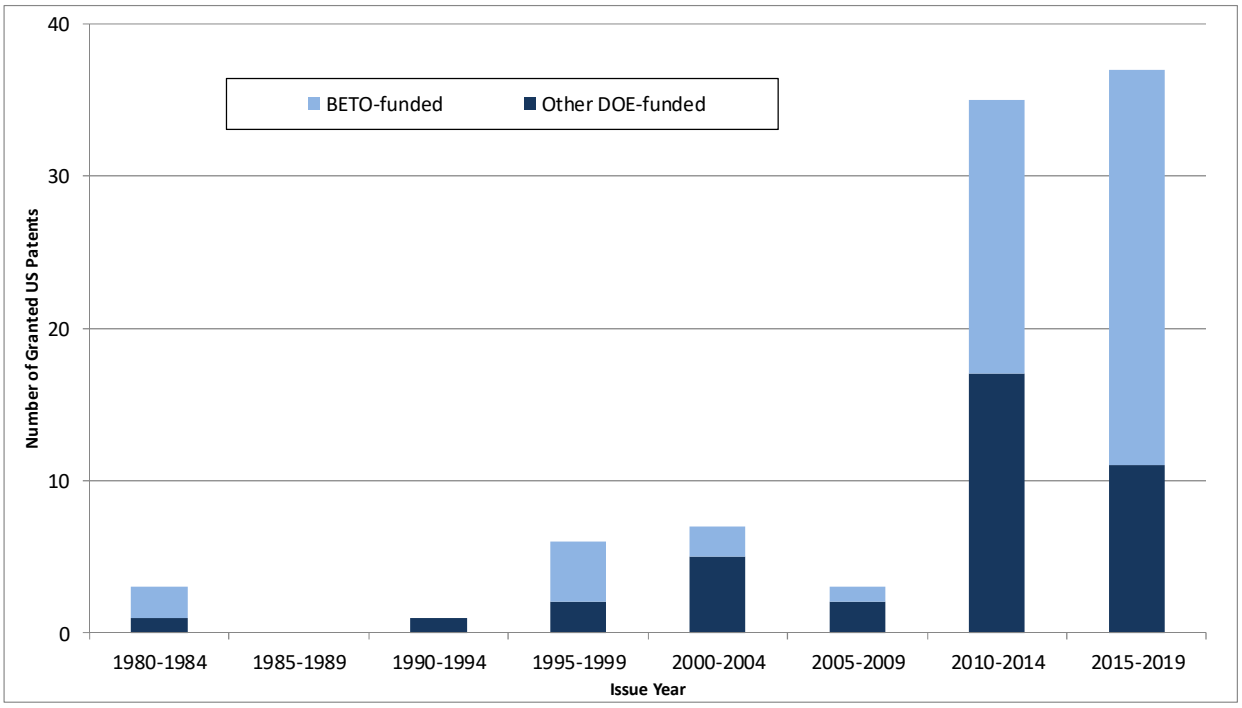
- In addition, we identified a further 60 algae patents (39 U.S. patents, 6 EPO patents and 15 WIPO patents) that are associated with DOE funding. These "Other DOE-funded" patents are grouped into 34 patent families.

- Out of these 34 Other DOE-funded patent families, 32 are definitely not BETO-funded. These patent families were either funded by a different DOE office, or were marked as being not BETO-funded by inventors or BETO technology managers, but without specifying funding from another DOE source. The funding source within DOE could not be determined for the remaining two Other DOE-funded patent families.

- The total number of DOE-funded algae patents (BETO-funded plus Other DOE-funded) is 134, corresponding to 76 patent families. This represents 3.2% of the total number of algae patent families in the period 1976-2018.

- Figure E-1 shows the number of BETO-funded and Other DOE-funded algae U.S. patents by issue year. This figure reveals that there was relatively little activity in the early time periods, with two BETO-funded and two Other DOE-funded patents issued through 1994. The number of patents then increased slightly in the periods through 2009, before increasing sharply from 2010 onwards. There were 35 DOE-funded algae U.S. patents issued in 2010-2014, 18 of which were BETO-funded. In 2015-2019 these numbers increased again to 37 DOE-funded patents (26 BETO-funded), even though data for this most recent time period are incomplete (see note below Figure E-1).

Figure E-1 - Number of BETO/Other DOE-funded Algae Granted U.S. Patents by Issue Year (5-Year Totals)



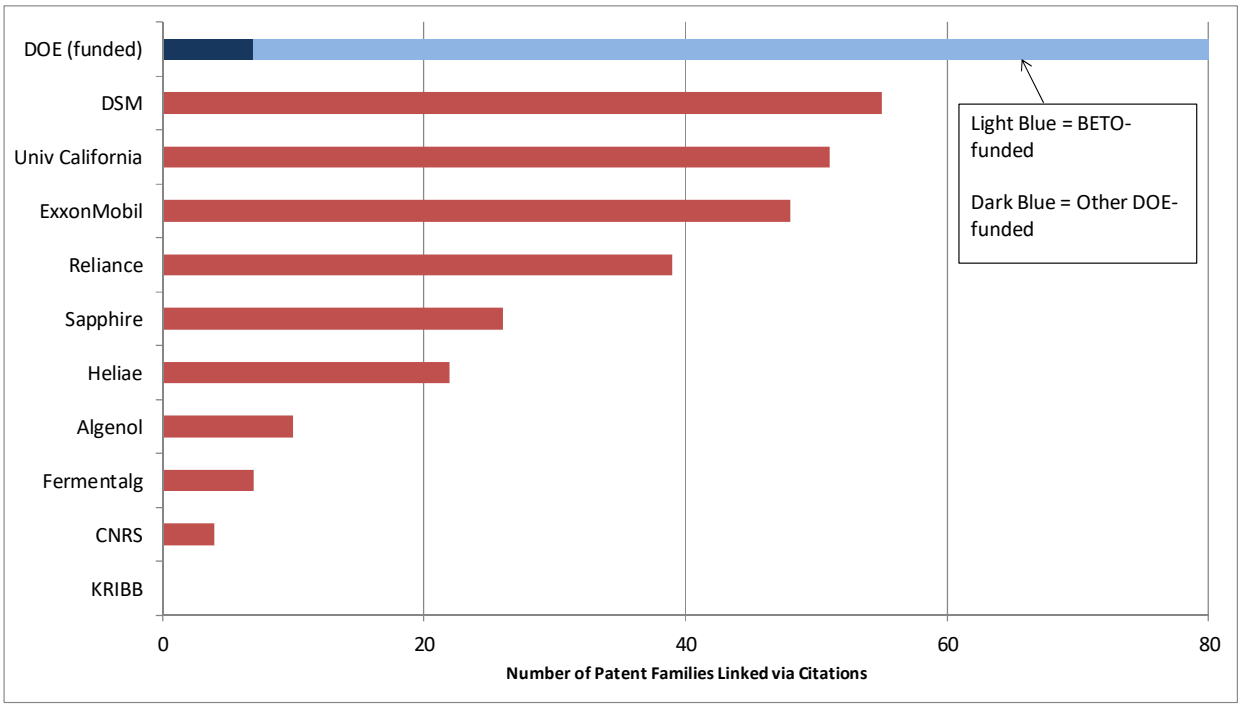
Note: The data collection period for this analysis ended with 2018. Any 2019 patents in the 2015-2019 column are additional patents that have been included because they are members of the same patent families as pre-2019 patents. No new patent search for 2019 was carried out.

- The ten organizations with the largest algae patent portfolios are: Heliae Development (39 patent families); Reliance Industries (36); ExxonMobil (34); Sapphire Energy (32); University of California (27); Centre National De La Recherche Scientifique – CNRS (22); Royal DSM (20); Korea Research Institute of Bioscience & Biotechnology – KRIBB (20); Fermentalg (19); and Algenol Biotech (19). The portfolio of 76 DOE-funded algae patent families (42 BETO-funded and 34 Other DOE-funded) is thus larger than the portfolios of each of the leading organizations.

- Taking the period 1976-2018 as a whole, BETO-funded and Other DOE-funded algae patents are contained primarily in patent classifications related to photobioreactors, unicellular algae, ethanol production and cell lysis. The leading algae organizations also have a notable presence in patent classifications related to photobioreactors and unicellular algae. They have less of a presence in classifications concerned with cell lysis and ethanol production. This difference in focus suggests that BETO-funded algae research has helped to fill a gap not addressed extensively by the leading organizations.

- Figure E-2 reveals that 80 leading organization algae patent families (i.e. 30% of these 267 families) are linked via citations to earlier DOE-funded algae patents, out of which 74 are linked to BETO-funded algae patents. This puts DOE at the head of Figure E-2, and means that more leading organization algae patent families are linked to earlier DOE-funded algae patents than are linked to the algae patents of any other leading organization. As such, it suggests that the leading organizations have built extensively on DOE-funded, and particularly BETO-funded, algae patents.

Figure E-2 - Number of Leading Organization Algae Patent Families Linked via Citations to Earlier Algae Patents from each Leading Organization
e.g. 80 leading organization families are linked to earlier BETO/Other DOE-funded families



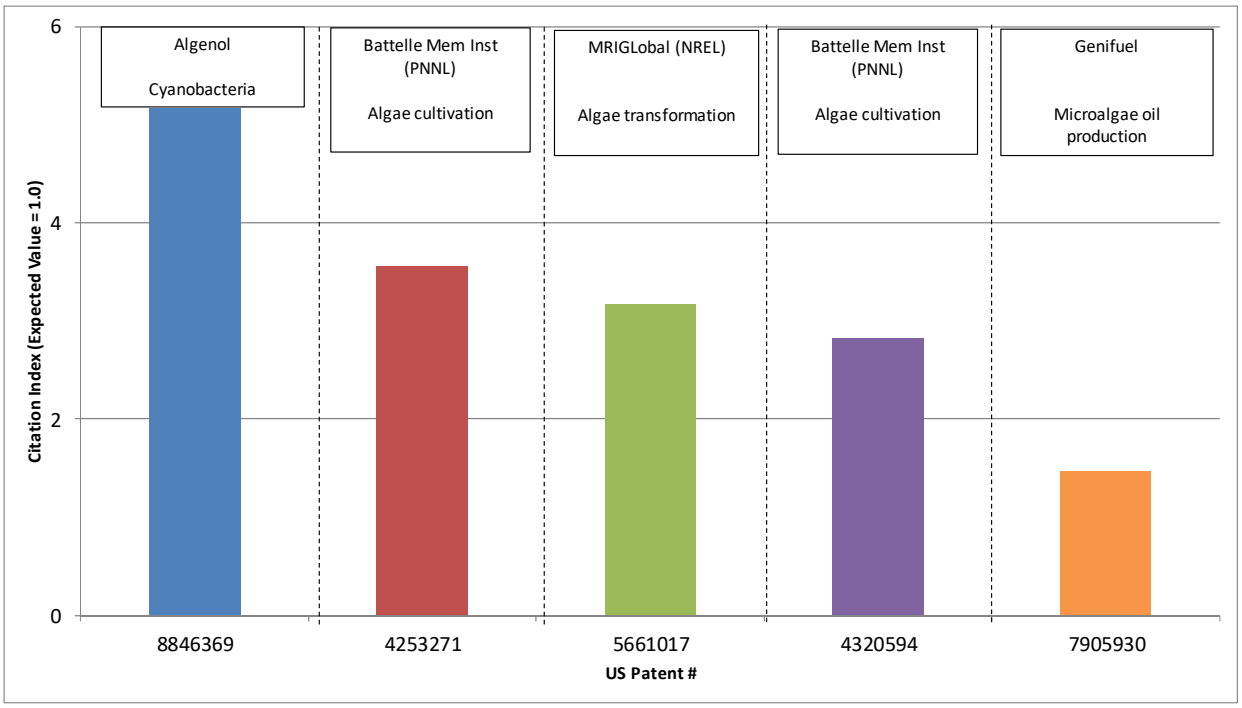
- Over half of Reliance's and Heliae's algae patent families are linked via citations to earlier BETO-funded algae patents. DSM, Algenol and ExxonMobil also have extensive citation links to BETO-funded patents. This suggests that BETO-funded research has had a particularly strong influence on innovations from these organizations.

- BETO-funded algae patents have an average Citation Index value of 1.19 (the Citation Index is a normalized citation metric with an expected value of 1.0; a value of 1.19 shows

that, based on their age and technology, BETO-funded algae patents have been cited as prior art 19% more frequently than expected by subsequent patents). The Citation Index for Other DOE-funded algae patents is similar at 1.18, showing that these patents have been cited 18% more frequently than expected. The influence of BETO-funded and Other DOE-funded algae patents can be seen extensively within algae technology. It can also be traced in other technologies such as waste water treatment, power generation and carbon dioxide sequestration.

- There are a number of individual high-impact BETO-funded algae patents, examples of which are shown in Figure E-3. They include an Algenol patent describing the genetic enhancement of cyanobacteria, which can be used in biofuel production; Battelle Memorial Institute (Pacific Northwest National Laboratory) patents for algae cultivation; an MRIGlobal (National Renewable Energy Laboratory) patent for algae transformation; and a Genifuel patent describing the production of biofuels from microalgae.

Figure E-3 – Examples of Highly-Cited BETO-funded Algae Patents



1.0 Introduction

This report focuses on algae technology. Its objective is to trace the influence of algae research funded by the Department of Energy (DOE) Bioenergy Technologies Office (BETO) – as well as algae research funded by DOE as a whole – upon subsequent developments both within and outside algae technology. The purpose of the report is to:

(i) Locate patents awarded for key BETO-funded (and other DOE-funded) innovations in algae technology; and

(ii) Determine the extent to which BETO-funded (and other DOE-funded) algae research has influenced subsequent technological developments both within and beyond algae.

The primary focus of the report is on the influence of BETO-funded algae patents. That said, we also extend many elements of the analysis to DOE-funded algae patents that could not be definitively linked to BETO 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 BETO itself upon the development of algae technology, while also tracing the influence of DOE more generally. Meanwhile, in practical terms, determining which patents were funded by BETO, 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 reported 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. For older patents, such information is often unavailable, because 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 BETO-funded, we instead included these patents in the analysis under a separate “Other DOE-funded” category.

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 BETO-funded and Other DOE-funded patents. These results show the distribution of BETO-funded (and Other DOE-funded) patents across algae technologies (as defined by Cooperative Patent Classifications). They also evaluate the extent of BETO’s influence (and DOE’s influence in general) on subsequent developments in algae and other technologies. Patent level results are then presented to highlight individual BETO-funded algae patents that have been

particularly influential, as well as to reveal key patents from other organizations that build extensively on BETO-funded algae research.[1]

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, along with 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 algae industry have used BETO-funded research as a foundation. Meanwhile, the primary purpose of the forward tracing is to examine how BETO-funded algae patents influenced subsequent developments more broadly, both within and outside algae 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 algae organizations.[2]

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 linkages between DOE-funded algae research and subsequent innovations. Examining all of these linkage types at the 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.

[1] 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.

[2] The analyses described in this report were carried out separately for BETO-funded and Other DOE-funded algae patents. However, referring repeatedly to "BETO-funded/Other DOE-funded patents" or "BETO-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.

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.[3]

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.

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 algae research. Specifically, we identify cases where patents cite DOE-funded algae 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 algae patents. These represent second-generation links between innovations and DOE-funded research. The idea behind this analysis is that the later patents build in some way on the earlier DOE-funded algae research. By determining how frequently DOE-funded algae 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 innovations both within and beyond algae technology.

Forward and Backward Tracing

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

[3] 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.

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 algae 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 algae organizations build on earlier BETO-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 algae patents resulting from research funded by DOE (i.e. BETO plus Other DOE). The influence of these patents on later generations of technology is then evaluated. This tracing is not restricted to subsequent algae patents, since the influence of a body of research may extend beyond its immediate technology. Hence, the forward tracing element of the project evaluates the influence of DOE-funded algae 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.[4] The backward tracing starts with patents assigned to the leading patenting organizations in algae 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 algae patents owned by leading organizations in this technology, and traces back through two generations of patents to identify the technologies upon which they were built, including those funded by DOE. Meanwhile, the forward tracing starts with DOE-funded patents in algae 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. Hence, the analysis starts with DOE-funded algae 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 algae patents; and backward through two generations starting from the patents owned by leading algae 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 algae patent as prior art.
2. **Indirect Links**: where a patent cites an earlier patent, which in turn cites a DOE-funded algae patent. The DOE patent is linked indirectly to the subsequent patent.

[4] As noted above, the forward and backward tracing were carried out separately for BETO-funded and Other DOE-funded algae 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 algae patents as a single portfolio.

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. That said, 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. 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.

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, an organization may file to protect a given invention in the U.S., China, Germany, Japan and many other countries. This results in multiple patent documents for the same invention.[5] In addition, in some systems – notably the U.S. – inventors may apply for a series of patents based on one 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 algae patents, and also for the patents owned by leading algae organizations. We also assembled families for all patents linked via citations to DOE-funded algae patents. To construct these 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.

[5] 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
• No. of BETO/Other DOE-funded algae patent families by year of priority application
• No. of BETO/Other DOE-funded granted U.S. algae patents by issue year
• Overall number of algae patent families by priority year
• Percentage of algae patents families funded by BETO/Other DOE by priority year
Assignee Metrics
• Number of algae patent families for leading patenting organizations
• Assignees with largest number of algae patent families funded by BETO/Other DOE
Technology Metrics
• Patent classification (CPC) distribution for BETO-funded algae patent families (vs Other DOE-funded, leading algae organizations, all algae)
Backward Tracing Metrics
• Total/Average number of leading organization algae patent families linked via citations to earlier patent families from BETO/Other DOE-funding and other leading organizations
• Number of algae patent families for each leading organization linked via citations to earlier BETO/Other DOE-funded patent families
• Total citation links from each leading organization to BETO/Other DOE-funded patent families
• Percentage of leading organization algae patent families linked via citations to earlier BETO/Other DOE-funded patent families
• BETO/Other DOE-funded algae patent families linked via citations to largest number of leading organization algae patent families
• Leading organization algae patent families linked via citations to largest number of BETO-funded algae patent families
• Highly cited leading organization algae patent families linked via citations to earlier BETO-funded algae patent families
Forward Tracing Metrics
• Citation Index for algae patent portfolios owned by leading organizations, plus portfolios of BETO/Other DOE-funded algae patents
• Number of patent families linked via citations to BETO/Other DOE-funded algae patents by patent classification
• Organizations (beyond leading algae organizations) linked via citations to largest number of BETO/Other DOE-funded algae patent families
• Highly cited BETO-funded algae U.S. patents
• BETO/Other DOE-funded algae patent families linked via citations to largest number of subsequent algae/non-algae patent families
• Highly cited patents (not leading organization-owned) linked via citations to BETO-funded algae patents

3.0 Methodology

The previous section of the report outlines the objective of our analysis – that is, to determine the influence of BETO-funded (and Other DOE-funded) algae research on subsequent developments both within and outside algae 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 backward tracing starts from the set of all algae patents owned by leading patenting organizations in this technology. Meanwhile, the forward tracing starts from the sets of algae patents funded by BETO and Other DOE. We therefore had to define various data sets – BETO-funded algae patents; Other DOE-funded algae patents; and algae patents assigned to the leading organizations in this technology.

