The Influence of Feedstock 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 bioenergy feedstock research funded by the U.S. Department of Energy (DOE)'s Bioenergy Technologies Office (BETO) and its precursor programs, as well as bioenergy feedstock 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 research related to bioenergy feedstocks (for simplicity, referred to hereafter as "feedstocks") has formed a foundation for innovations patented by leading feedstock organizations. Meanwhile, the primary purpose of the forward tracing is to examine the broader influence of BETO-funded feedstock research upon subsequent technological developments, both within and outside feedstocks. In addition to these BETO-based analyses, we also extend many elements of the analysis to other DOE-funded feedstock patents, in order to gain insights into their influence.

The main finding of this report is:

- Bioenergy feedstock research funded by BETO, and by DOE in general, has had a significant influence on subsequent developments, both within and beyond feedstock technology. This influence can be seen upon innovations associated with the leading feedstock organizations. It can also be traced in other technologies, notably biofuel production, chemical manufacturing, and waste treatment.

More detailed findings from this report include:

- In feedstock technology, in the period 1976-2018, we identified a total of 4,035 patents (1,201 U.S. patents, 1,144 EPO patents and 1,690 WIPO patents). We grouped these patents into 2,237 patent families, where each family contains all patents resulting from the same initial application (named the priority application). A patent family may contain multiple patents from across patent systems, for example U.S., EPO, and WIPO patents.

- 146 feedstock patents are confirmed to be associated with BETO funding (87 U.S. patents, 25 EPO patents, and 34 WIPO patents). We grouped these BETO-funded feedstock patents into 68 patent families, again based on shared priority applications.

- In addition, we identified a further 96 feedstock patents (62 U.S. patents, 12 EPO patents and 22 WIPO patents) that are associated with DOE funding. These "Other DOE-funded" patents are grouped into 54 patent families.

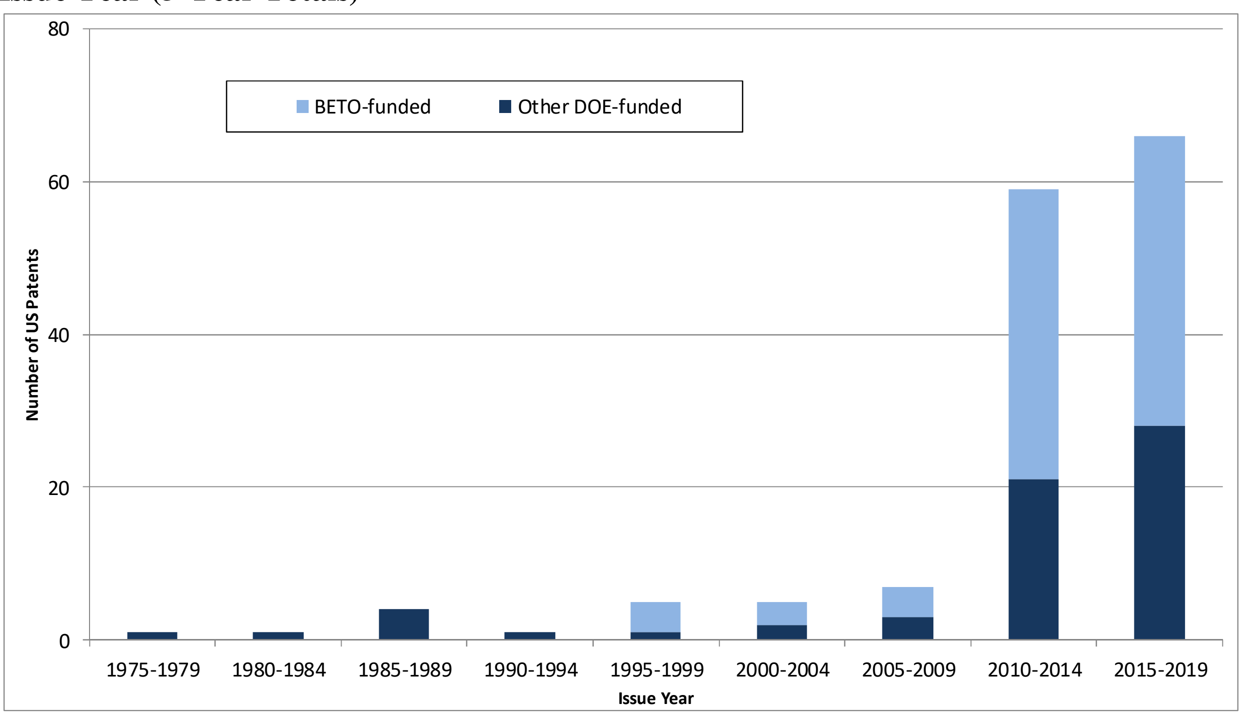
- Out of these 54 Other DOE-funded patent families, 45 are definitely not BETO-funded. These patent families were either funded by a different DOE office, or were marked as being not BETO-funded by inventors or BETO technology managers, but without specifying funding from another DOE source.