Identifying BETO-funded and Other DOE-funded Algae Patents

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

(i) Defining the universe of DOE-funded patents;
(ii) Determining which of these DOE-funded patents are relevant to algae technology;
(iii) Categorizing these DOE-funded algae patents according to whether or not they can be linked definitively to BETO 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 resulting 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 may 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 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 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 is a legacy code listed on a number of 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 any additional DOE funded patents in the database.

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

Identifying DOE-Funded Algae Patents

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

Filter B OR Filter C OR Filter D OR Filter E), so patents that qualify under any of the five filters in Table 2 were included in the initial patent set.

Table 2 – Filters Used to Identify DOE-funded Algae Patents

Filter A
Cooperative Patent Classification
C12N 1/12 – Unicellular algae
C12N 1/125 – Unicellular algae isolates
Filter B
Cooperative Patent Classification
A01G 33/00 – Algae/seaweed cultivation
NOT
Title/Abstract
sea(-)weed*
Filter C
Cooperative Patent Classification
C12* - Biochemistry and microbiology
AND
Title/Abstract
alga* or micro(-)alga* or macro(-)alga* or cyano(-)bact*
Filter D
Title/Abstract
(algae or algal or micro(-)alga* or macro(-)alga* or cyano(-)bact*) AND (biomass* or fuel* or bio(-)fuel* or ethanol* or bio(-)diesel* or bio(-)reactor*)
Filter E
Title/Abstract
algae or algal or micro(-)alga* or macro(-)alga* or cyano(-)bact*
NOT
(Title/Abstract
biofoul* or foul* or contamin* or pollut* or inhibit* or cosmetic* or medic* or immun* or food* or diet* or animal* or fish*
OR
Cooperative Patent Classification
A61* - Medical/veterinary science
A01N* - Preservation of human/animal bodies
C02F* - Treatment of waste water
A21* - Baking
A23* - Food)

***** Wildcard representing unlimited characters; (-) Wildcard for zero or one character, including a space

We manually checked this initial list of patents to determine which of them appear relevant to algae, and then sent the resulting patent list to BETO for review. Following this review, and

based on feedback from BETO, the initial list of algae patents funded by DOE contained a total of 85 granted U.S. patents.

Defining BETO-funded vs. Other DOE-funded Algae 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 85 DOE-funded algae patents in the initial list could be linked definitively to BETO 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 BETO technology managers to verify individual patents,
(iv) Asking BETO 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 BETO, 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 BETO-funded and Other DOE-funded Algae Patents

Based on the process described above, we divided the initial list of 85 DOE-funded algae U.S. patents into two categories – BETO-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. 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 BETO-funded and Other DOE-funded algae patents and patent families. These DOE-funded portfolios include patent families back to the late-1970s, although most of the families are much more recent.

Table 3 – No. of BETO-funded and Other DOE-funded Algae Patents and Patent Families

	# Patent Families	# U.S. Patents	# EPO Patents	# WIPO Patents
BETO-funded	42	53	6	15
Other DOE-funded	34	39	6	15
Total DOE-funded	76	92	12	30

Table 3 shows that we identified a total of 42 BETO-funded algae patent families, containing 53 U.S. patents, 6 EPO patents, and 15 WIPO patents (see Appendix A for patent list). We also identified 34 Other DOE-funded algae patent families, containing 39 U.S. patents, 6 EPO patents, and 15 WIPO patents (see Appendix B for patent list). Out of these 34 Other DOE-funded patent families, 32 are definitely not BETO-funded, while the funding source within DOE could not be determined for the other two families.

Identifying Algae Patents Assigned to Leading Organizations

The backward tracing element of our analysis is designed to evaluate the influence of BETO-funded (and Other DOE-funded) research on algae innovations produced by leading organizations in this technology. To identify such organizations, we first defined the universe of algae patents in the period 1976-2018 using the patent filter detailed earlier in Table 2. Based on this filter, we identified a total of 1,333 algae U.S. patents, 988 algae EPO patents, and 1,815 algae WIPO patents. We grouped these patents into 2,365 patent families by matching priority documents.

We then located the most prolific patenting organizations in this overall algae patent universe, based on number of patent families. The ten organizations with the largest number of algae patent families are shown in Table 4.[6] The number of patent families listed in this table includes all variant names under which these organizations have patents, taking into account including all subsidiaries and acquisitions.

Table 4 – Top 10 Patenting Algae Organizations

Organization	# Algae Patent Families
Heliae Development	39
Reliance Industries	36
ExxonMobil	34
Sapphire Energy	32
University of California	27
Centre National De La Recherche Scientifique (CNRS)	22
Royal DSM	20
Korea Research Institute of Bioscience & Biotechnology (KRIBB)	20
Fermentalg	19
Algenol Biotech	19

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 algae technology. The patent sets for the forward tracing consisted of BETO-funded (and, separately, Other DOE-funded) algae patent families. We then traced backward through two generations of citations from the leading organizations' algae patents, and forward through two generations of citations from the BETO/Other DOE-funded algae 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.

[6] These organizations are selected based on patent portfolio size, which does not necessarily reflect units sold, revenues etc. A fuller description would be the leading patenting algae organizations, but this is a cumbersome term to use throughout the results section of the report.

4.0 Results

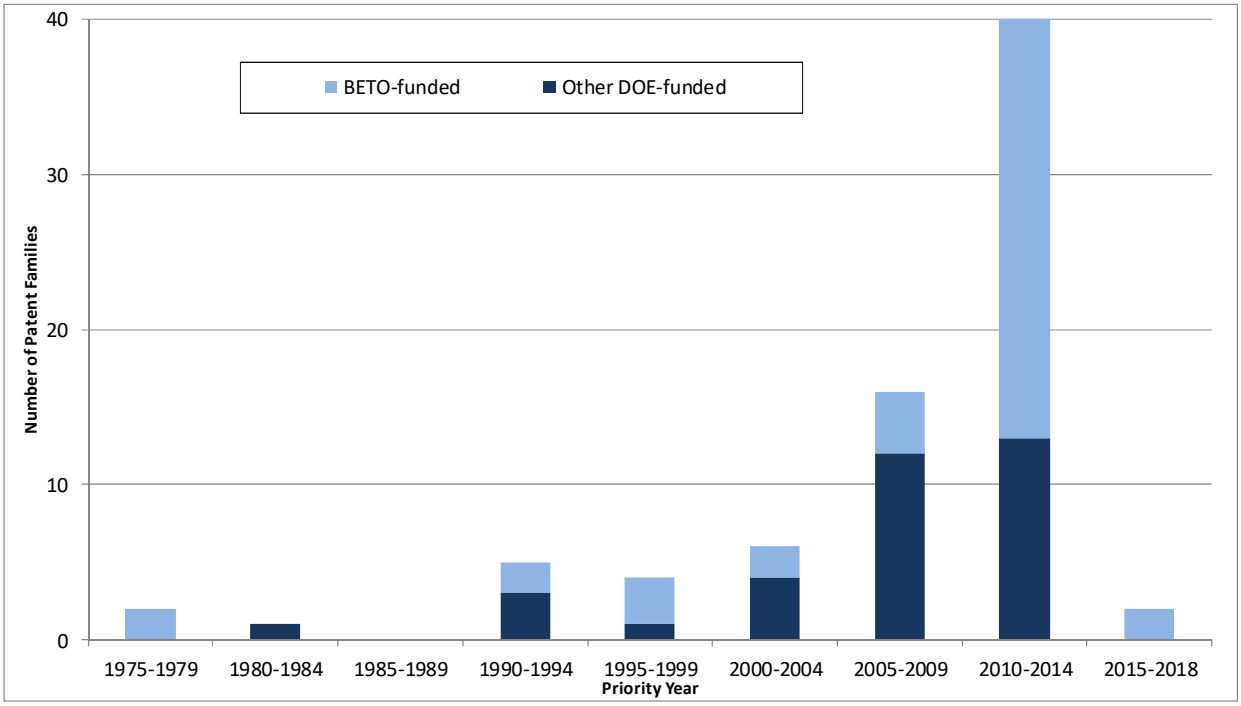
This section of the report outlines the results of our analysis tracing the influence of BETO-funded and Other DOE-funded algae research on subsequent developments both within and beyond algae technology. The results are divided into three main sections. In the first section, we examine trends in algae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

Overall Trends in Algae Patenting

Trends in Algae Patenting over Time

Figure 1 shows the number of BETO-funded and Other DOE-funded algae patent families by priority year – i.e. the year of the first application in each patent family. BETO-funded patent families are shown in light blue and Other DOE-funded families in dark blue.

Figure 1 - Number of BETO/Other DOE-funded Algae Patent Families by Priority Year (5-Year Totals)

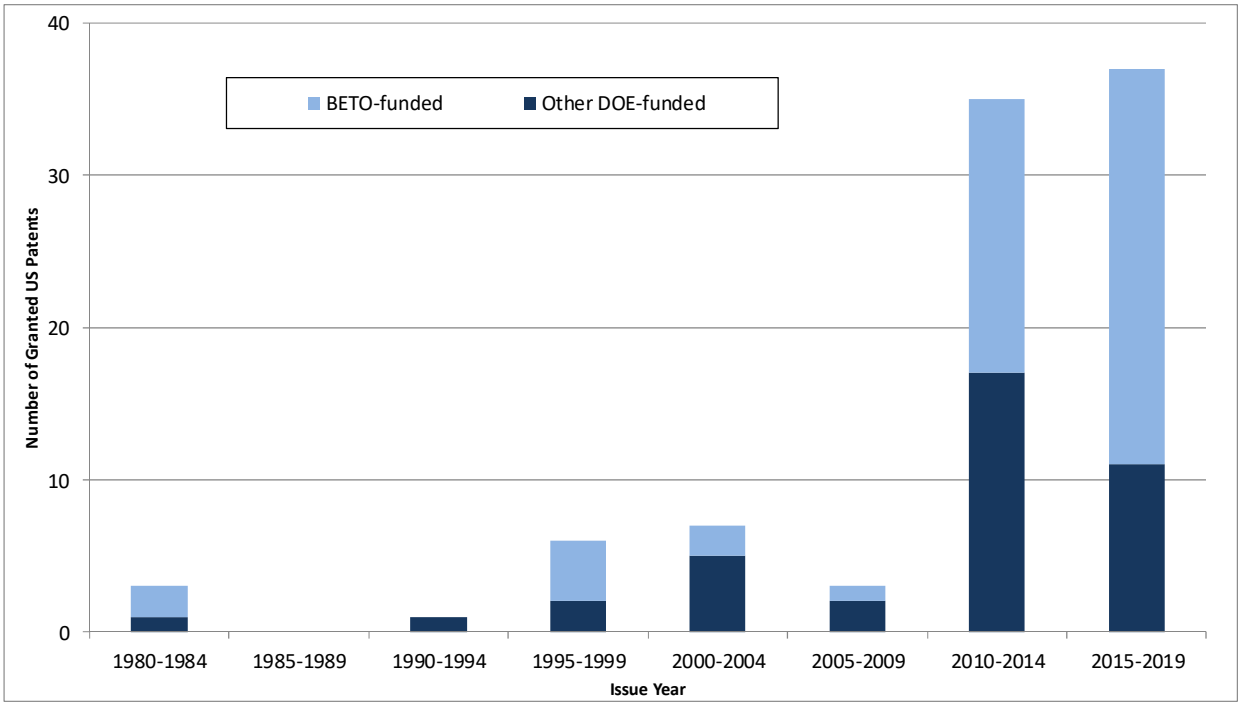


Note: The final time period in this figure is 2015-2018, and is shown for completeness, although data for this time period are incomplete. Our primary data collection covered only patents issued through 2018. Due to time lags associated with the patenting process, only a fraction of the patent families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

This figure reveals that there was very little DOE-funded algae patenting in the earliest periods in the analysis, with a total of only three patent families filed through 1989 (two of them funded by BETO). There was then a slight increase in activity, with five DOE-funded algae patent families in 1990-1994 (two of which were BETO-funded), four in 1995-1999 (three BETO-funded), and six in 2000-2004 (two BETO-funded). The number of DOE-funded patent families then increased markedly, to 16 in 2005-2009 (four BETO-funded), before peaking at 40 (27 BETO-funded) in 2010-2014. The number of DOE-funded patent families fell sharply in 2015-2018, but data for this time period are incomplete (see note below Figure 1). Overall, there are 76 DOE-funded algae patent families, 42 of which are BETO-funded.

Figure 2 shows the number of algae granted U.S. patents funded by DOE in each time period. This figure follows a similar trend to Figure 1. There is relatively little activity in the early time periods, with two BETO-funded and two Other DOE-funded patents issued through 1994. The number of patents then increased slightly in the periods through 2009, before increasing sharply from 2010 onwards. There were 35 DOE-funded algae U.S. patents issued in 2010-2014, 18 of which were BETO-funded. In 2015-2019 these numbers increased again to 37 DOE-funded patents (26 BETO-funded), even though data for this most recent time period are incomplete (see note below Figure 2).

Figure 2 - Number of BETO/Other DOE-Funded Algae Granted U.S. Patents by Issue Year (5-Year Totals)

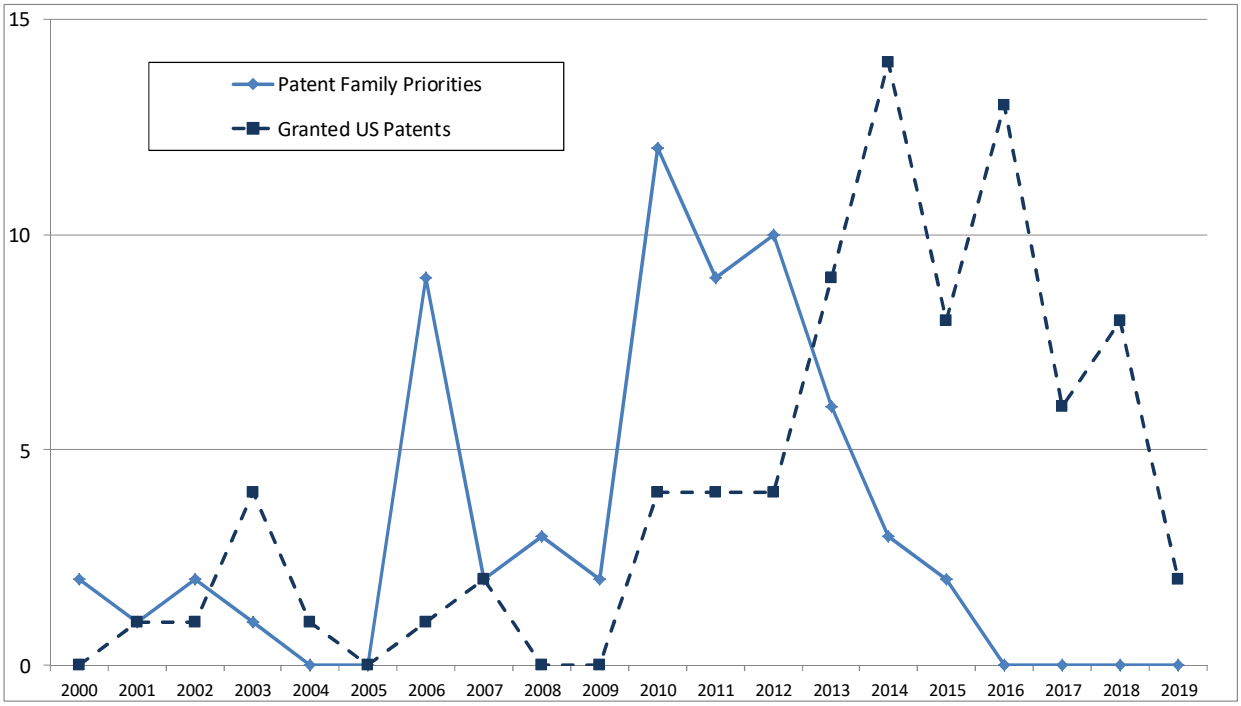


Note: The data collection period for this analysis ended with 2018. Any 2019 patents in the 2015-2019 column are additional patents that have been included because they are members of the same patent families as pre-2019 patents. No new patent search for 2019 was carried out.

Comparing Figures 1 and 2 shows the effect of time lags in the patenting process, with many of the patent families with priority dates in 2005-2009 and 2010-2014 (Figure 1) resulting in granted U.S. patents in 2010-2014 and 2015-2019 (Figure 2). These time lags can also be seen in

Figure 3, which shows algae patent family priority years alongside issue years for granted U.S. algae patents (in order to simplify the presentation, this figure focuses on the period from 2000 onwards, and data for BETO and Other DOE are combined). In this figure, the peaks in patent family filings occurred in 2010-2012, with subsequent peaks in granted U.S. patents occurring in 2013-2016. Note that, due to the primary data collection for this analysis ending in 2018, the number of U.S. patents declines sharply in 2019 and the number of families is zero.

Figure 3 - Number of DOE-funded Algae Patent Families (by Priority Year) and Granted U.S. Patents (by Issue Year)



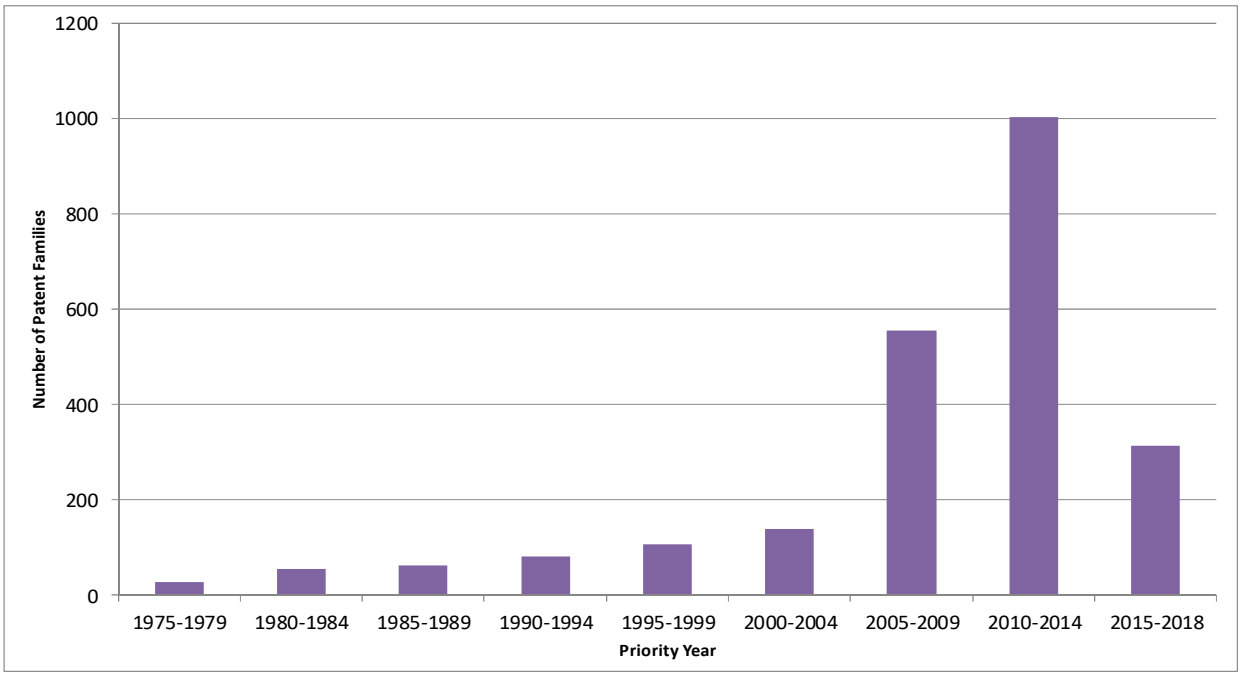
Note: The data collection period for this analysis ended with 2018. Any 2019 patents are additional patents that have been included because they are members of the same patent families as pre-2019 patents. No new patent search for 2019 was carried out.

Figures 1-3 focus on DOE-funded algae patent families. Figure 4 broadens the scope, and shows the overall number of algae patent families by priority year (based on USPTO, EPO, and WIPO filings). In the earliest time periods, there was relatively little patent activity in algae technology, with fewer than 100 patent families in each 5-year period through 1994. The number of algae patent families then grew slowly through 2004, before increasing sharply to 563 families in 2005-2009 and 1,007 families in 2010-2014 (i.e. almost ten times as many algae patent families were filed in 2010-2014 as in 1990-1994). The number of patent families declined to 312 in 2015-2018, although data for this time period are incomplete. Comparing Figure 4 with Figure 1 suggests that the trend in DOE-funded (and BETO-funded) algae patenting is in line with the broader trend in this technology. Both figures show relatively little patent activity throughout the earliest years, before a sharp increase from 2005 onwards.

Figure 5 shows the percentage of algae patent families that were funded by DOE (BETO plus Other DOE) in each time period. In most of the time periods, these percentages are not particularly robust, since they are based on low numbers of patents (e.g. 7% of patent families in 1975-1979 were funded by BETO, but this is two out of 28 families). Of more interest are the

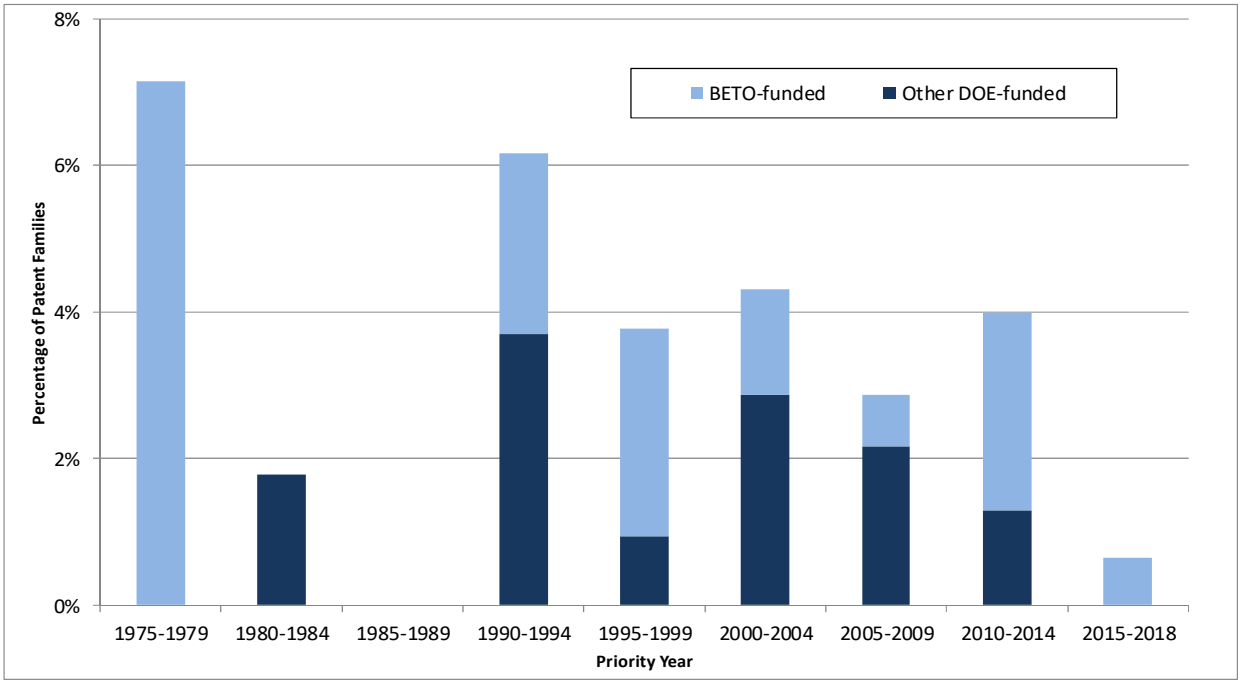
recent time periods, where the numbers of patents are higher. For example, in 2005-2009, 2.9% of the 563 patent families are DOE-funded (with 0.7% BETO-funded), while in 2010-2014, 4% of families are DOE funded (with 2.7% BETO-funded). Overall, 3.2% of algae patent families filed in 1976-2018 were funded by DOE (1.8% by BETO).

Figure 4 - Total No. of Algae 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. Our primary data collection covered only patents issued through 2018. Due to time lags associated with the patenting process, only a fraction of the patent families from 2015-2018 will be included.

Figure 5 - Percent of Algae Patent Families Funded by BETO/Other DOE by Priority Year



Leading Algae Assignees

The ten leading patenting organizations in algae technology are listed above in Table 4, along with their number of algae patent families. Figure 6 shows the same information in graphical form, while also including DOE-funded patent families.

Figure 6 – Top 10 Algae Organizations (based on number of patent families)

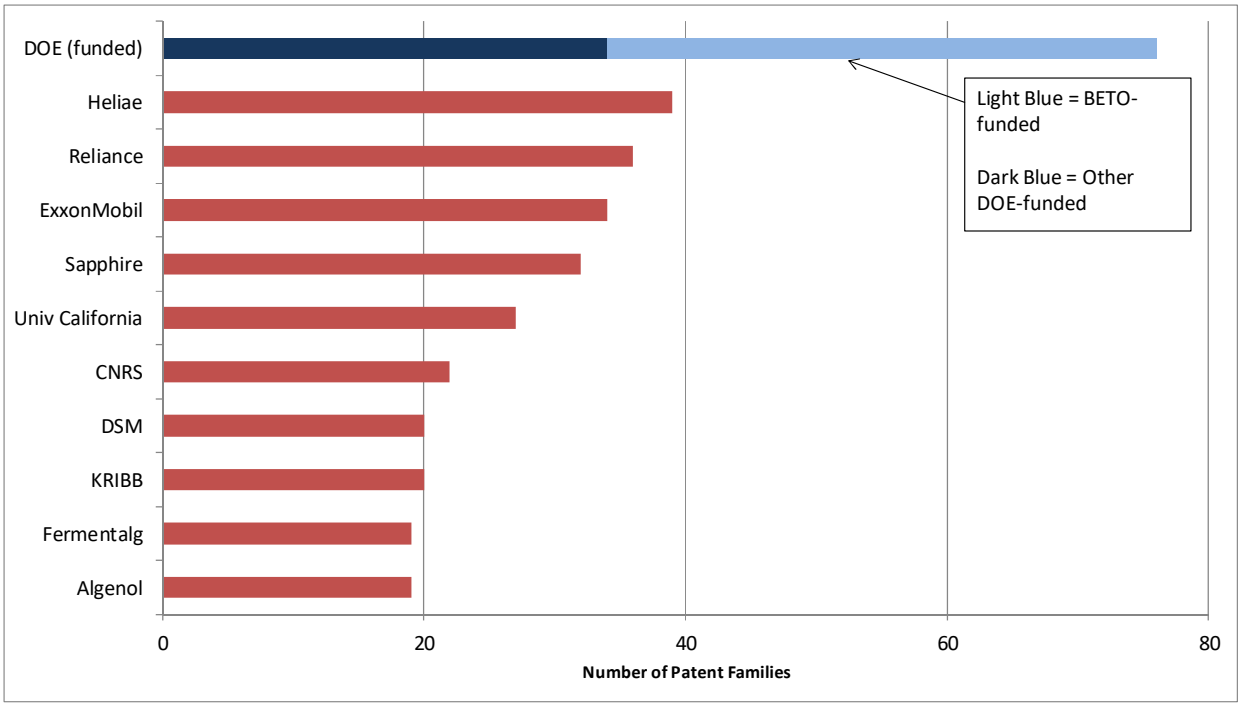


Figure 6 reveals that the portfolio of 76 DOE-funded algae patent families (42 BETO-funded; 34 Other DOE-funded) is larger than the algae patent portfolios associated with each of the ten leading algae organizations. Heliae has the largest portfolio among these organizations, containing 39 patent families, followed by Reliance (36 families), ExxonMobil (34 families) and Sapphire (32 families). All of the other organizations in Figure 6 have algae patent portfolios containing fewer than 30 patent families. In assessing the impact of BETO-funded and Other DOE-funded algae patents, versus the impact of the patent portfolios associated with the leading organizations, we therefore take into account this difference in portfolio sizes. It is also interesting to note the geographical distribution of the leading algae organizations in Figure 6. Out of these ten organizations, five are based in North America, three in Europe and two in Asia.

It should be noted that there is some double-counting of algae patent families in Figure 6, where innovations developed by a leading organization were funded in whole or in part by BETO (or another office within DOE). Specifically, Algenol has five patent families that were funded by BETO, while the University of California has five Other DOE-funded patent families. In Figure 6, these patent families are counted in both the BETO-funded or Other DOE-funded segment of the DOE column, and in the respective organization columns. This double-counting is appropriate, since these patent families are both funded by DOE and assigned to a leading organization.

Assignees of BETO/Other DOE-funded Algae Patents

The DOE-funded algae patent portfolios are constructed somewhat differently from the portfolios of the top ten organizations listed in Figure 6. Specifically, DOE's 76 patent families are those funded by DOE, but they are not necessarily assigned to the agency. For example, BETO (or another DOE office) may have partially or fully funded research projects at DOE labs or external organizations. In such cases, the assignees of any resulting patents will be the respective DOE lab managers or organizations (as in the case of the Algenol and University of California patent families discussed above).

Figure 7 shows the leading assignees on BETO-funded algae patent families. This chart is headed by MRIGlobal (formerly Midwest Research Institute) with six patent families, through its management of the National Renewable Energy Laboratory (NREL). Three organizations share second place in Figure 7 with five BETO-funded algae patent families each – Streamline Automation, Algenol and Battelle Memorial Institute (through its management of Pacific Northwest National Laboratory). The remaining organizations in Figure 7 include DOE lab managers, universities and corporations, reflecting the range of organizations that have carried out BETO-funded algae research.

Figure 7 - Assignees with Largest Number of BETO-Funded Algae Patent Families

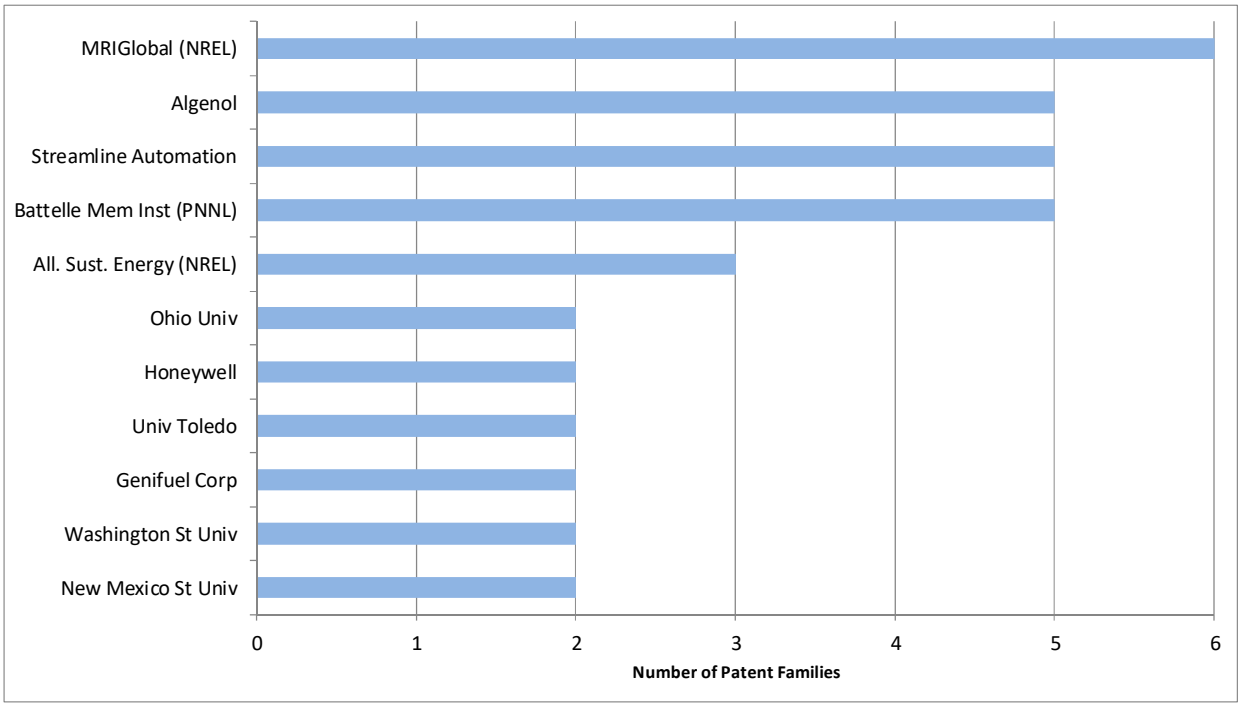
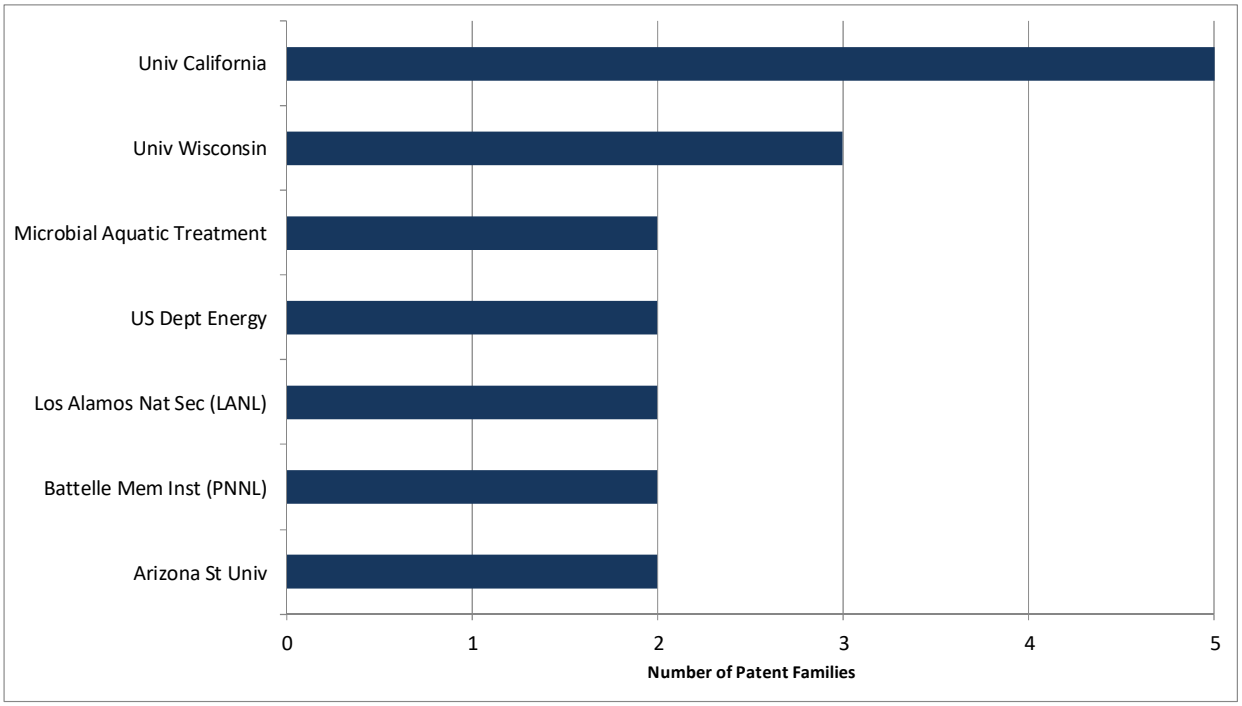


Figure 8 shows the leading assignees on Other DOE-funded algae patent families. This figure is headed by the University of California with five patent families, followed by the University of Wisconsin with three families. The remaining organizations in Figure 8 each have two Other DOE-funded algae patent families. These organizations include DOE itself. Patents may be assigned to DOE 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.

Figure 8 - Assignees with Largest Number of Other DOE-funded Algae Patent Families



Distribution of Algae Patents across Patent Classifications

We analyzed the distribution of BETO-funded algae U.S. patents across Cooperative Patent Classifications (CPCs).[7] We then compared this distribution to those associated with Other DOE-funded algae patents; algae patents assigned to the ten leading organizations; and the universe of all algae patents. This analysis provides insights into the technological focus of BETO funding in algae, versus the focus of the rest of DOE, leading algae organizations, and all algae technology.

The results from this CPC analysis are shown in two separate charts, each from a different perspective. The first chart (Figure 9) is based on the six CPCs that are most prevalent among BETO-funded algae patents. The purpose of this chart is thus to show the main focus areas of BETO-funded algae research, and the extent to which these areas translate to other portfolios (Other DOE-funded; leading algae organizations; all algae patents). This figure shows that BETO-funded research includes relatively balanced coverage across the six CPCs (which is not particularly surprising, since the BETO-funded patent portfolio forms the basis for the CPCs included in the chart). The most common CPC among BETO-funded algae patents is C12M 21/02, which appears on 30% of these patents. This CPC is related to photobioreactors, which are used to cultivate microorganisms such as algae. This figure also includes CPCs related to unicellular algae (C12N 1/12), ethanol production (C12P 7/065 and Y02E 50/17) and cell lysis (C12M 47/06). The other portfolios also have a notable presence in CPCs related to photobioreactors and unicellular algae. They have less of a presence in the other CPCs in Figure 9, particularly those concerned with cell lysis and ethanol production. This difference in focus

[7] The CPC is a patent classification system. Patent offices attach numerous CPC classifications to a patent, covering the different aspects of the subject matter in the claimed invention. In generating these charts, all CPCs associated with each patent are included.

suggests that, taking the period 1976-2018 as a whole, BETO-funded algae research helped fill a gap not addressed extensively by other organizations.