- The remaining nine Other DOE-funded feedstock patent families could not be linked definitively to a specific DOE funding source, and may in fact have been BETO-funded. Hence, up to 17% (9 out of 54) of the Other DOE-funded feedstock patent families in this analysis may be BETO-funded. As such, the results presented in this report may understate the influence of BETO-funded feedstock research, relative to the influence of feedstock research funded by DOE in general.

- The total number of DOE-funded feedstock patents (BETO-funded plus Other DOE-funded) is 242, corresponding to 122 patent families. This represents 5.5% of the total number of feedstock patent families in the period 1976-2018.

- Figure E-1 shows the number of BETO-funded and Other DOE-funded feedstock U.S. patents by issue year. This figure reveals that there was relatively little patent activity in the early time periods, with a total of eleven BETO-funded and thirteen Other DOE-funded U.S. patents issued through 2009. The number of patents then increased sharply from 2010 onwards. There were 59 DOE-funded feedstock U.S. patents issued in 2010-2014, 38 of which were BETO-funded. In 2015-2019 these numbers increased again to 66 DOE-funded patents (38 BETO-funded), even though data for this time period are incomplete (see note below Figure E-1).

Figure E-1 - Number of BETO/Other DOE-funded Feedstock 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.

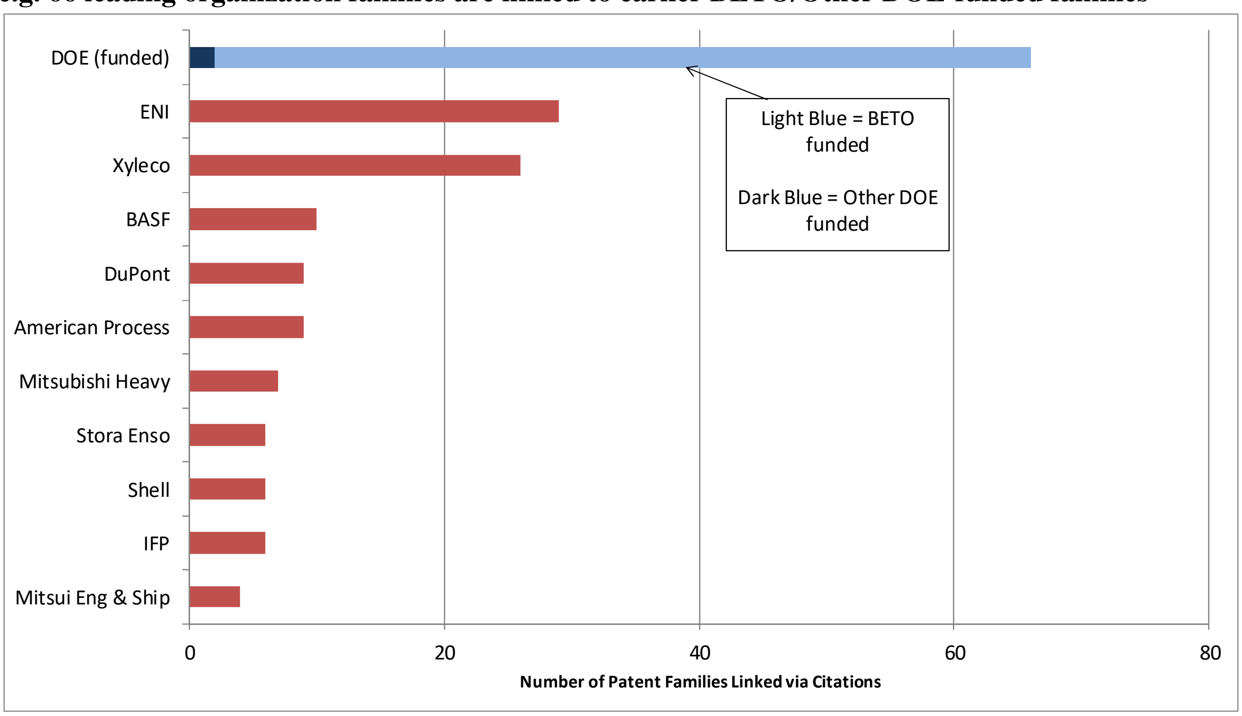
- The ten organizations with the largest bioenergy feedstock patent portfolios are: DuPont (40 patent families); American Process (35); Shell (35); Mitsubishi Heavy Industries

(30); ENI (28); Xyleco (25); BASF (21); Institut Français du Pétrole (19); Stora Enso (16); and Mitsui Engineering & Shipbuilding (15). The portfolio of 122 DOE-funded feedstock patent families (68 BETO-funded and 54 Other DOE-funded) is thus larger than the portfolios of each of the ten leading organizations. These size differences are taken into account in assessing the influence of the various patent portfolios.

- Taking the period 1976-2018 as a whole, the most common patent classification attached to BETO-funded feedstock patents is related to cellulosic ethanol. This reflects the fact that a number of the BETO-funded patents describe the chemical pretreatment of biomass for improved ethanol production (patent classifications concerned with biomass pretreatment are also prominent among BETO-funded patents). BETO-funded feedstock patents can also be found in patent classifications related to cutting fibrous materials, in particular comminution processes for crops and wood. These classifications are largely absent from the feedstock patents of leading companies, suggesting that BETO-funded feedstock research has helped to fill a research gap not addressed by these companies.