Figure 9 - Percentage of Algae U.S. Patents in Most Common Cooperative Patent Classifications (Among BETO-Funded Patents)

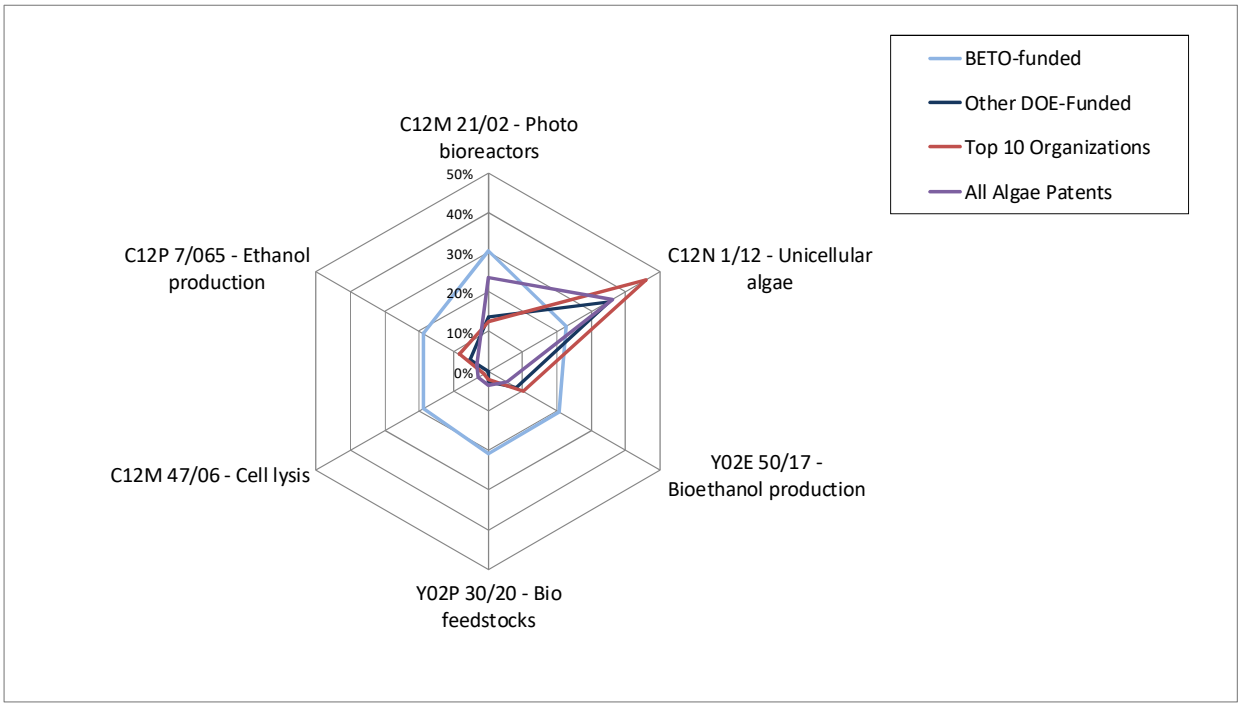


Figure 10 - Percentage of Algae U.S. Patents in Most Common Cooperative Patent Classifications (Among All Algae Patents)

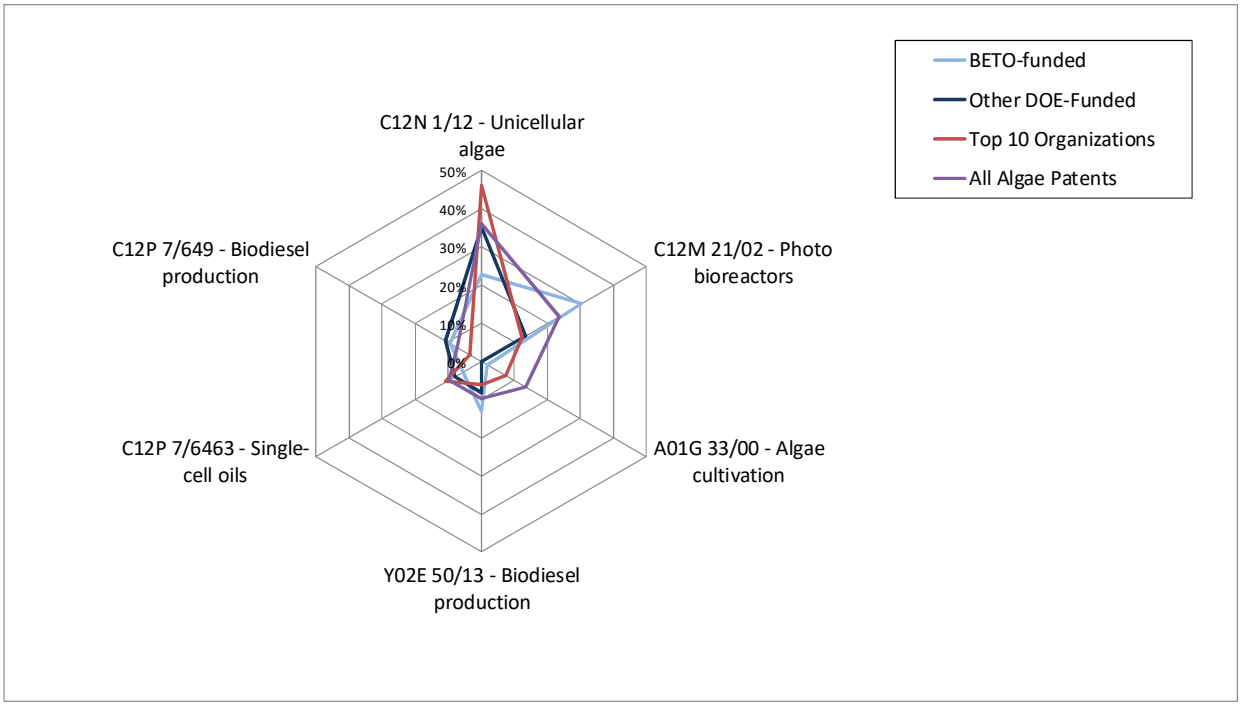
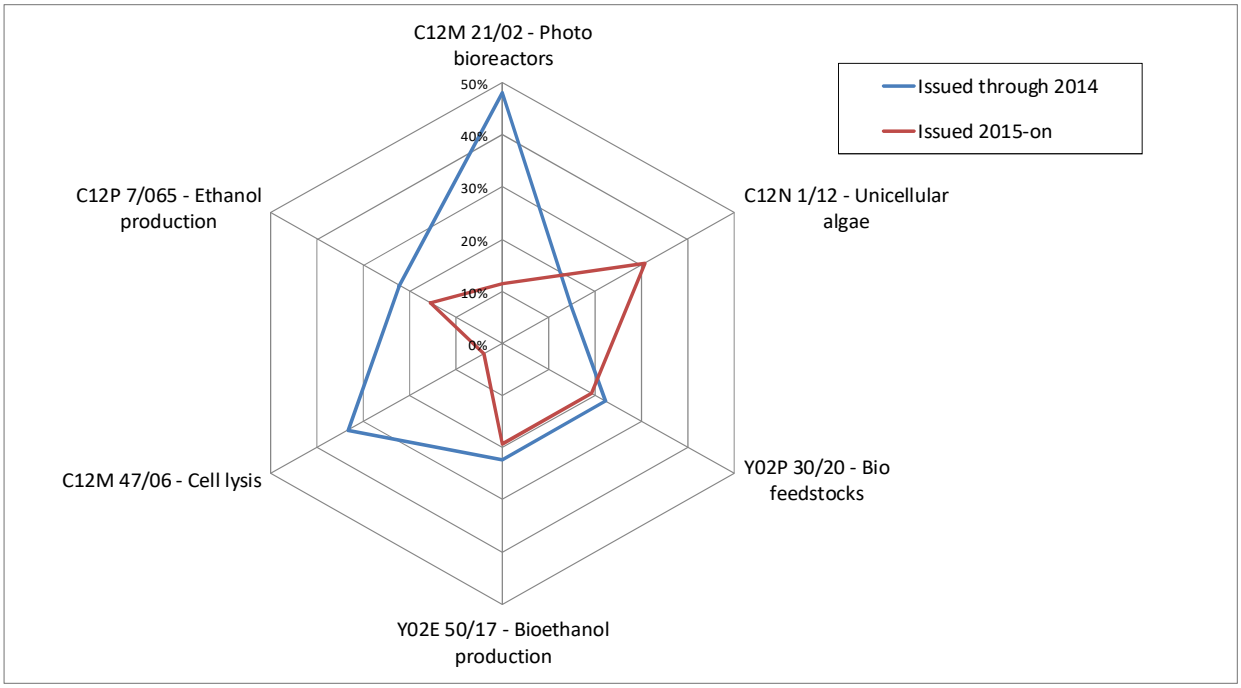


Figure 10 is similar to Figure 9, except that it is from the perspective of the most common CPCs among all algae patents. Hence, the purpose of this chart is to show the main research areas within algae technology as a whole, and how these areas are represented in selected algae portfolios (BETO-funded; Other DOE-funded; leading algae organizations). The most common CPC among all algae patents is C12N 1/12, which is concerned with unicellular algae. Over 36% of all algae patents have this CPC attached (compared to 46% for the leading organizations, 23% for BETO-funded patents and 35% for Other DOE-funded patents). Also prominent in Figure 10 are CPCs related to biodiesel production (C12P 7/649 and Y02E 50/13). Neither of these biodiesel CPCs appeared in Figure 9, although both BETO-funded and Other DOE-funded patents do have some presence in these CPCs.

Figure 11 compares the CPC distribution of BETO-funded algae U.S. patents across two time periods – patents issued through 2014, and those issued from 2015 onwards (these dates are selected to divide the patents into two groups of approximately equal size). This figure reveals a distinct shift in focus between the two time periods. BETO-funded algae patents issued through 2014 focus on CPCs related to photobioreactors (C12M 21/02) and cell lysis (C12M 47/06). Meanwhile, patents issued from 2015 onwards have a greater focus on CPCs associated with unicellular algae (C12N 1/12).

Figure 11 - Percentage of BETO-funded Algae U.S. Patents in Most Common Cooperative Patent Classifications across Two Time Periods



Tracing Backwards from Algae Patents Owned by Leading Organizations

This section reports the results of an analysis tracing backwards from algae patents owned by leading organizations in this technology to earlier research, including that funded by DOE. 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 BETO-funded (and Other DOE-funded) research forms a foundation for subsequent innovations associated with leading algae organizations. Second, we drill down to the level of individual patents, with a particular focus on BETO-funded

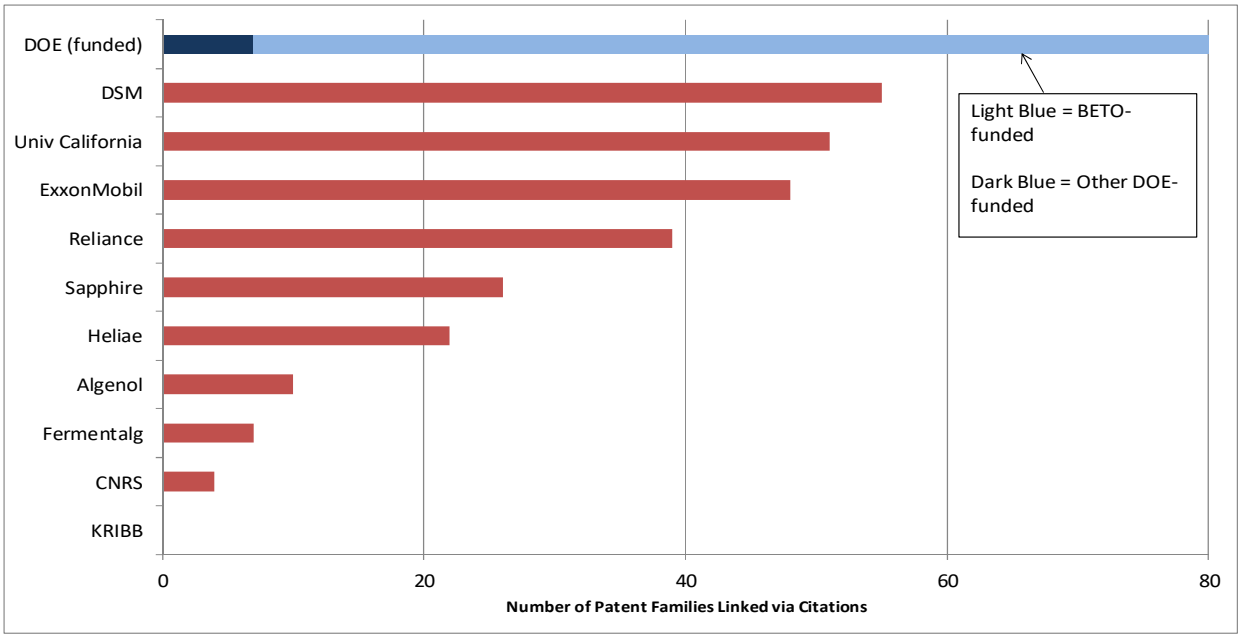
algae patents. These patent-level results highlight specific BETO-funded patents that have influenced subsequent patents owned by leading organizations. They also highlight which algae patents owned by these leading organizations are linked particularly extensively to earlier BETO-funded research.

Organizational Level Results

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

Figure 12 compares the influence of DOE-funded algae research to the influence of research carried out by the top ten algae organizations. Specifically, this figure shows the number of algae patent families owned by the leading organizations that are linked via citations to earlier algae 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 innovations associated with leading algae organizations.[8]

Figure 12 - Number of Leading Organization Algae Patent Families Linked via Citations to Earlier Algae Patents from each Leading Organization
e.g. 80 leading organization families are linked to earlier BETO/Other DOE-funded families

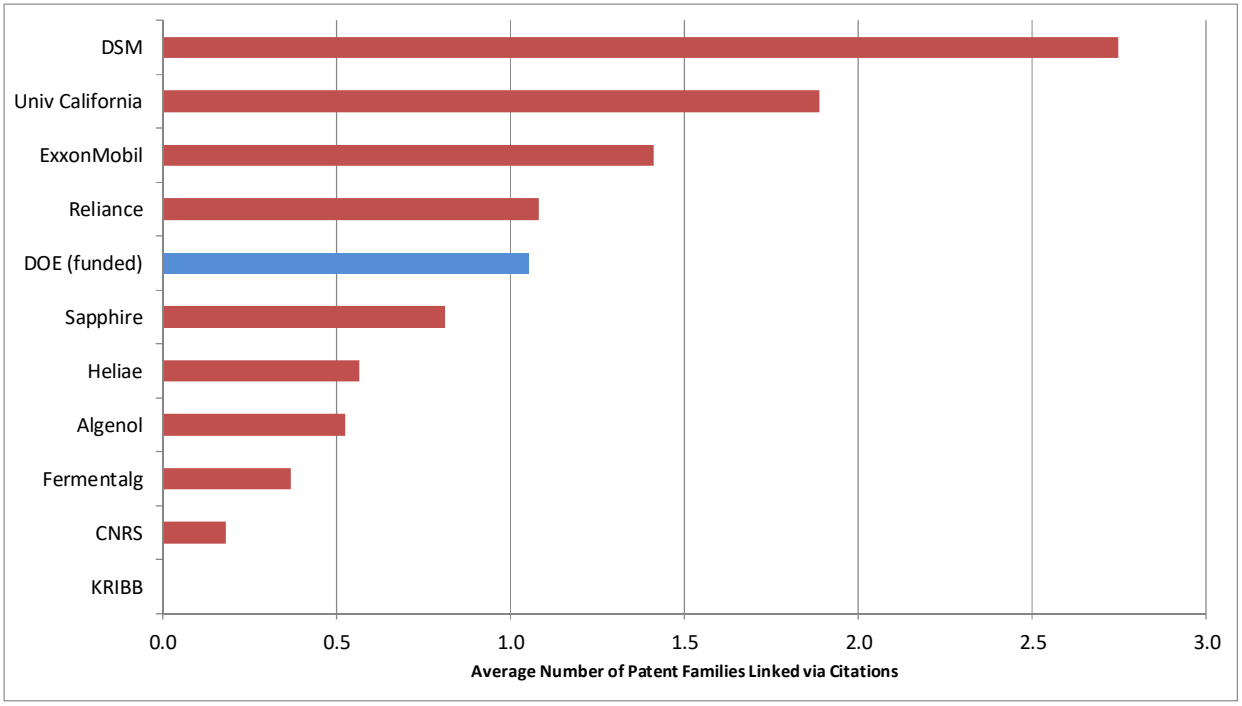


[8] This figure compares the influence of patents *funded* by BETO/DOE against patents *owned* by (i.e. assigned to) organizations. Such a comparison is reasonable, since patents funded by organizations through their research budgets will be assigned to those organizations. Also, organizations (notably companies) 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 6, there is some double-counting in Figure 12 and Figure 13, as some patent families assigned to Algenol and the University of California were funded by DOE. Also, in Figures 12, 14 and 16, leading organization patent families linked to both BETO-funded and Other DOE-funded patents are allocated to the BETO-funded segment of the DOE column, in order to avoid double-counting these families.

In total, 80 leading organization algae patent families (i.e. 30% of these 267 families) are linked via citations to earlier DOE-funded algae patents, out of which 73 are linked to BETO-funded algae patents. This finding puts DOE-funded patents at the head of Figure 12, and means that more leading organization algae patent families are linked to earlier DOE-funded algae patents than are linked to the algae patents of any other leading organization. As such, it suggests that the leading organizations have built extensively on the portfolios of DOE-funded (and particularly BETO-funded) algae patents. That said, it should be noted that Figure 12 does not take into account the different sizes of the patent portfolios associated with the various organizations. For example, it is not surprising that more leading organization families are linked via citations to DOE-funded patents than to other leading organizations, since the DOE-funded portfolio is larger, and so contains more patents to be cited as prior art by subsequent patents.

Figure 13 takes into account the differences in patent portfolio size. It shows the average (mean) number of leading organization patent families linked to patent families associated with each of the leading organizations, plus DOE. For example, on average, DOE-funded algae patent families are each linked to an average of 1.05 patent families assigned to the leading organizations. This puts DOE near the center of the distribution in Figure 13, which is headed by DSM, whose algae patent families are each linked to an average of 2.75 families owned by the leading organizations. It suggests that the prominence of DOE in Figure 12 is largely due to its portfolio size, with its influence being around the average once this size is taken into account.

Figure 13 – Average Number of Leading Organization Algae Patent Families Linked via Citations to Algae Families from Each Leading Organization
e.g. on average, each DOE-funded family is linked to 1.05 leading organization patent families



Figures 14 through 16 examine which of the leading organizations build particularly extensively on earlier DOE-funded patents. Figure 14 shows how many algae patent families owned by each of the leading organizations are linked via citations to earlier DOE-funded patents. This figure

reveals that, out of the ten leading algae organizations, nine (i.e. all except KRIBB) have at least one patent family linked to earlier DOE-funded algae patents. Reliance is at the head of Figure 14, with 21 patent families linked via citations to earlier DOE-funded algae patents, all but one of which is linked to BETO-funded patents. Heliae is in second place in this figure, with 20 patent families linked via citations to DOE (all linked to BETO), followed by ExxonMobil (12 families linked to DOE; all to BETO) and DSM (8 families linked to DOE; 7 to BETO).

Figure 14 – Number of Patent Families Linked via Citations to Earlier BETO/Other DOE-funded Algae Patents for each Leading Algae Organization

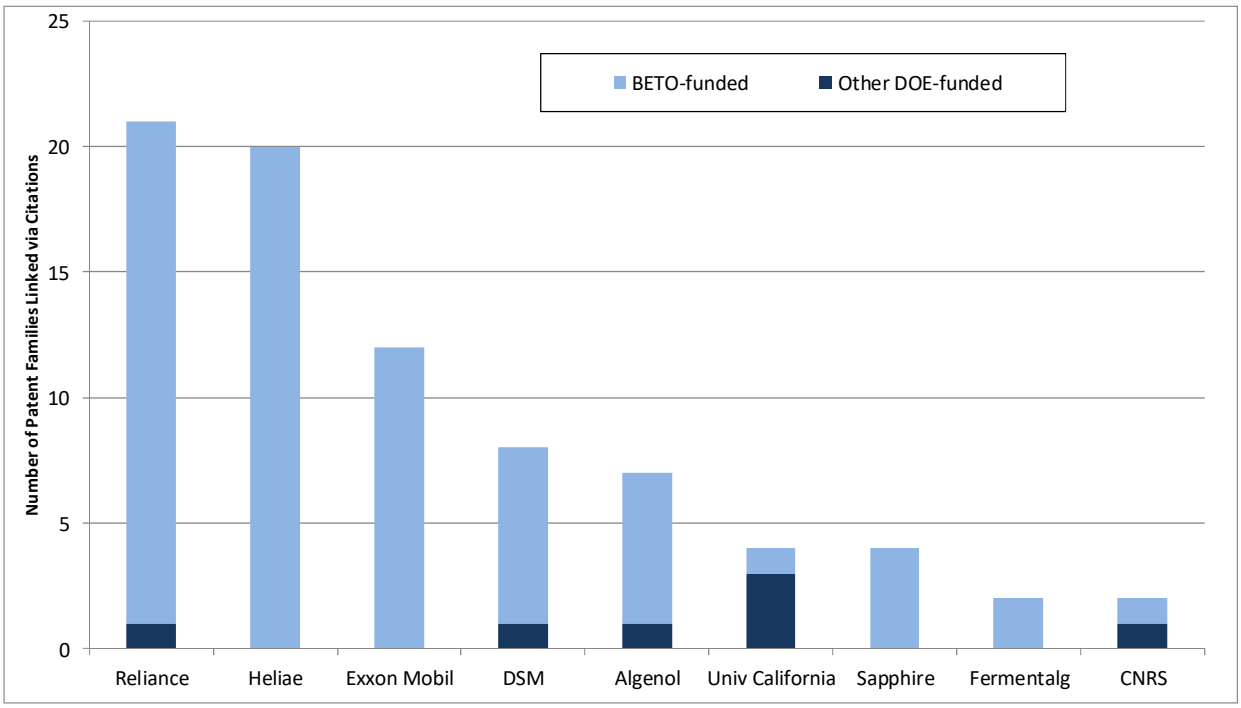


Figure 15 counts the total number of citation links from leading organizations to earlier DOE-funded patents. This differs slightly from the count of linked families in Figure 14, since a single patent family may be linked to multiple earlier DOE-funded patents. The same three organizations are at the head of Figure 15 – Reliance, Heliae and ExxonMobil – reinforcing their close links to earlier DOE-funded algae research. The main difference in Figure 15 versus Figure 14 is that Reliance leads by a much wider margin once total citation links to DOE are counted.

There is an element of portfolio size bias in the patent family counts in Figures 14 and 15. Organizations with larger algae 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 organization's algae patent families that are linked via citations to earlier DOE-funded algae patents, rather than their absolute number. This is a measure of how extensively each organization builds on DOE-funded research, relative to their overall patent output. Figure 16 further emphasizes the extensive citation links between DOE-funded algae patents and subsequent patent families owned by Reliance and Heliae. More than half of each of these organizations' algae patent families are linked via citations to earlier DOE-funded (and particularly BETO-funded) algae patents. DSM, Algenol and ExxonMobil all

have at least one-third of their algae patent families linked via citations to DOE, again primarily to BETO-funded patents.

Figure 15 - Number of Citation Links from Leading Algae Organization Patent Families to Earlier BETO/Other DOE-funded Algae Patents

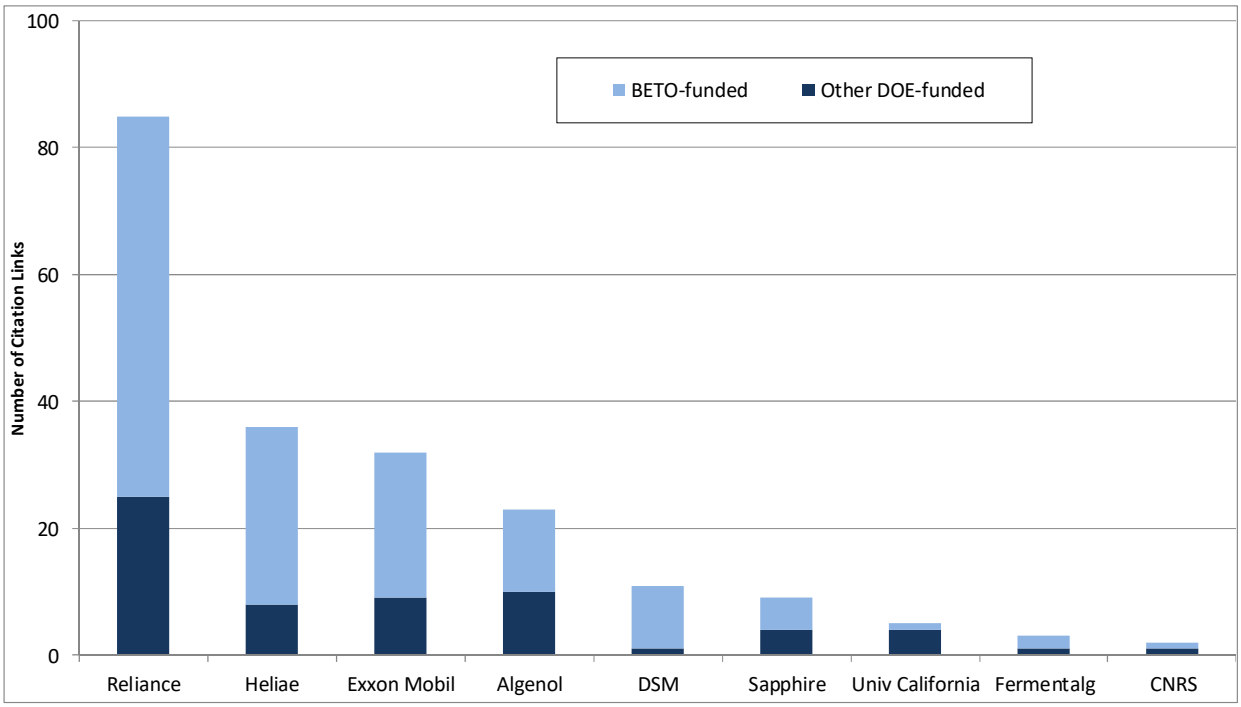
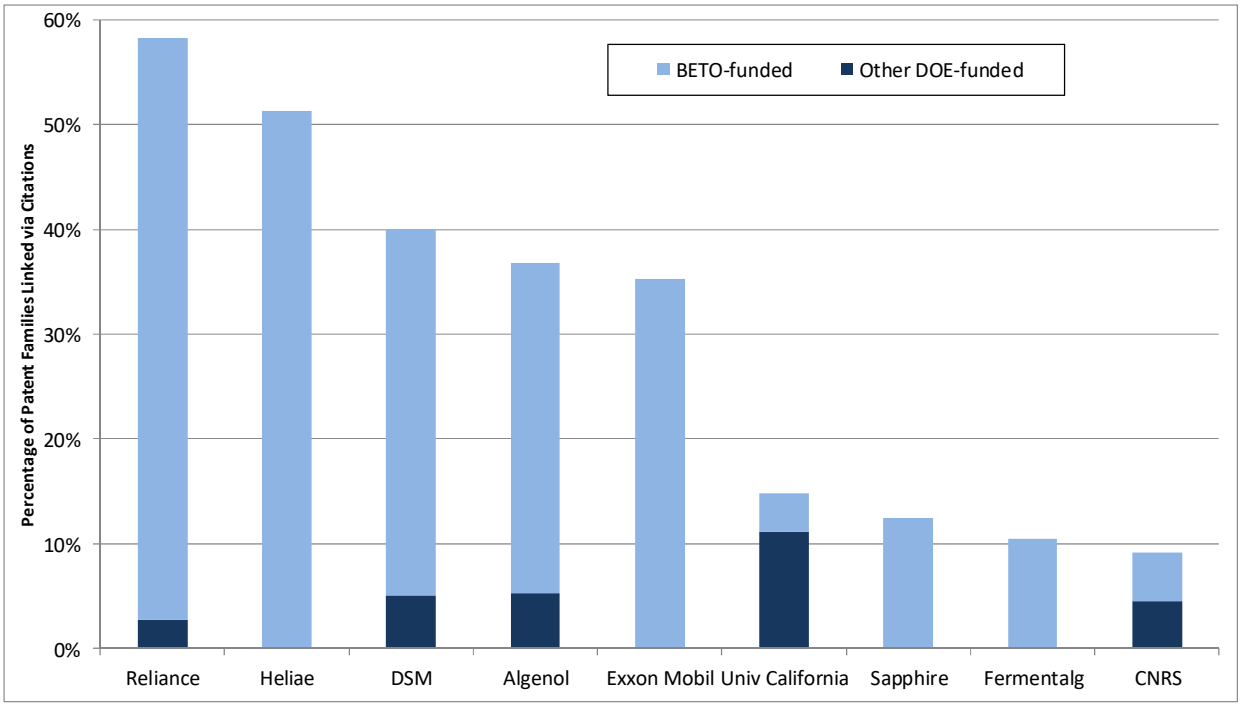


Figure 16 - Percentage of Leading Algae Organization Patent Families Linked via Citations to Earlier BETO/Other DOE-funded Algae Patents



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 algae patent families (in particular BETO-funded families) that have had a strong influence on subsequent algae patents owned by leading organizations in this technology. Looking in the opposite direction, it also identifies individual algae patents owned by leading organizations that have extensive links to earlier BETO-funded research.

Table 5 shows the BETO-funded algae patent families linked via citations to the largest number of subsequent patent families owned by leading organizations in this technology. As such, the patent families in this table represent BETO-funded technologies that are linked to subsequent innovations associated with leading organizations in the algae industry.

Table 5 – BETO-Funded Algae Patent Families Linked via Citations to Most Subsequent Leading Organization Algae Patent Families

Patent Family #	Representative Patent #	Priority Year	# Linked Families	Assignee	Title
25521521	4253271	1978	33	Battelle Mem Inst (PNNL)	Mass algal culture system
46250260	5661017	1993	29	MRI Global (NREL)	Method to transform algae, materials therefor, and products produced thereby
26879312	4320594	1978	28	Battelle Mem Inst (PNNL)	Mass algal culture system
22393377	5559220	1993	22	MRI Global (NREL)	Gene encoding acetyl-coenzyme A carboxylase
25270743	5871952	1997	16	MRI Global (NREL)	Process for selection of Oxygen-tolerant algal mutants that produce H2 under aerobic conditions
50975059	8846369	2012	7	Algenol Biotech	Cyanobacterium sp. host cell and vector for production of chemical compounds in cyanobacterial cultures
50975054	9157101	2012	6	Algenol Biotech	Cyanobacterium sp. For production of compounds
39584530	7905930	2006	3	Genifuel Corp	Two-stage process for producing oil from microalgae

The BETO-funded patent family linked to the most leading organization families was filed in 1978 and assigned to Battelle Memorial Institute, through its management of Pacific Northwest National Laboratory (PNNL). This patent family (whose representative patent[9] is US #4,253,271) describes a system for the mass culture of unicellular algae. It is linked via citations to 33 subsequent patent families assigned to the leading organizations, including Reliance, Heliae, ExxonMobil and Sapphire. There is also a similar PNNL family in third place in Table 5 (representative patent US #4,320,594) that is linked via citations to 28 subsequent leading organization families, assigned to Reliance, Heliae and DSM.

MRIGlobal (through its management of NREL) is also prominent in Table 5, with three of the five patent families at the head of this table. These include the patent family in second place

[9] The representative patent is a single patent from a family, but it is not necessarily the priority filing.

(representative patent US #5,661,017), which describes the genetic transformation of algae. This patent family is linked via citations to 29 subsequent families owned by the leading organizations, including families assigned to six of these organizations.

Table 5 lists BETO-funded patents linked to large numbers of subsequent algae patent families owned by leading organizations. Table 6 looks in the opposite direction, and lists the algae patent families owned by leading organizations that are linked to multiple earlier families funded by BETO. The three patent families at the head of this table are all assigned to Reliance, through its ownership of Aurora Algae. These Reliance patent families (for example, representative patent US #9,101,942) describe methods for processing algae-containing fluids, and extracting lipids from these algae. They are each linked via citations to the four BETO-funded PNNL and NREL families at the head of Table 5. Table 6 also includes patent families assigned to ExxonMobil (e.g. representative patent US #9,175,256) and Algenol (representative patent US #9,157,101) that are linked via citations to the NREL families in Table 5. It also contains a Heliae family (representative patent US #9,758,756) linked to the PNNL families in Table 5.

Table 6 - Leading Organization Algae Patent Families Linked via Citations to Largest Number of BETO-Funded Algae Patent Families

Patent Family #	Representative Patent #	Priority Year	# BETO Fams	Assignee	Title
43305511	9101942	2009	4	Reliance Ind (Aurora)	Clarification of suspensions
43306757	8865452	2009	4	Reliance Ind (Aurora)	Systems and methods for extracting lipids from wet algal biomass
45064758	8926844	2011	4	Reliance Ind (Aurora)	Systems and methods for processing algae cultivation fluid
46314359	9175256	2010	3	Exxon Mobil	Production of fatty acids and fatty acid derivatives by recombinant microorganisms expressing polypeptides having lipolytic activity
46383470	8940508	2010	3	Exxon Mobil	Enhancement of biomass production by disruption of light energy dissipation pathways
49679609	9758756	2012	3	Heliae Development	Method of culturing microorganisms using phototrophic and mixotrophic culture conditions
50975054	9157101	2012	3	Algenol Biotech	Cyanobacterium sp. for production of compounds

We also identified high-impact algae patents owned by leading organizations that have citation links back to BETO-funded patents.[10] The idea is to highlight important technologies owned by

[10] 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 C12N 1/12 (Unicellular algae) 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 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 a patent has been cited 50% more frequently than expected. Meanwhile a Citation Index of 0.7 reveals a patent has been cited 30% less frequently than expected. By extension, the expected

leading organizations that are linked to earlier algae research funded by BETO. Table 7 lists algae patents owned by leading organizations that have Citation Index values of 1.75 or over (i.e. they have been cited at least 75% more frequently as expected), and are linked via citations to earlier BETO-funded algae patents. The patents are listed in descending order based on their Citation Index.

The patent at the head of Table 7 (US #7,939,710) is assigned to DSM through its ownership of Martek Biosciences. It describes the genetic transformation of algae. Since this patent was issued in 2011, it has been cited as prior art by 59 subsequent patents, which is more than six times as many citations as expected given its age and technology. In turn, this patent is linked via citations to the earlier BETO-funded NREL algae transformation patents highlighted above in Table 5. The second patent in Table 7 (US #8,202,425) is assigned to Heliae and describes the extraction of lipids from algae. This patent is linked via citations to the BETO-funded PNNL algae cultivation patent family listed third in Table 5. In turn, the Heliae patent has been cited as prior art by 41 subsequent patents, more than five times as many citations as expected. It is the first of two Heliae patents in Table 7 related to lipid extraction, the second of which (US #8,242,296) is also linked via citations to the same earlier BETO-funded PNNL family.

Table 7 - Highly Cited Leading Organization Algae Patents Linked via Citations to Earlier BETO-funded Algae Patents

Patent	Issue Year	# Cites Received	Citation Index	Assignee	Title
7939710	2011	59	6.66	Royal DSM (Martek)	Trophic conversion of obligate phototrophic algae through metabolic engineering
8202425	2012	41	5.41	Heliae Development	Extraction of neutral lipids by a two solvent method
8119859	2012	18	5.18	Reliance Ind (Aurora)	Transformation of algal cells
8242296	2012	30	4.53	Heliae Development	Products from step-wise extraction of algal biomasses
8314228	2012	16	3.40	Reliance Ind (Aurora)	Bidirectional promoters in Nannochloropsis
6027900	2000	56	1.79	Royal DSM / Carnegie Inst	Methods and tools for transformation of eukaryotic algae

While the patent-level results focus on BETO-funded algae patent families, we also identified Other DOE-funded algae families linked via citations to the largest number of patent families owned by the leading organizations. These Other DOE-funded families are shown in Table 8. The patent family at the head of this table (representative patent US #6,555,500) is assigned to the University of California, through its management of Los Alamos National Laboratory (LANL). This family, filed in 2000, describes a method for improving the growth of plants and algae. It is linked via citations to 21 subsequent patent families assigned to the leading organizations, including families assigned to Reliance, Heliae and Sapphire. The second patent family in Table 8 (representative patent US #4,442,211) is assigned to DOE and describes a

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 been cited less frequently than expected. Note that the Citation Index is calculated for U.S. patents only, since citation rates differ across patent systems.

method for hydrogen and oxygen production using algae. It was filed in 1982, and is linked via citations to 11 subsequent patent families owned by the leading organizations. These include families assigned to Reliance, Heliae, Sapphire and the University of California. Table 8 also includes more recent patent families. Examples include a family filed in 2006 by Arizona State University (representative patent US #8,753,840) outlining cyanobacteria, and a UT-Battelle (Oak Ridge National Laboratory) family (representative patent US #7,973,214) describing ethanol production, which was also filed in 2006.

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

Patent Family #	Representative Patent #	Priority Year	# Linked Families	Assignee	Title
23958651	6555500	2000	21	Univ California (LANL)	Use of prolines for improving growth and other properties of plants and algae
23535884	4442211	1982	11	US Dept Energy	Method for producing hydrogen and oxygen by use of algae
39876106	8753840	2006	8	Arizona St Univ	Modified cyanobacteria
39230797	7973214	2006	5	UT-Battelle (ORNL)	Designer organisms for photosynthetic production of ethanol from carbon dioxide and water
27396594	6667171	2000	4	Ohio University	Enhanced practical photosynthetic CO2 mitigation
41799618	8518690	2008	3	Battelle Mem Inst (PNNL)	Production of bio-based materials using photobioreactors with binary cultures

Overall, the backward tracing element of the analysis suggests that the portfolios of BETO-funded and Other DOE-funded algae patents have had an important influence on subsequent innovations associated with the leading algae organizations. This influence can be seen both over time and across technologies, with various BETO-funded patent families linked via citations to subsequent patents assigned to a number of the leading organizations.