- Figure E-2 reveals that 66 feedstock patent families owned by the leading organizations (i.e. 25% of these 266 families) are linked via citations to earlier DOE-funded feedstock patents, out of which 64 are linked to BETO-funded feedstock patents. This puts DOE at the head of Figure E-2, and means that more leading organization feedstock patent families are linked to earlier DOE-funded feedstock patents than are linked to the patents of any other leading organization. As such, it suggests that the leading organizations have built extensively on DOE-funded, and particularly BETO-funded, feedstock patents.

Figure E-2 - Number of Leading Organization Feedstock Patent Families Linked via Citations to Earlier Feedstock Patents from each Leading Organization
e.g. 66 leading organization families are linked to earlier BETO/Other DOE-funded families

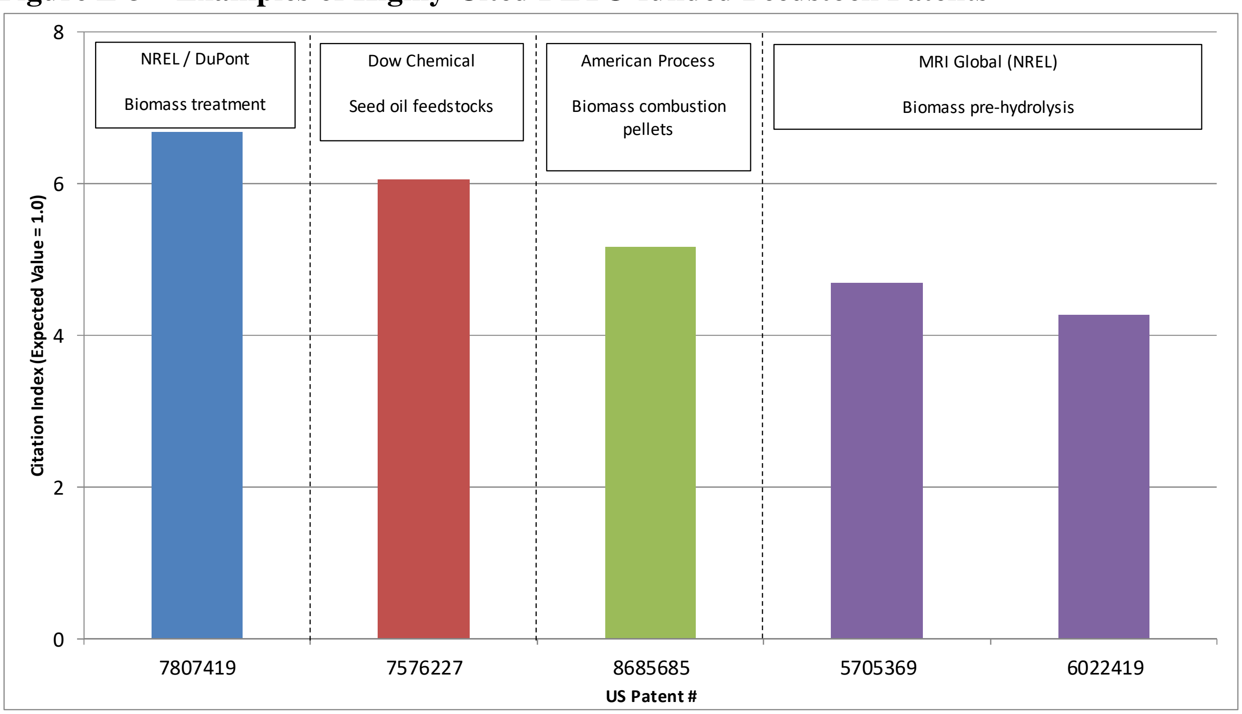


- Over half of DuPont's feedstock patent families are linked via citations to earlier BETO-funded feedstock patents. ENI, Xyleco and Stora Enso also have extensive citation links to BETO-funded patents. This suggests that BETO-funded research has had a particularly strong influence on feedstock innovations from these organizations.

- BETO-funded feedstock patents have an average Citation Index value of 2.17 (the Citation Index is a normalized citation metric with an expected value of 1.0; a value of 2.17 shows that, based on their age and technology, BETO-funded feedstock patents have been cited as prior art more than twice as frequently as expected by subsequent patents). The Citation Index for Other DOE-funded feedstock patents is lower at 0.90, showing that these patents have been cited slightly less frequently than expected. The influence of BETO-funded and Other DOE-funded feedstock patents can be seen extensively within feedstock technology. It can also be traced in other technologies such as biofuel production, chemical manufacturing and waste treatment.

- There are a number of individual high-impact BETO-funded feedstock patents, examples of which are shown in Figure E-3. They include a patent related to biomass treatment that is co-assigned to DuPont and the Alliance for Sustainable Energy – the latter through its management of the National Renewable Energy Laboratory (NREL). They also include a Dow Chemical patent describing seed oil feedstocks; an American Process patent for biomass combustion pellets; and a series of patents assigned to MRIGlobal (also through its management of NREL) outlining pre-hydrolysis of biomass.