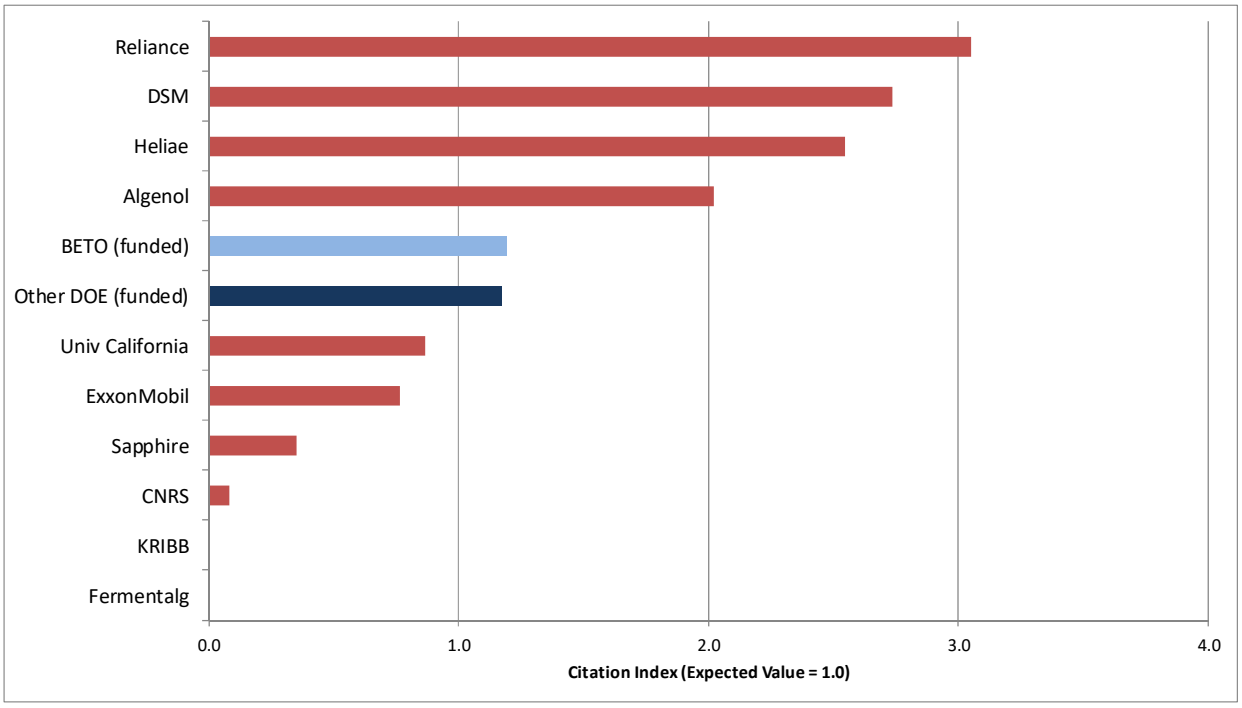
Tracing Forwards from DOE-funded Algae Patents

The previous section of the report examined the influence of DOE-funded algae research upon technological developments associated with leading algae 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 BETO-funded (and Other DOE-funded) algae patents, and tracing forwards in time through two generations of citations. Hence, while the previous section of the report focused on DOE's influence upon a specific patent set (i.e. patents owned by leading algae organizations), this section of the report examines on the broader influence of BETO-funded (and Other DOE-funded) algae research, both within and beyond algae technology. Also, in order to avoid repeating earlier results, the forward tracing concentrates primarily on patents that are linked to DOE-funded algae research, but are not owned by the leading algae organizations.

Organizational Level Results

We first generated average Citation Index values for the portfolios of BETO-funded and Other DOE-funded algae patents. We then compared these Citation Indexes against those of the ten leading algae organizations. The results are shown in Figure 17.

Figure 17 – Average Citation Index for Leading Organizations' Algae Patents, plus BETO-funded and Other DOE-funded Algae Patents



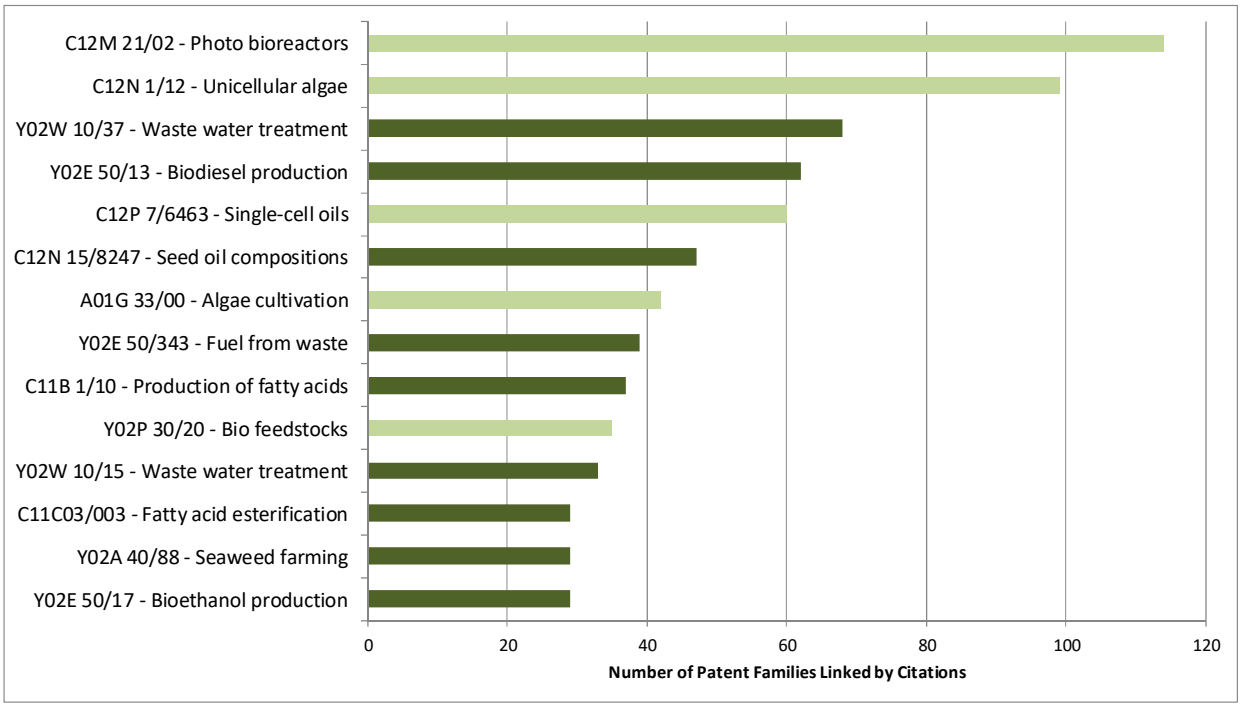
This figure reveals that BETO-funded algae patents have an average Citation Index value of 1.19. This means that they have been cited 19% more frequently than expected by subsequent patents, given their age and technology. Other DOE-funded algae patents have a similar Citation Index of 1.18, showing that they have been cited 18% more frequently than expected. These Citation Index values put the DOE-funded portfolios near the center of the distribution in Figure 17, which is headed by Reliance with a Citation Index of 3.05 (i.e. its patents have been cited more than three times as frequently as expected).

The Citation Index measures the overall influence of the DOE-funded algae patent portfolios, but does not necessarily 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 algae patent families.[11] These CPCs reflect the influence of DOE-funded research across technologies.

[11] 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 via citations to earlier DOE-funded algae patent families.

Figure 18 shows the CPCs with the largest number of patent families linked to BETO-funded algae patents. These CPCs are presented in two different colors – i.e. those related to algae technology and those beyond this technology. The former represent the influence of BETO-funded patents on algae technology itself, while the latter represent spillovers of the influence of BETO-funded algae research into other technology areas.

Figure 18 - Number of Patent Families Linked via Citations to Earlier BETO-Funded Algae Patents by CPC (Light Green = Algae-related; Dark Green = Other)



The two CPCs at the head of Figure 18 are both related to algae technologies. These CPCs are C12M 21/02 (Photobioreactors) and C12N 1/12 (Unicellular algae). They are the most prominent among five algae-related CPCs in Figure 18. The remaining nine CPCs are primarily concerned with technologies beyond algae. For example, there are CPCs related to waste water treatment (Y02W 10/37 and Y02W 10/15), generating fuel from waste (Y02E 50/243), and biofuel production (Y02E 50/13 and Y02E 50/17). These are examples of BETO-funded algae patents being linked to subsequent developments in adjacent technologies.

Figure 19 is similar to Figure 18, but is based on patent families linked to Other DOE-funded algae patents, rather than to BETO-funded algae patents. The main difference between the two figures is the greater presence of CPCs from beyond algae technology in Figure 19. This figure is headed by two CPCs related to waste water treatment (Y02W 10/15 and Y02W 10/37) and a CPC concerned with carbon dioxide removal (B01D 2257/504). There are also CPCs in this figure related to power plants (Y02E 20/16 and F02C 3/34). These are examples of Other DOE-funded algae patents being connected to subsequent developments in other technologies. Figure 19 also contains CPCs from within algae technology, notably C12M 21/02 (Photobioreactors) and C12N 1/12 (Unicellular algae).

Figure 19 - Number of Patent Families Linked via Citations to Earlier Other DOE-Funded Algae Patents by CPC (Light Green = Algae-related; Dark Green = Other)

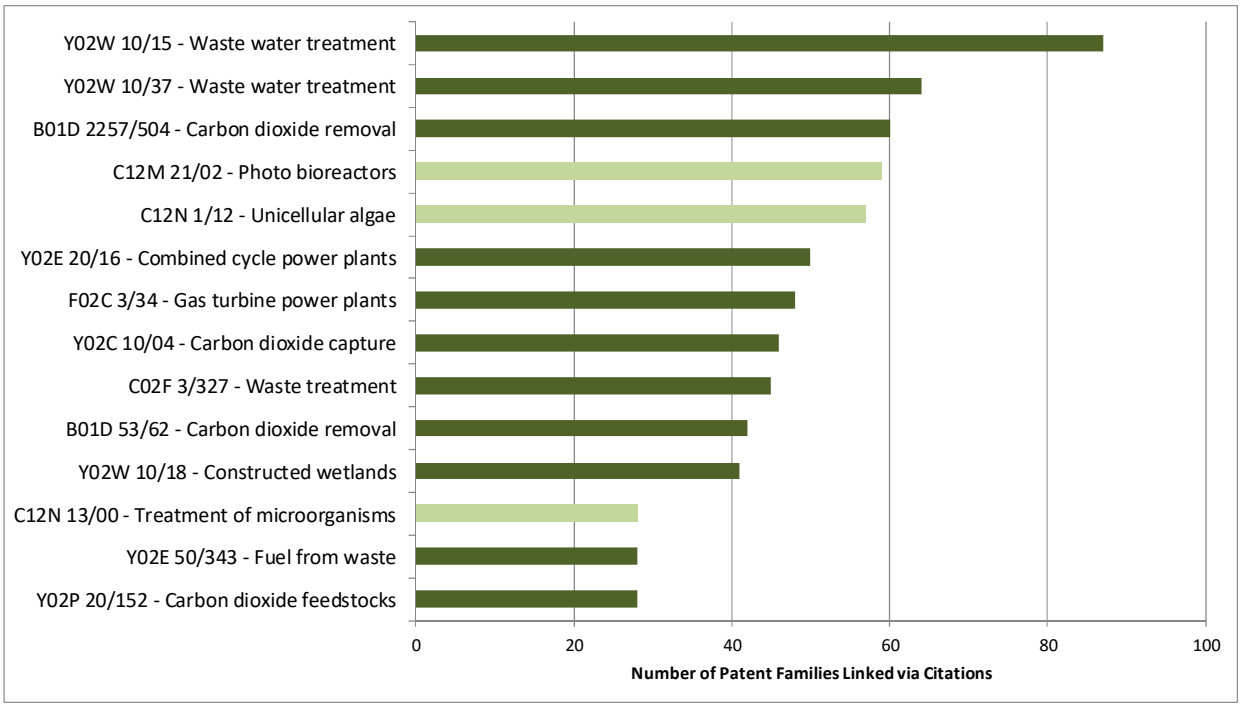
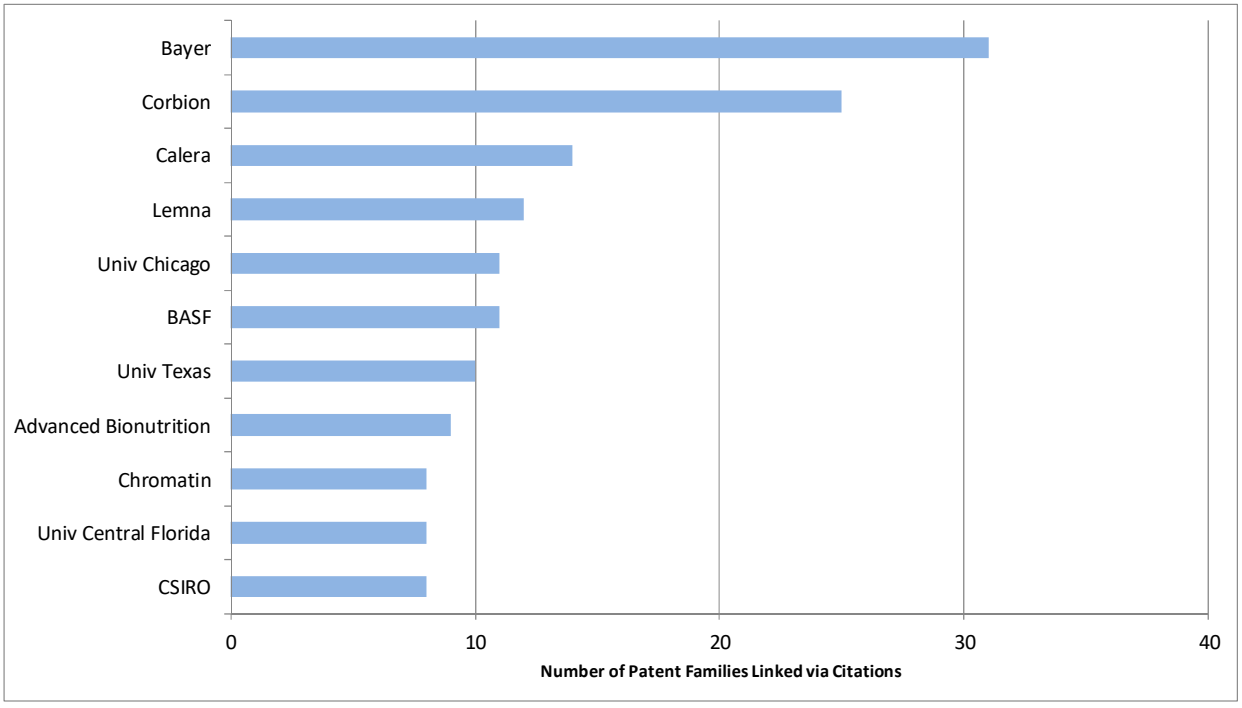


Figure 20 - Organizations with Largest Number of Patent Families Linked via Citations to BETO-funded Algae Patents (excluding leading algae organizations)



The organizations with the largest number of patent families linked via citations to earlier BETO-funded algae patents are shown in Figure 20. To avoid repeating the results from earlier, this figure excludes the leading algae organizations used in the backward tracing element of the

analysis. Also, note that Figure 20 includes all patent families assigned to these organizations, not just their patent families describing algae technology.

Bayer is at the head of Figure 20, with 31 patent families linked via citations to earlier BETO-funded algae patents. These Bayer patent families focus on plant productivity and weed control, and are linked to various earlier BETO-funded patents, notably NREL patents for herbicide-resistant microorganisms (e.g. US #5,559,220). Corbion is in second place in Figure 20, with 25 patent families linked via citations to earlier BETO-funded patents. Many of these Corbion families describe oils extracted from microalgae, and are also linked via citations to earlier BETO-funded NREL patents for algae cultivation. The third-place company in Figure 20 is Calera, which has 14 patent families describing carbon dioxide sequestering building materials. These families are linked to an earlier BETO-funded Ohio University patent (US #8,470,584) for growing microorganisms from exhaust gas. The remaining organizations in Figure 20 include companies (Lemna, BASF) and universities (Chicago, Texas, Florida), reflecting the influence of BETO-funded algae research across a range of organizations.

Figure 21 - Organizations with Largest Number of Patent Families Linked via Citations to Other DOE-funded Algae Patents (excluding leading algae organizations)

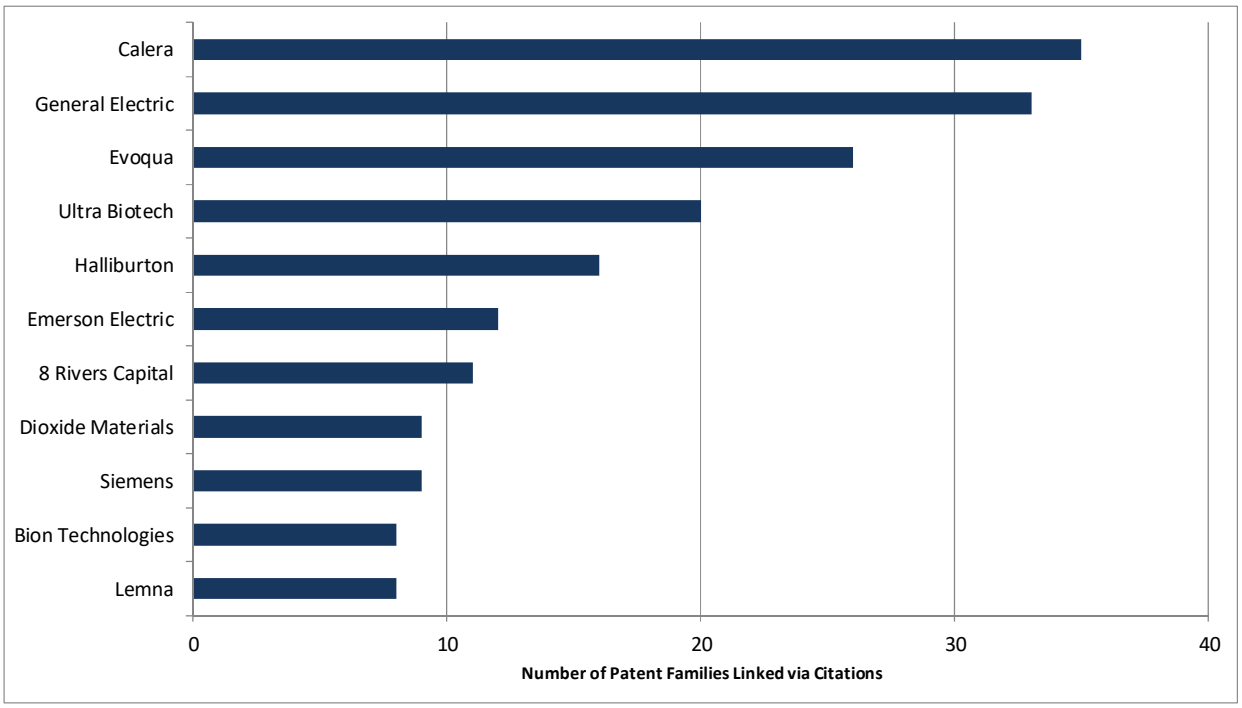


Figure 21 shows the organizations with the largest number of patent families linked to earlier Other DOE-funded algae patents. Calera is at the head of this figure, with 35 patent families linked via citations to earlier Other DOE-funded algae patents. These Calera patent families again focus on carbon dioxide sequestering building materials. They are linked via citations to earlier patents assigned to DOE (e.g. US #6,648,949) describing the removal of carbon dioxide from flue gas, and the mixing of this carbon dioxide with algae-laden water to aid algae growth. General Electric is in second place in Figure 21, with 33 patent families linked via citations to earlier Other DOE-funded patents. These General Electric patent families outline various aspects of power plants, and are linked via citations to an earlier DOE-funded Ohio University patent

(US #6,667,171) detailing algae cultivation and its use in carbon dioxide sequestration. Meanwhile, Evoqua, the third company in Figure 21, has 26 patent families for waste water treatment that are linked via citations to earlier Other DOE-funded patents outlining microbial mats (e.g. US #5,614,097). These are examples of DOE-funded algae research influencing innovations beyond algae technology.

Patent Level Results

This section of the report drills down to identify individual DOE-funded (and particularly BETO-funded) algae patents whose influence on subsequent technological developments has been particularly strong. Looking in the opposite direction, it also highlights patents that have extensive citation links to earlier BETO-funded algae research.