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



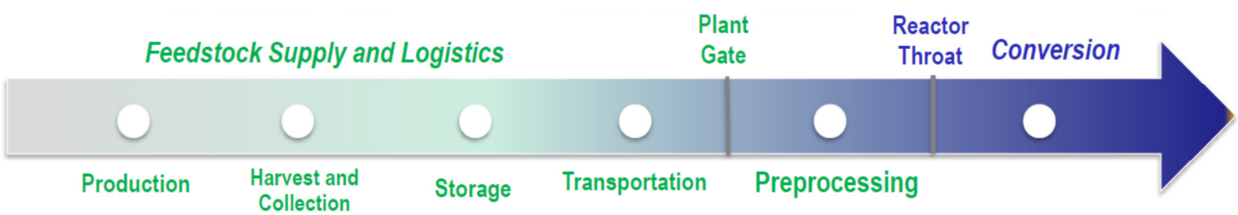
1.0 Introduction

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

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

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

Feedstock research focuses on technologies and processes that transform renewable and waste carbon sources to conversion-ready feedstocks. Raw, unprocessed materials obtained at the site of production (e.g., field, forest, pond, or landfill) are often not suitable for direct conversion into biofuels, bioproducts, and/or biopower due to quality and quantity issues. Instead, they need to first undergo one or more logistics and preprocessing operations (as noted in the figure below). These operations may include both mechanical and chemical processes. All such processes are considered within the scope of the feedstocks analysis described in this report.



Source: DOE Bioenergy Technologies Office

The primary focus of the report is on the influence of BETO-funded feedstock patents. That said, we also extend many elements of the analysis to DOE-funded feedstock 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 feedstock 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. Some of these patents are confirmed as being linked to funding from other DOE offices, while for others the source of funding within DOE is unknown. Many of these "unknown" patents may in fact have been funded by BETO, although a definitive link could not be established. Hence, the results reported here may underestimate the influence of BETO-funded feedstock research, relative to the influence of feedstock research funded by the rest of DOE.

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 feedstock 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 feedstocks and spillovers of this influence into other technologies. Patent level results are then presented to highlight individual BETO-funded feedstock patents that have been particularly influential, as well as to reveal key patents from other organizations that build extensively on BETO-funded feedstock 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 feedstock industry have used BETO-funded research as a foundation. Meanwhile, the primary purpose of the forward tracing is to examine how BETO-funded feedstock patents have influenced subsequent developments in feedstock technology, while also highlighting spillovers into other technologies. Many elements

[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.

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 feedstock 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 feedstock 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.

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

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[2] The analyses described in this report were carried out separately for BETO-funded and Other DOE-funded feedstock 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.

[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.

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 feedstock research. Specifically, we identify cases where patents cite DOE-funded feedstock 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 feedstock 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 feedstock research. By determining how frequently DOE-funded feedstock 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 feedstock technology.

Forward and Backward Tracing

As noted above, the purpose of this analysis is to trace the influence of DOE-funded feedstock research upon subsequent developments both within and beyond feedstock technology. There are two approaches to such a tracing study – backward tracing and forward tracing – each of which has a slightly different objective. Backward tracing, as the name suggests, looks backwards over time. The idea of backward tracing is to take a particular technology, product, or industry, and to trace back to identify the earlier technologies upon which it has built. In the context of this project, we first identify the leading feedstock 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 feedstock 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 feedstock 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 feedstock 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 feedstock 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 feedstock 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 feedstock 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 feedstock 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 feedstock 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 feedstock patents; and backward through two generations starting from the patents owned by leading feedstock 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 feedstock patent as prior art.
2. **Indirect Links**: where a patent cites an earlier patent, which in turn cites a DOE-funded feedstock patent. The DOE patent is linked indirectly to the subsequent patent.

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

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

Constructing Patent Families

The coverage of a patent is limited to the jurisdiction of its issuing authority. For example, a patent granted by the U.S. Patent & Trademark Office (a "U.S. patent") provides protection only within the United States. If an organization wishes to protect an invention in multiple countries, it must file patents in each of those countries' systems. For example, 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 feedstock patents, and also for the patents owned by leading feedstock organizations. We also assembled families for all patents linked via citations to DOE-funded feedstock 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 feedstock patent families by year of priority application
• No. of BETO/Other DOE-funded granted U.S. feedstock patents by issue year
• Overall number of feedstock patent families by priority year
• Percentage of feedstock patents families funded by BETO/Other DOE by priority year
Assignee Metrics
• Number of feedstock patent families for leading patenting organizations
• Assignees with largest number of feedstock patent families funded by BETO/Other DOE
Technology Metrics
• Patent classification (CPC) distribution for BETO-funded feedstock patent families (vs Other DOE-funded, leading feedstock organizations, all feedstock)
Backward Tracing Metrics
• Total/Average number of leading organization feedstock patent families linked via citations to earlier patent families from BETO/Other DOE-funding and other leading organizations
• Number of feedstock 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 feedstock patent families linked via citations to earlier BETO/Other DOE-funded patent families
• BETO/Other DOE-funded feedstock patent families linked via citations to largest number of leading organization feedstock patent families
• Leading organization feedstock patent families linked via citations to largest number of BETO-funded feedstock patent families
• Highly cited leading organization feedstock patent families linked via citations to earlier BETO-funded feedstock patent families
Forward Tracing Metrics
• Citation Index for feedstock patent portfolios owned by leading organizations, plus portfolios of BETO/Other DOE-funded feedstock patents
• Number of patent families linked via citations to BETO/Other DOE-funded feedstock patents by patent classification
• Organizations (beyond leading feedstock organizations) linked via citations to largest number of BETO/Other DOE-funded feedstock patent families
• Highly cited BETO-funded feedstock U.S. patents
• BETO/Other DOE-funded feedstock patent families linked via citations to largest number of subsequent feedstock/non-feedstock patent families
• Highly cited patents (not leading organization-owned) linked via citations to BETO-funded feedstock 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) feedstock research on subsequent developments both within and outside feedstock 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 feedstock patents owned by leading patenting organizations in this technology. Meanwhile, the forward tracing starts from the sets of feedstock patents funded by BETO and Other DOE. We therefore had to define various data sets – BETO-funded feedstock patents; Other DOE-funded feedstock patents; and feedstock patents assigned to the leading organizations in this technology.

Identifying BETO-funded and Other DOE-funded Feedstock Patents

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

(i) Defining the universe of DOE-funded patents;
(ii) Determining which of the DOE-funded patents are relevant to feedstock technology;
(iii) Categorizing these DOE-funded feedstock 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 Feedstock Patents

Having defined the universe of DOE-funded patents, the next step was to determine which of these patents are relevant to feedstock technology. We designed a custom patent filter to identify feedstock 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), so patents that qualify under any of the three filters in Table 2 were included in the initial patent set.

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

Filter A
Cooperative Patent Classification
C10L 5/363 – Solid fuel pellets
C10L 5/44, 442, 445, 447 – Biomass from vegetable sources (e.g. wood, corn, grass etc).
C10L 9/083 – Torrefaction of solid fuels
F26B 2200/02 – Drying biomass
Filter B
Cooperative Patent Classification
C08H 8/00 – Macromolecular compounds from lignocellulosic materials
C08L 97/02 – Lignocellulosic materials
Y02P 60/20 – Reduction of greenhouse gases in agriculture
AND
Title/Abstract
biomass* or feedstock* or switch(-)grass$ or sorghum or willow or poplar or stover or miscanthus or ligno(-)cellul*
Filter C
Title/Abstract
(biomass* or feedstock*) AND (switch(-)grass$ or sorghum or willow or poplar or stover or miscanthus or ligno(-)cellul*)
NOT
(Title/Abstract
bio(-)fuel* or ethanol* or bio(-)ethanol* or bio(-)diesel*
OR
Cooperative Patent Classification
Y02E 50 – Technologies for non-fossil fuel production
Y02P 30/42 – Ethylene production using bio-feedstocks
Y02P 30/20 – Oil refining using bio-feedstocks)

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

In addition to this filter, BETO technology managers supplied specific terms related to feedstock harvesting, feedstock storage, feedstock supply logistics, preprocessing, agriculture residues and, forestry residues. These keywords were also checked, and relevant patents added to the patent set generated from the filters.

We manually checked this initial list of patents to determine which of them appear relevant to feedstocks, and then sent the resulting patent list to BETO for review. Following this review, and based on feedback from BETO, the initial list of feedstock patents funded by DOE contained a total of 143 granted U.S. patents.

Defining BETO-funded vs. Other DOE-funded Feedstock 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 143 DOE-funded feedstock 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 Feedstock Patents

Based on the process described above, we divided the initial list of 143 DOE-funded feedstock 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 feedstock patents and patent families. These DOE-funded portfolios include patent families back to the 1970s, although most of the families are much more recent.

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

	# Patent Families	# U.S. Patents	# EPO Patents	# WIPO Patents
BETO-funded	68	87	25	34
Other DOE-funded	54	62	12	22
Total DOE-funded	122	149	37	56

Table 3 shows that we identified a total of 68 BETO-funded feedstock patent families, containing 87 U.S. patents, 25 EPO patents, and 34 WIPO patents (see Appendix A for patent list). We also identified 54 Other DOE-funded feedstock patent families, containing 62 U.S. patents, 12 EPO patents, and 22 WIPO patents (see Appendix B for patent list).

As noted throughout this report, the approach used to define patents as BETO-funded was very stringent. Hence, a number of the 54 Other DOE-funded patent families may in fact have been funded by BETO, but are not categorized as such because a definite link could not be established. To get a better sense of how many of these Other DOE-funded patents (and patent families) may in fact be BETO-funded, we divided them into two groups. The first group contains DOE-funded patent families that were definitely not funded by BETO. These include families linked specifically to funding from an office other than BETO, or that the inventor or BETO technology manager said were not funded by BETO (but without specifying funding from a different office). There are 45 such patent families. The second group contains DOE-funded patent families where the funding source within DOE could not be established, and inventors and BETO technology managers could not state categorically whether or not they were funded by BETO. There are nine such patent families. Hence, up to 17% (9 out of 54) of the Other DOE-funded patent families included in this analysis may in fact be BETO-funded. As a result, the findings in this analysis may understate the influence of BETO-funded feedstock patents, relative to the influence of the remainder of DOE patents.