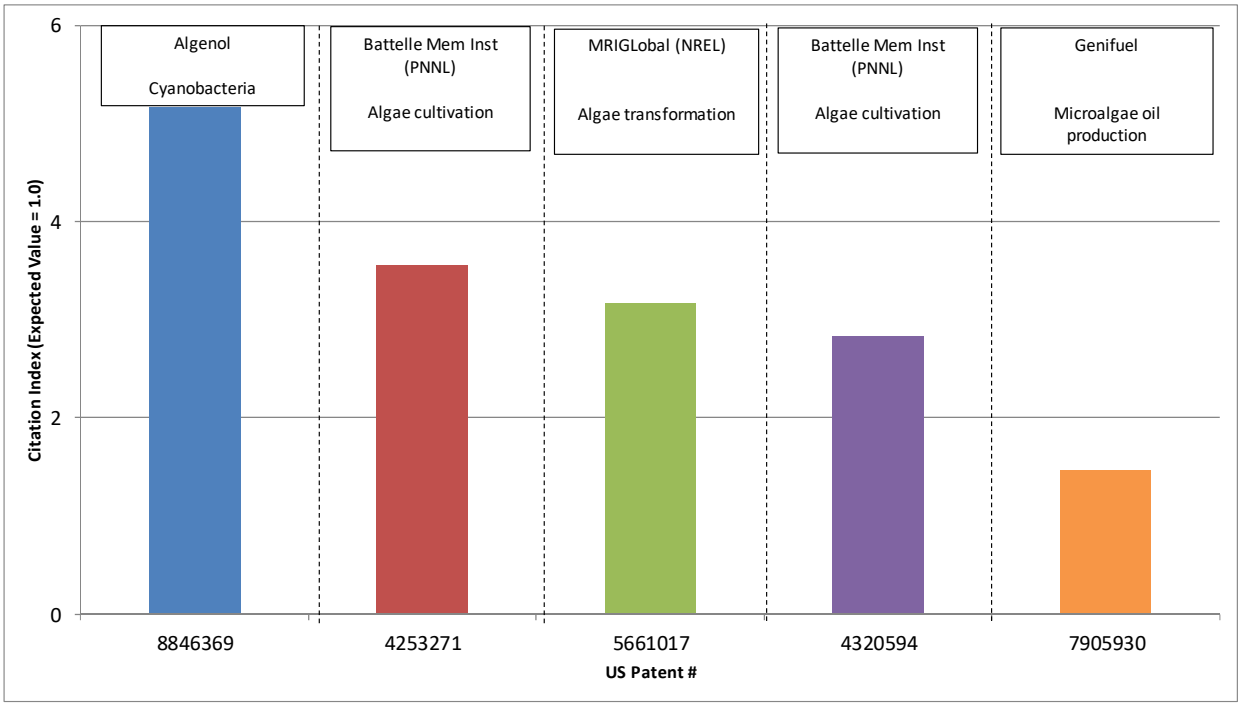
The simplest way of identifying high-impact BETO-funded algae patents is via overall Citation Indexes. The BETO-funded patents with the highest Citation Index values are shown in Table 9, and also presented in graphical form in Figure 22. The patents in this table are a mix of older patents that have 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 #8,846,369) is assigned to Algenol and relates to the genetic enhancement of cyanobacteria, which can be used in biofuel production. Since being issued in 2014, this patent has been cited as prior art by 11 subsequent patents, more than five times as many citations as expected given its age and technology. The next three patents in Table 9 are the early PNNL algae cultivation and NREL algae transformation patents that were highlighted in the backward tracing element of the report. The final patent in this table (US #7.905.930) is a 2011 Genifuel patent describing the production of biofuels from microalgae. This patent has been cited by eight subsequent patents, almost 50% more citations than expected given its age and technology.

Table 9 – List of Highly Cited BETO-Funded Algae Patents

Patent #	Issue Year	# Cites Received	Citation Index	Assignee	Title
8846369	2014	11	5.16	Algenol Biotech	Cyanobacterium sp. host cell and vector for production of chemical compounds in cyanobacterial cultures
4253271	1981	76	3.55	Battelle Mem Inst (PNNL)	Mass algal culture system
5661017	1997	88	3.17	MRI Global (NREL)	Method to transform algae, materials therefor, and products produced thereby
4320594	1982	67	2.82	Battelle Mem Inst (PNNL)	Mass algal culture system
7905930	2011	8	1.46	Genifuel Corp	Two-stage process for producing oil from microalgae

Figure 22 – Examples of Highly-Cited BETO-funded Algae Patents



The Citation Indexes in Table 9 are based on a single generation of citations to BETO-funded algae patents. Table 10 extends this by examining a second generation of citations – i.e. it shows the BETO-funded algae patents linked directly or indirectly to the largest number of subsequent patent families. These subsequent families are divided into two groups, based on whether they are within or beyond algae technology (i.e. whether or not they are in the universe of algae patents defined in the first stage of this project). This highlights which BETO-funded patent families have been particularly influential within algae technology, and which have had a wider impact beyond algae.

The two patent families at the head of Table 10 (representative patents US #4,253,271 and US #4,320,594) are the early PNNL algae cultivation patent families highlighted earlier in the backward tracing element of the analysis. These two PNNL patent families are linked via citations to 431 and 351 subsequent patent families respectively, with approximately one-third of these subsequent families being from within algae technology. The next four patent families in Table 10 are the NREL families also highlighted earlier in this report, the most prominent of which (representative patent US #5,661,017) is linked via citations to 252 subsequent patent families, 66 of which are within algae technology. Table 10 does include two more recent patent families, filed in 2006 by Ohio University and Genifuel. These families are linked via citations to 32 and 20 subsequent families respectively. That said, it should be noted that they have had less time to become linked to later generations of patents than the PNNL and NREL patent families at the head of Table 10.

Table 10 – BETO-funded Algae Patent Families Linked via Citations to Largest Number of Subsequent Algae/Other Patent Families

Family #	Priority Year	Rep. Patent #	# Linked Families	# Linked Algae Fams	Assignee	Title
25521521	1978	4253271	431	157	Battelle Mem Inst (PNNL)	Mass algal culture system
26879312	1978	4320594	351	112	Battelle Mem Inst (PNNL)	Mass algal culture system
46250260	1993	5661017	252	66	MRI Global (NREL)	Method to transform algae, materials therefor, and products produced thereby
22393377	1993	5559220	158	38	MRI Global (NREL)	Gene encoding acetyl-coenzyme A carboxylase
25270743	1997	5871952	62	26	MRI Global (NREL)	Process for selection of Oxygen-tolerant algal mutants that produce H2 under aerobic conditions
26774612	1998	6277589	54	1	MRI Global (NREL)	System for rapid biohydrogen phenotypic screening of microorganisms using a chemochromic sensor
38694687	2006	8470584	32	9	Ohio University	Apparatus and method for growing biological organisms for fuel and other purposes
39584530	2006	7905930	20	14	Genifuel Corp	Two-stage process for producing oil from microalgae

The tables above identify BETO-funded patent families linked particularly strongly to subsequent technological developments. Table 11 looks in the opposite direction, and identifies highly-cited patents linked to earlier BETO-funded algae patents. As such, these are examples where BETO-funded algae research has formed part of the foundation for subsequent high-impact technologies. This table focuses on patents not owned by the leading algae organizations, since those patents were examined in the backward tracing element of the analysis.

The patent at the head of Table 11 (US #6,524,486) was granted in 2003 to Sepal Technologies. This patent describes a process for separating microalgae from water. It has been cited as prior art by 110 subsequent patents, which is more than seven times as many citations as expected for a patent of its age and technology. The second patent in Table 11 (US #7,745,209) is assigned to Corning and outlines a cell culture apparatus. This patent has been cited as prior art by 40 subsequent patents since it was issued in 2010, more than seven times as many citations as expected. In terms of raw citation counts, the most highly-cited patent in Table 11 was issued in 2003 and assigned to Micro Gaia Limited. This patent (US #6,579,714), which describes methods for culturing algae, has been cited by 112 subsequent patents, more than six times as many as expected. Table 11 also includes patents related to various other technologies, including waste water treatment, microfluidics and bioreactor technologies. These examples reflect the breadth of influence of BETO-funded algae research on subsequent high-impact technological developments.

Table 11 - Highly Cited Patents (not from leading algae organizations) Linked via Citations to Earlier BETO-funded Algae Patents

Patent #	Issue Year	# Cites Received	Citation Index	Assignee	Title
6524486	2003	110	7.27	Sepal Technologies	Microalgae separator apparatus and method
7745209	2010	40	7.01	Corning	Multilayered cell culture apparatus
6579714	2003	112	6.30	Micro Gaia Ltd	Method of culturing algae capable of producing phototrophic pigments, highly unsaturated fatty acids, or polysaccharides
6673532	2004	72	5.01	Univ Maryland	Bioreactor and bioprocessing technique
6000551	1999	47	3.45	Eastman Chemical	Method for rupturing microalgae cells
5337516	1994	52	3.39	Unassigned	Treatment of polluted water using wetland plants in a floating habitat
7410637	2008	24	3.34	Ohio St Univ / Phycotransgenics	Transgenic algae for delivering antigens to an animal
6811752	2004	58	3.30	Biocrystal Ltd	Device having microchambers and microfluidics
7897798	2011	24	3.07	McNeff Research Consultants	Methods and apparatus for producing alkyl esters from lipid feed stocks and systems including same
5527456	1996	61	3.01	Unassigned	Apparatus for water purification by culturing and harvesting attached algal communities

As with the backward tracing element of the analysis, the patent-level results from the forward tracing focus on BETO-funded algae patents. That said, within the forward tracing, we did also identify Other DOE-funded algae patent families linked to the largest number of subsequent patent families within and beyond algae technology. These Other DOE-funded algae families are shown in Table 12.

Table 12 - Other DOE-funded Algae Patent Families Linked via Citations to Largest Number of Subsequent Algae/Other Patent Families

Family #	Priority Year	Rep. Patent #	# Linked Families	# Linked Algae Fams	Assignee	Title
23890840	1990	5011604	331	21	DuPont	Use of microalgae to remove pollutants from power plant discharges
29420982	2001	6648949	237	23	US Dept Energy	System for small particle and CO2 removal from flue gas using an improved chimney or stack
27396594	2000	6667171	135	49	Ohio University	Enhanced practical photosynthetic CO2 mitigation
26717244	1993	5614097	70	7	Microbial & Aquatic Treat Syst	Compositions and method of use of constructed microbial mats
23535884	1982	4442211	67	32	US Dept Energy	Method for producing hydrogen and oxygen by use of algae
23958651	2000	6555500	59	30	Univ California (LANL)	Use of prolines for improving growth and other properties of plants and algae
39876106	2006	8753840	38	18	Arizona St University	Modified cyanobacteria
39230797	2006	7973214	22	8	UT-Battelle (ORNL)	Designer organisms for photosynthetic production of ethanol from CO2 and water

The patent family at the head of Table 12 (representative patent US #5,011,604) is assigned to DuPont and describes the use of microalgae to decontaminate power plant discharges. This DuPont patent family is linked via citations to 331 subsequent patent families, only 21 of which are related to algae, with many of the remainder being related to power plant technologies. The second patent family in Table 12 (representative patent US #6,648,949) is assigned to DOE itself. It is linked via citations to 237 subsequent families, only 23 of which are related to algae technology. Note that this DOE patent was marked as unknown in terms of funding source, so it is possible that it could have been funded by BETO. There are a number of patent families in Table 12 with stronger citation links within algae technology. For example, the third patent family listed in Table 12 (representative patent US #6,667,171) is linked via citations to 135 subsequent families, 49 of which are related to algae.

Overall, the forward tracing element of the analysis shows that BETO-funded and Other DOE-funded algae research has had a strong influence on subsequent technologies. This influence can be seen most extensively in algae technology, but can also be traced in other technologies such as waste water treatment, carbon dioxide sequestration and power generation.

5.0 Conclusions

This report describes the results of an analysis tracing links between algae research funded by DOE (BETO plus Other DOE) and subsequent developments both within and beyond algae 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 BETO-funded (and Other DOE-funded) research forms a foundation for innovations associated with the leading algae organizations. The purpose of the forward tracing is to examine the influence of BETO-funded (and Other DOE-funded) algae patents both within and outside algae technology.

The backward tracing element of the analysis suggests that the portfolios of BETO-funded and Other DOE-funded algae patents have had an important influence on subsequent innovations associated with the leading algae organizations. This influence can be seen both over time and across technologies, with a various DOE-funded patent families linked via citations to subsequent patents assigned to a number of the leading organizations. Meanwhile, the forward tracing element of the analysis shows that BETO-funded and Other DOE-funded algae research has had a strong influence on subsequent technologies. This influence can be seen most extensively within algae technology, but can also be traced in other technologies such as waste water treatment, carbon dioxide sequestration and power generation.

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

Appendix A. Algae Patents in Families Associated with BETO Funding

Patent #	Application Year	Issue / Publication Year	Original Assignee	Title
4253271	1978	1981	BATTELLE MEMORIAL INSTITUTE	MASS ALGAL CULTURE SYSTEM
4320594	1980	1982	BATTELLE MEMORIAL INSTITUTE	MASS ALGAL CULTURE SYSTEM
5559220	1995	1996	MIDWEST RESEARCH INSTITUTE	GENE ENCODING ACETYL-COENZYME A CARBOXYLASE
5661017	1995	1997	MIDWEST RESEARCH INSTITUTE	METHOD TO TRANSFORM ALGAE, MATERIALS THEREFOR, AND PRODUCTS PRODUCED THEREBY
5871952	1997	1999	MIDWEST RESEARCH INSTITUTE	PROCESS FOR SELECTION OF OXYGEN-TOLERANT ALGAL MUTANTS THAT PRODUCE H2 UNDER AEROBIC CONDITIONS
5928932	1996	1999	MIDWEST RESEARCH INSTITUTE	ISOLATED GENE ENCODING AN ENZYME WITH UDP-GLUCOSE PYROPHOSPHORYLASE AND PHOSPHOGLUCOMUTASE ACTIVITIES FROM CYCLOTELLA CRYPTICA
6277589	1999	2001	MIDWEST RESEARCH INSTITUTE	METHOD AND APPARATUS FOR RAPID BIOHYDROGEN PHENOTYPIC SCREENING OF MICROORGANISMS USING A CHEMOCHROMIC SENSOR
6448068	2001	2002	MIDWEST RESEARCH INSTITUTE	SYSTEM FOR RAPID BIOHYDROGEN PHENOTYPIC SCREENING OF MICROORGANISMS USING A CHEMOCHROMIC SENSOR
WO2005042694	2003	2005	ALLIANCE FOR SUSTAINABLE ENERGY LLC	MULTI-STAGE MICROBIAL SYSTEM FOR CONTINUOUS HYDROGEN PRODUCTION
7229785	2004	2007	MIDWEST RESEARCH INSTITUTE	FLUORESCENCE TECHNIQUE FOR ON-LINE MONITORING OF STATE OF HYDROGEN-PRODUCING MICROORGANISMS
WO2007134141	2007	2007	OHIO UNIVERSITY	APPARATUS AND METHOD FOR GROWING BIOLOGICAL ORGANISMS FOR FUEL AND OTHER PURPOSES
WO2008144619	2008	2008	OHIO UNIVERSITY	FLOW-CONTROLLING HEADER
EP2016166	2007	2009	OHIO UNIVERSITY	APPARATUS AND METHOD FOR GROWING BIOLOGICAL ORGANISMS FOR FUEL AND

				OTHER PURPOSES
7732174	2003	2010	ALLIANCE FOR SUSTAINABLE ENERGY LLC	MULTI-STAGE MICROBIAL SYSTEM FOR CONTINUOUS HYDROGEN PRODUCTION
7905930	2007	2011	GENIFUEL CORP	TWO-STAGE PROCESS FOR PRODUCING OIL FROM MICROALGAE
7977076	2007	2011	GENIFUEL CORP	INTEGRATED PROCESSES AND SYSTEMS FOR PRODUCTION OF BIOFUELS USING ALGAE
WO2011163514	2011	2011	STREAMLINE AUTOMATION LLC	DECONSTRUCTING ALGAE USING IONIC LIQUIDS
8211307	2011	2012	STREAMLINE AUTOMATION LLC	METHOD AND APPARATUS FOR PROCESSING ALGAE
8303818	2010	2012	STREAMLINE AUTOMATION LLC	METHOD AND APPARATUS USING AN ACTIVE IONIC LIQUID FOR ALGAE BIOFUEL HARVEST AND EXTRACTION
WO2012040698	2011	2012	MONTANA STATE UNIVERSITY	BICARBONATE TRIGGER FOR INDUCING LIPID ACCUMULATION IN ALGAL SYSTEMS
WO2012071467	2011	2012	MICHIGAN STATE UNIVERSITY	AN ENVIRONMENTAL PHOTOBIOREACTOR ARRAY (EPBRA) SYSTEM AND METHODS RELATED THERETO
WO2012116335	2012	2012	ALGENOL BIOTECH LLC	MAGNETICALLY COUPLED SYSTEM FOR MIXING
8388846	2011	2013	STREAMLINE AUTOMATION LLC	METHOD AND APPARATUS FOR LYSING AND PROCESSING ALGAE
8398296	2012	2013	ALGENOL BIOTECH LLC	MAGNETICALLY COUPLED SYSTEM FOR MIXING
8404004	2007	2013	GENIFUEL CORP	PROCESS OF PRODUCING OIL FROM ALGAE USING BIOLOGICAL RUPTURING
8450111	2010	2013	STREAMLINE AUTOMATION LLC	LIPID EXTRACTION FROM MICROALGAE USING A SINGLE IONIC LIQUID
8470584	2007	2013	OHIO UNIVERSITY	APPARATUS AND METHOD FOR GROWING BIOLOGICAL ORGANISMS FOR FUEL AND OTHER PURPOSES
8475543	2011	2013	GENIFUEL CORP	TWO-STAGE PROCESS FOR PRODUCING OIL FROM MICROALGAE
EP2585582	2011	2013	STREAMLINE AUTOMATION LLC	DECONSTRUCTING ALGAE USING IONIC LIQUIDS
EP2619304	2011	2013	MONTANA STATE UNIVERSITY	BICARBONATE TRIGGER FOR INDUCING LIPID ACCUMULATION IN ALGAL