Identifying Feedstock 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 feedstock innovations produced by leading organizations in this technology. To identify such organizations, we first defined the universe of feedstock patents in the period 1976-2018 using the patent filter detailed earlier in Table 2. Based on this filter, we identified a total of 1,201 feedstock U.S. patents, 1,144 feedstock EPO patents, and 1,690 feedstock WIPO patents. We grouped these patents into 2,237 patent families by matching priority documents.

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

Table 4 – Top 10 Patenting Feedstock Organizations

Organization	# Feedstock Patent Families
DuPont de Nemours Inc.	40
American Process Inc.	35
Royal Dutch Shell Group of Cos	35
Mitsubishi Heavy Industries Ltd.	30
ENI SPA	28
Xyleco Inc.	25
BASF SE	21
Institut Français du Pétrole	19
Stora Enso AB	16
Mitsui Engineering & Shipbuilding Co Ltd	15

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 feedstock technology. The patent sets for the forward tracing consisted of BETO-funded (and, separately, Other DOE-funded) feedstock patent families. We then traced backward through two generations of citations from the leading organizations' feedstock patents, and forward through two generations of citations from the BETO/Other DOE-funded feedstock 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, plus 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 number of units sold or revenues, profits etc. A fuller description would be the leading patenting feedstock organizations, but this is a cumbersome description to use throughout the results section of the report.

4.0 Results

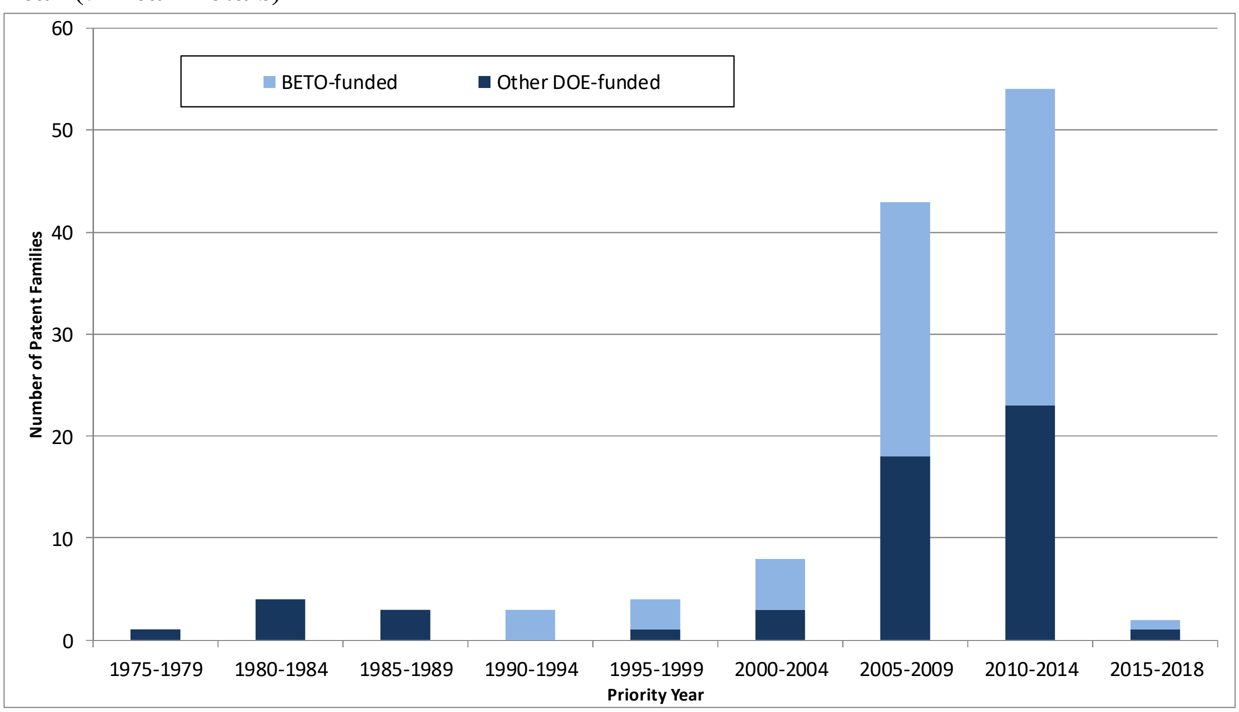
This section of the report outlines the results of our analysis tracing the influence of BETO-funded and Other DOE-funded feedstock research on subsequent developments both within and beyond feedstock technology. The results are divided into three main sections. In the first section, we examine trends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

Overall Trends in Feedstock Patenting

Trends in Feedstock Patenting over Time

Figure 1 shows the number of BETO-funded and Other DOE-funded feedstock 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 Feedstock Patent Families by Priority Year (5-Year Totals)

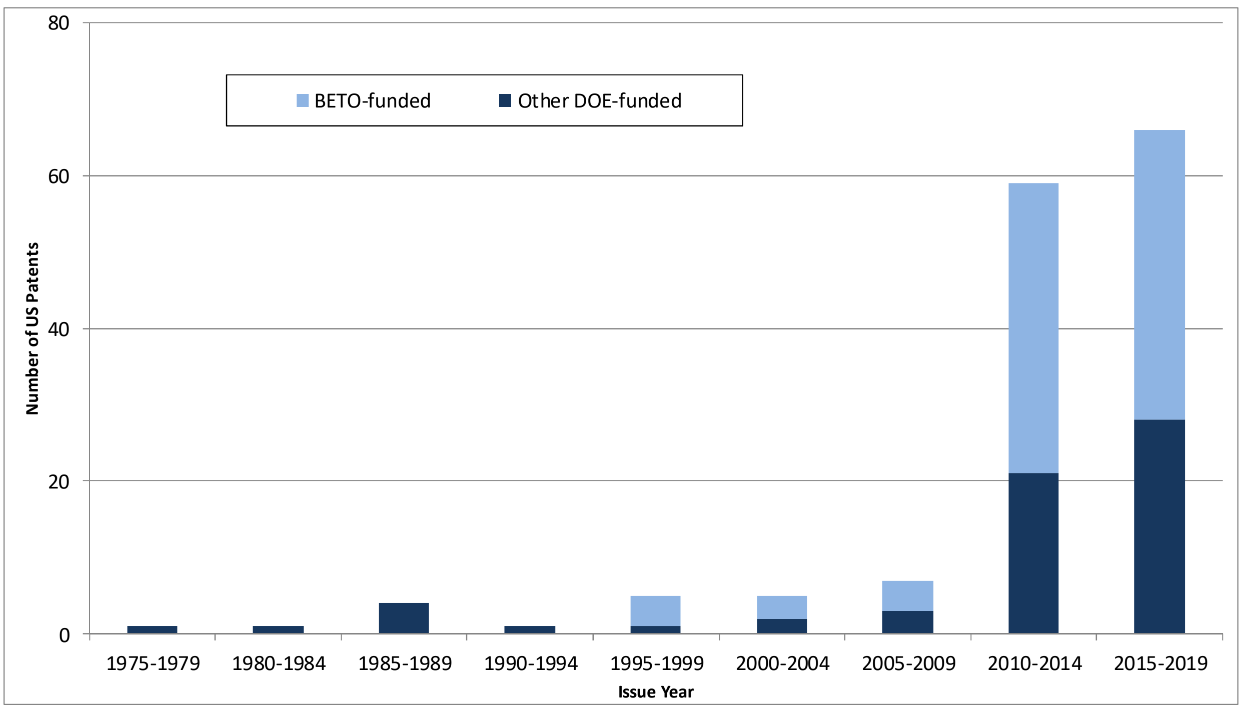


Note: The final time period in this figure is 2015-2018, and is shown for completeness, although data for this time period are incomplete. Our primary data collection covered only patents issued through 2018. Due to time lags associated with the patenting process, only a fraction of the patent families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

This figure reveals that there was very little DOE-funded feedstock patenting in the earliest periods in the analysis, with a total of only fifteen patent families filed in the twenty-five year period from 1975 through 1999. Six of these patent families were funded by BETO. There was then a slight increase in activity, with eight DOE-funded feedstock patent families in 2000-2004 (five of which were BETO-funded). The number of DOE-funded patent families then increased markedly, to 43 in 2005-2009 (25 BETO-funded), before peaking at 54 (31 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 122 DOE-funded feedstock patent families, 68 of which are BETO-funded.

Figure 2 shows the number of feedstock 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 a total of eleven BETO-funded and thirteen Other DOE-funded U.S. patents issued through 2009. The number of patents then increased sharply from 2010 onwards. There were 59 DOE-funded feedstock U.S. patents issued in 2010-2014, 38 of which were BETO-funded. In 2015-2019 these numbers increased again to 66 DOE-funded patents (38 BETO-funded), even though data for this time period are incomplete (see note below Figure 2).