				SYSTEMS
WO2013063085	2012	2013	WASHINGTON STATE UNIVERSITY (PULLMAN WA)	SEQUENTIAL HYDROTHERMAL LIQUIFACTION (SEQHTL) FOR EXTRACTION OF SUPERIOR BIO-OIL AND OTHER ORGANIC COMPOUNDS FROM OLEAGINOUS BIOMASS
WO2013184317	2013	2013	BATTELLE MEMORIAL INSTITUTE	COMBINED HYDROTHERMAL LIQUEFACTION AND CATALYTIC HYDROTHERMAL GASIFICATION SYSTEM AND PROCESS FOR CONVERSION OF BIOMASS FEEDSTOCKS
8636815	2011	2014	GENIFUEL CORP	PROCESS OF PRODUCING OIL FROM ALGAE USING BIOLOGICAL RUPTURING
8684592	2013	2014	ALGENOL BIOTECH LLC	MAGNETICALLY COUPLED SYSTEM FOR MIXING
8703478	2008	2014	OHIO UNIVERSITY	FLOW-CONTROLLING HEADER
8722389	2011	2014	UNITED STATES OF AMERICA DEPARTMENT OF ENERGY	METHOD AND SYSTEM OF CULTURING AN ALGAL MAT
8828705	2011	2014	IOWA STATE UNIVERSITY	MAGNETIC MESOPOROUS MATERIAL FOR THE SEQUESTRATION OF ALGAE
8846369	2013	2014	ALGENOL BIOTECH LLC	CYANOBACTERIUM SP. HOST CELL AND VECTOR FOR PRODUCTION OF CHEMICAL COMPOUNDS IN CYANOBACTERIAL CULTURES
8858657	2011	2014	ARROWHEAD CENTER INC	DIRECT CONVERSION OF ALGAL BIOMASS TO BIOFUEL
WO2014100798	2013	2014	ALGENOL BIOTECH LLC	NOVEL SHUTTLE VECTOR CAPABLE OF TRANSFORMING MULTIPLE GENERA OF CYANOBACTERIA
WO2014100799	2013	2014	ALGENOL BIOTECH LLC	CYANOBACTERIUM SP. FOR PRODUCTION OF COMPOUNDS
WO2014145185	2014	2014	ALGENOL BIOTECH LLC	PROCESS FOR INOCULATING CLOSED PHOTOBIOREACTORS WITH CYANOBACTERIA
WO2014209469	2014	2014	HONEYWELL INTERNATIONAL INC.	METHODS FOR REMOVING CONTAMINANTS FROM OILS USING BASE WASHING AND ACID WASHING
9005955	2012	2015	WASHINGTON UNIVERSITY IN ST. LOUIS (ST. LOUIS MISSOURI)	BUOYANT TRIACYLGLYCEROL-FILLED GREEN ALGAE AND METHODS THEREFOR
9045698	2013	2015	HONEYWELL	METHODS FOR REMOVING

			INTERNATIONAL INC.	CONTAMINANTS FROM OILS USING BASE WASHING AND ACID WASHING
9096875	2011	2015	MONTANA STATE UNIVERSITY	BICARBONATE TRIGGER FOR INDUCING LIPID ACCUMULATION IN ALGAL SYSTEMS
9121012	2013	2015	ALGENOL BIOTECH LLC	STAGED INOCULATION OF MULTIPLE CYANOBACTERIAL PHOTOBIOREACTORS
9139805	2013	2015	ALGENOL BIOTECH LLC	MAGNETICALLY COUPLED SYSTEM FOR MIXING
9157101	2013	2015	ALGENOL BIOTECH LLC	CYANOBACTERIUM SP. FOR PRODUCTION OF COMPOUNDS
9200235	2012	2015	STREAMLINE AUTOMATION LLC	METHOD AND APPARATUS FOR ITERATIVE LYSIS AND EXTRACTION OF ALGAE
EP2859070	2013	2015	BATTELLE MEMORIAL INSTITUTE	COMBINED HYDROTHERMAL LIQUEFACTION AND CATALYTIC HYDROTHERMAL GASIFICATION SYSTEM AND PROCESS FOR CONVERSION OF BIOMASS FEEDSTOCKS
EP2935566	2013	2015	ALGENOL BIOTECH LLC	CYANOBACTERIUM SP. FOR PRODUCTION OF COMPOUNDS
WO2015069845	2014	2015	BATTELLE MEMORIAL INSTITUTE	SYSTEM AND PROCESS FOR EFFICIENT SEPARATION OF BIOCRUDES AND WATER IN A HYDROTHERMAL LIQUEFACTION SYSTEM
9309541	2015	2016	ALLIANCE FOR SUSTAINABLE ENERGY LLC	BIOLOGICAL PRODUCTION OF ORGANIC COMPOUNDS
9315403	2013	2016	ELDORADO BIOFUELS LLC	SYSTEM FOR ALGAE-BASED TREATMENT OF WATER
9315832	2014	2016	ALGENOL BIOTECH LLC	CYANOBACTERIUM SP. HOST CELL AND VECTOR FOR PRODUCTION OF CHEMICAL COMPOUNDS IN CYANOBACTERIAL CULTURES
9328310	2013	2016	ARROWHEAD CENTER INC	SUBCRITICAL WATER EXTRACTION OF LIPIDS FROM WET ALGAL BIOMASS
9388364	2015	2016	BATTELLE MEMORIAL INSTITUTE	LIQUEFACTION PROCESSES AND SYSTEMS AND LIQUEFACTION PROCESS INTERMEDIATE COMPOSITIONS
9404063	2014	2016	BATTELLE MEMORIAL INSTITUTE	SYSTEM AND PROCESS FOR EFFICIENT SEPARATION OF BIOCRUDES AND WATER IN A HYDROTHERMAL

				LIQUEFACTION SYSTEM
9453181	2014	2016	HONEYWELL INTERNATIONAL INC.	METHODS FOR REMOVING CONTAMINANTS FROM ALGAL OIL
9476067	2015	2016	ALGENOL BIOTECH LLC	SHUTTLE VECTOR CAPABLE OF TRANSFORMING MULTIPLE GENERA OF CYANOBACTERIA
9522965	2012	2016	WASHINGTON STATE UNIVERSITY (PULLMAN WA)	SEQUENTIAL HYDROTHERMAL LIQUIFACTION (SEQHTL) FOR EXTRACTION OF SUPERIOR BIO-OIL AND OTHER ORGANIC COMPOUNDS FROM OLEAGINOUS BIOMASS
9528119	2014	2016	LOS ALAMOS NATIONAL SECURITY LLC	TRANSGENIC CELLS WITH INCREASED PLASTOQUINONE LEVELS AND METHODS OF USE
WO2016201059	2016	2016	BATTELLE MEMORIAL INSTITUTE	LIQUEFACTION PROCESSES AND SYSTEMS AND LIQUEFACTION PROCESS INTERMEDIATE COMPOSITIONS
9562210	2015	2017	UNIVERSITY OF TOLEDO	METHODS FOR PRODUCTION OF FATTY ACID ALKANOLAMIDES (FAAAS) FROM MICROALGAE BIOMASS
9758728	2013	2017	BATTELLE MEMORIAL INSTITUTE	COMBINED HYDROTHERMAL LIQUEFACTION AND CATALYTIC HYDROTHERMAL GASIFICATION SYSTEM AND PROCESS FOR CONVERSION OF BIOMASS FEEDSTOCKS
9765362	2013	2017	GENIFUEL CORP	CLOSED-LOOP SYSTEM FOR GROWTH OF AQUATIC BIOMASS AND GASIFICATION THEREOF
9816065	2011	2017	MICHIGAN STATE UNIVERSITY	ENVIRONMENTAL PHOTOBIOREACTOR ARRAY (EPBRA) SYSTEMS AND APPARATUS RELATED THERETO
9862974	2013	2018	ALGENOL BIOTECH LLC	CYANOBACTERIUM SP. HOST CELL AND VECTOR FOR PRODUCTION OF CHEMICAL COMPOUNDS IN CYANOBACTERIAL CULTURES
9914947	2016	2018	ALLIANCE FOR SUSTAINABLE ENERGY LLC	BIOLOGICAL PRODUCTION OF ORGANIC COMPOUNDS
10077422	2016	2018	UNIVERSITY OF TOLEDO	MICROALGAE HARVESTING USING STIMULI-SENSITIVE HYDROGELS

10106809	2016	2018	LOS ALAMOS NATIONAL SECURITY LLC	TRANSGENIC CELLS WITH INCREASED PLASTOQUINONE LEVELS AND METHODS OF USE
10138426	2017	2018	BATTELLE MEMORIAL INSTITUTE	COMBINED HYDROTHERMAL LIQUEFACTION AND CATALYTIC HYDROTHERMAL GASIFICATION SYSTEM AND PROCESS FOR CONVERSION OF BIOMASS FEEDSTOCKS
EP3415614	2013	2018	ALGENOL BIOTECH LLC	CYANOBACTERIUM SP. FOR PRODUCTION OF COMPOUNDS

Appendix B. Algae Patents in Families Associated with Other DOE Funding

Patent #	Application Year	Issue / Publication Year	Original Assignee	Title
4442211	1982	1984	UNITED STATES OF AMERICA DEPARTMENT OF ENERGY	METHOD FOR PRODUCING HYDROGEN AND OXYGEN BY USE OF ALGAE
5011604	1990	1991	UNASSIGNED	USE OF MICROALGAE TO REMOVE POLLUTANTS FROM POWER PLANT DISCHARGES
5614097	1995	1997	MICROBIAL & AQUATIC TREATMENT SYSTEMS INC	COMPOSITIONS AND METHOD OF USE OF CONSTRUCTED MICROBIAL MATS
6008028	1997	1999	MICROBIAL & AQUATIC TREATMENT SYSTEMS INC	COMPOSITIONS OF CONSTRUCTED MICROBIAL MATS
WO2001054500	2001	2001	UNIVERSITY OF CALIFORNIA	USE OF PROLINES FOR IMPROVING GROWTH AND OTHER PROPERTIES OF PLANTS AND ALGAE
6555500	2002	2003	UNIVERSITY OF CALIFORNIA	USE OF PROLINES FOR IMPROVING GROWTH AND OTHER PROPERTIES OF PLANTS AND ALGAE
6593275	2002	2003	UNIVERSITY OF CALIFORNIA	USE OF PROLINES FOR IMPROVING GROWTH AND OTHER PROPERTIES OF PLANTS AND ALGAE
6648949	2001	2003	UNITED STATES OF AMERICA DEPARTMENT OF ENERGY	SYSTEM FOR SMALL PARTICLE AND CO2 REMOVAL FROM FLUE GAS USING AN IMPROVED CHIMNEY OR STACK
6667171	2001	2003	OHIO UNIVERSITY	ENHANCED PRACTICAL PHOTOSYNTHETIC CO2 MITIGATION
6831040	2000	2004	UNIVERSITY OF CALIFORNIA	USE OF PROLINES FOR IMPROVING GROWTH AND OTHER PROPERTIES OF PLANTS AND ALGAE
WO2005072254	2005	2005	UNIVERSITY OF CALIFORNIA	MODULATION OF SULFATE PERMEASE FOR PHOTOSYNTHETIC HYDROGEN PRODUCTION
6989252	2000	2006	MIDWEST RESEARCH INSTITUTE	HYDROGEN PRODUCTION USING HYDROGENASE-CONTAINING OXYGENIC PHOTOSYNTHETIC ORGANISMS
7176005	2004	2007	UNIVERSITY OF CALIFORNIA	MODULATION OF SULFATE PERMEASE FOR PHOTOSYNTHETIC

				HYDROGEN PRODUCTION
WO2007134340	2007	2007	UNASSIGNED	DESIGNER PROTON-CHANNEL TRANSGENIC ALGAE FOR PHOTOBIOLOGICAL HYDROGEN PRODUCTION
WO2007143354	2007	2007	UNASSIGNED	SWITCHABLE PHOTOSYSTEM-II DESIGNER ALGAE FOR PHOTOBIOLOGICAL HYDROGEN PRODUCTION
WO2008039450	2007	2008	UT-BATTELLE LLC	DESIGNER ORGANISMS FOR PHOTOSYNTHETIC PRODUCTION OF ETHANOL FROM CARBON DIOXIDE AND WATER
WO2008097691	2008	2008	ARIZONA PUBLIC SERVICE CO	SYSTEM AND METHOD FOR PRODUCING SUBSTITUTE NATURAL GAS FROM COAL
WO2008130437	2007	2008	ARIZONA STATE UNIVERSITY	MODIFIED CYANOBACTERIA
WO2008143630	2007	2008	SYNTHETIC GENOMICS INC	RECOMBINANT HYDROGEN-PRODUCING CYANOBACTERIUM AND USES THEREOF
EP2076586	2007	2009	SYNTHETIC GENOMICS INC	RECOMBINANT HYDROGEN-PRODUCING CYANOBACTERIUM AND USES THEREOF
EP2087096	2007	2009	ARIZONA STATE UNIVERSITY	MODIFIED CYANOBACTERIA
EP2125996	2008	2009	ARIZONA PUBLIC SERVICE CO	SYSTEM AND METHOD FOR PRODUCING SUBSTITUTE NATURAL GAS FROM COAL
7642405	2007	2010	UNASSIGNED	SWITCHABLE PHOTOSYSTEM-II DESIGNER ALGAE FOR PHOTOBIOLOGICAL HYDROGEN PRODUCTION
7745696	2006	2010	UNIVERSITY OF CALIFORNIA	SUPPRESSION OF TLA1 GENE EXPRESSION FOR IMPROVED SOLAR CONVERSION EFFICIENCY AND PHOTOSYNTHETIC PRODUCTIVITY IN PLANTS AND ALGAE
7803601	2007	2010	UNIVERSITY OF TEXAS	PRODUCTION AND SECRETION OF GLUCOSE IN PHOTOSYNTHETIC PROKARYOTES (CYANOBACTERIA)
WO2010030658	2009	2010	BATTELLE MEMORIAL INSTITUTE	PRODUCTION OF BIO-BASED MATERIALS

				USING PHOTOBIOREACTORS WITH BINARY CULTURES
7932437	2007	2011	UNASSIGNED	DESIGNER PROTON-CHANNEL TRANSGENIC ALGAE FOR PHOTOBIOLOGICAL HYDROGEN PRODUCTION
7973214	2007	2011	UT-BATTELLE LLC	DESIGNER ORGANISMS FOR PHOTOSYNTHETIC PRODUCTION OF ETHANOL FROM CARBON DIOXIDE AND WATER
WO2011106778	2011	2011	LOS ALAMOS NATIONAL SECURITY LLC / UNIV MAINE	TRANSGENIC ALGAE ENGINEERED FOR HIGHER PERFORMANCE
8236072	2007	2012	ARIZONA PUBLIC SERVICE CO	SYSTEM AND METHOD FOR PRODUCING SUBSTITUTE NATURAL GAS FROM COAL
8252561	2010	2012	UNIVERSITY OF GEORGIA	PRODUCTION OF BIOFUEL USING MOLLUSCAN PSEUDOFECES DERIVED FROM ALGAL CELLS
EP2468848	2007	2012	ARIZONA STATE UNIVERSITY	MODIFIED CYANOBACTERIA
EP2522735	2007	2012	ARIZONA STATE UNIVERSITY	MODIFIED CYANOBACTERIA
WO2012003460	2011	2012	ARIZONA STATE UNIVERSITY	COMPOSITIONS AND METHODS FOR BACTERIAL LYSIS AND NEUTRAL LIPID PRODUCTION
WO2012092666	2012	2012	HONEYWELL INTERNATIONAL INC.	APPARATUS AND METHOD FOR CONTROLLING AUTOTROPH CULTIVATION
8478444	2011	2013	HONEYWELL INTERNATIONAL INC.	APPARATUS AND METHOD FOR CONTROLLING AUTOTROPH CULTIVATION
8481974	2011	2013	LOCKHEED MARTIN CORP.	APPARATUS AND METHOD FOR MEASURING SINGLE CELL AND SUB-CELLULAR PHOTOSYNTHETIC EFFICIENCY
8518690	2009	2013	BATTELLE MEMORIAL INSTITUTE	PRODUCTION OF BIO-BASED MATERIALS USING PHOTOBIOREACTORS WITH BINARY CULTURES

EP2661510	2012	2013	HONEYWELL INTERNATIONAL INC.	APPARATUS AND METHOD FOR CONTROLLING AUTOTROPH CULTIVATION
WO2013162729	2013	2013	STANFORD UNIVERSITY / UNIV CALIFORNIA	METHOD FOR DELIVERY OF SMALL MOLECULES AND PROTEINS ACROSS THE CELL WALL OF ALGAE USING MOLECULAR TRANSPORTERS
8653331	2009	2014	UNASSIGNED	PHOTOBIOLOGICAL HYDROGEN PRODUCTION WITH SWITCHABLE PHOTOSYSTEM-II DESIGNER ALGAE
8715973	2013	2014	UNIVERSITY OF WISCONSIN	ORGANIC ACID-TOLERANT MICROORGANISMS AND USES THEREOF FOR PRODUCING ORGANIC ACIDS
8753840	2007	2014	ARIZONA STATE UNIVERSITY	MODIFIED CYANOBACTERIA
8846329	2014	2014	UNIVERSITY OF WISCONSIN	MICROORGANISMS FOR PRODUCING ORGANIC ACIDS
8846354	2014	2014	UNIVERSITY OF WISCONSIN	MICROORGANISMS FOR PRODUCING ORGANIC ACIDS
8859744	2007	2014	SYNTHETIC GENOMICS INC	RECOMBINANT HYDROGEN-PRODUCING CYANOBACTERIUM AND USES THEREOF
8865451	2011	2014	LOS ALAMOS NATIONAL SECURITY LLC / UNIV MAINE	TRANSGENIC ALGAE ENGINEERED FOR HIGHER PERFORMANCE
WO2014164320	2014	2014	CORNELL UNIVERSITY	PHOTOBIOREACTOR APPARATUS, METHOD AND APPLICATION
8986977	2012	2015	ALLIANCE FOR SUSTAINABLE ENERGY LLC	DISRUPTION OF CELL WALLS FOR ENHANCED LIPID RECOVERY
WO2015130832	2015	2015	UNIVERSITY OF CALIFORNIA	AGENTS FOR ENHANCEMENT OF PRODUCTION OF BIOFUEL PRECURSORS IN MICROALGAE
9255283	2011	2016	ARIZONA STATE UNIVERSITY	COMPOSITIONS AND METHODS FOR BACTERIAL LYSIS AND NEUTRAL LIPID PRODUCTION
9322013	2014	2016	LOS ALAMOS NATIONAL SECURITY	MAGNETIC SEPARATION OF ALGAE

			LLC	
9523070	2014	2016	CORNELL UNIVERSITY	PHOTOBIOREACTOR APPARATUS, METHOD AND APPLICATION
9556456	2010	2017	BATTELLE MEMORIAL INSTITUTE	PRODUCTION OF BIO-BASED MATERIALS USING PHOTOBIOREACTORS WITH BINARY CULTURES
9816066	2013	2017	STANFORD UNIVERSITY / UNIV CALIFORNIA	METHOD FOR DELIVERY OF SMALL MOLECULES AND PROTEINS ACROSS THE CELL WALL OF ALGAE USING MOLECULAR TRANSPORTERS
9970034	2015	2018	WOODS HOLE OCEANOGRAPHIC INST / WESTERN WASHINGTON UNIV	USE OF MARINE ALGAE FOR CO-PRODUCING ALKENONES, ALKENONE DERIVATIVES, AND CO-PRODUCTS
10077454	2015	2018	NATIONAL TECHNOLOGY & ENGINEERING SOLUTIONS OF SANDIA LLC	TANDEM BIOCHEMICAL AND THERMOCHEMICAL CONVERSION OF ALGAL BIOMASS
10155954	2016	2018	UNIVERSITY OF CALIFORNIA	AGENTS FOR ENHANCEMENT OF PRODUCTION OF BIOFUEL PRECURSORS IN MICROALGAE
10208321	2018	2019	WOODS HOLE OCEANOGRAPHIC INST / WESTERN WASHINGTON UNIV	USE OF MARINE ALGAE FOR CO-PRODUCING ALKENONES, ALKENONE DERIVATIVES, AND CO-PRODUCTS
10472643	2018	2019	UNIVERSITY OF CALIFORNIA	AGENTS FOR ENHANCEMENT OF PRODUCTION OF BIOFUEL PRECURSORS IN MICROALGAE

An Analysis of the Influence of BETO-funded Algae Patents

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