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

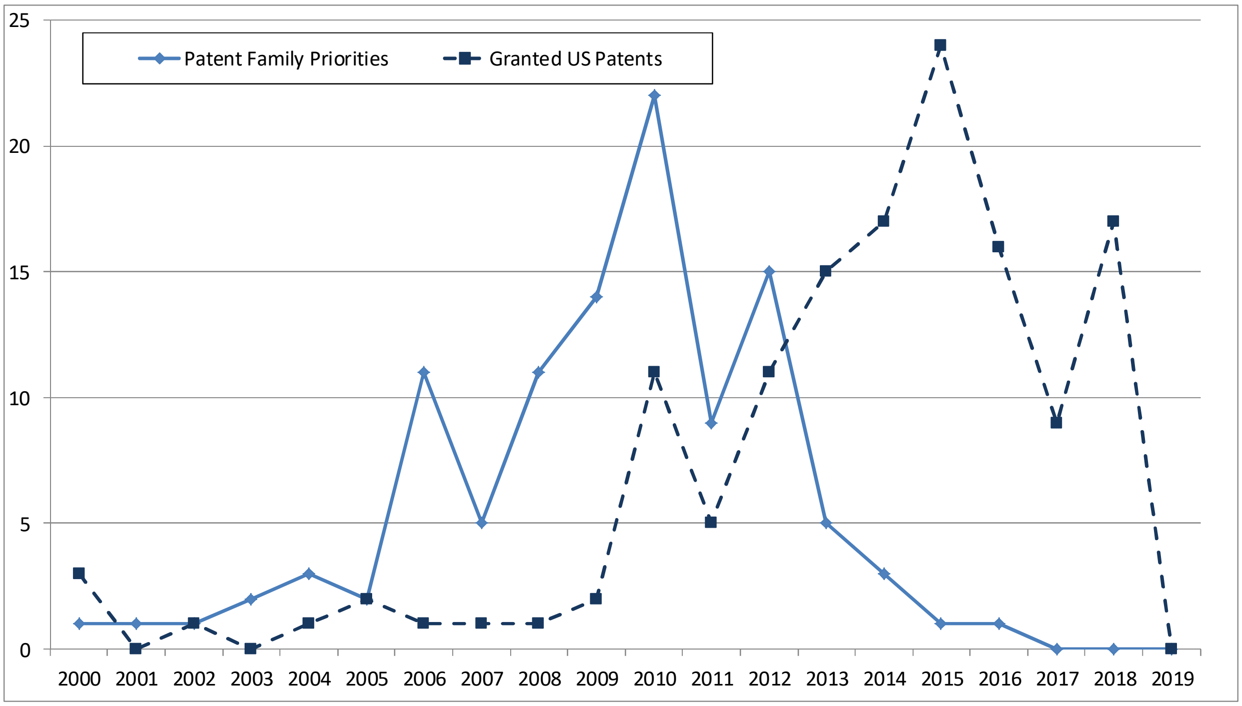


Note: The data collection period for this analysis ended with 2018. Any 2019 patents in the 2015-2019 column are additional patents that have been included because they are members of the same patent families as pre-2019 patents. No new patent search for 2019 was carried out.

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 feedstock patent family priority years alongside issue years for granted

U.S. feedstock 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 Figure 3, the peaks in patent family filings occurred in 2009-2012, with subsequent peaks in granted U.S. patents occurring in 2014-2016. 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 Feedstock Patent Families (by Priority Year) and Granted U.S. Patents (by Issue Year)

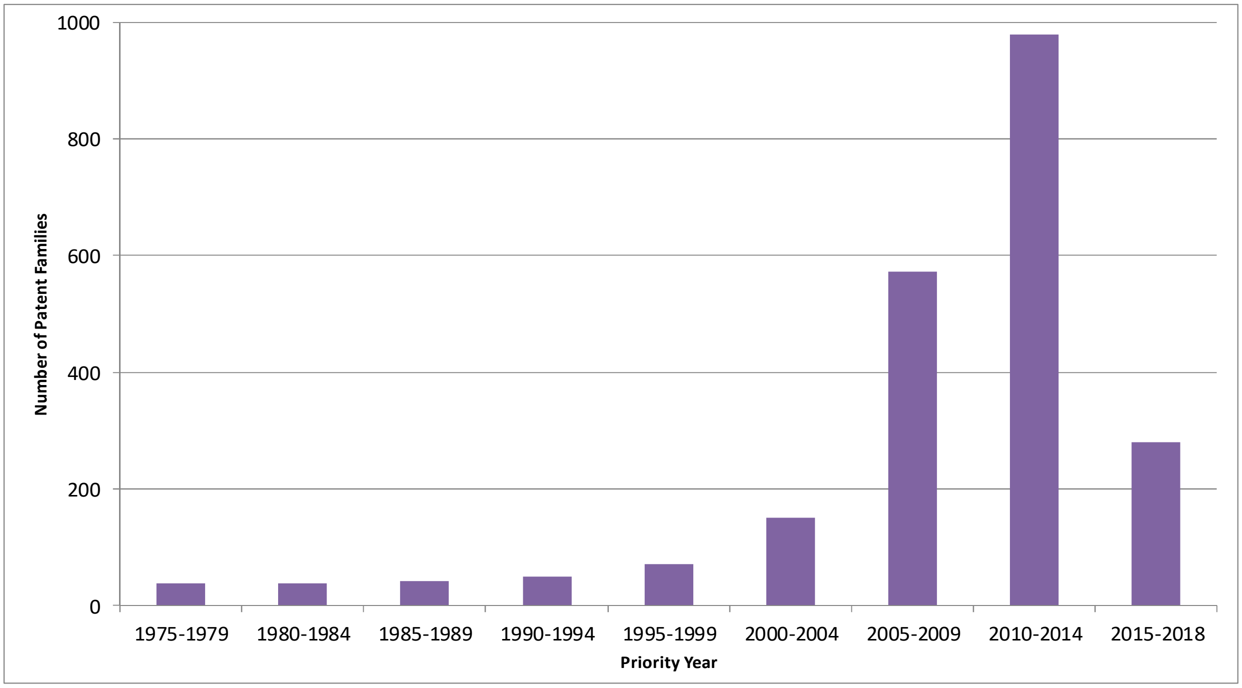


Note: The data collection period for this analysis ended with 2018. Any 2019 patents are additional patents that have been included because they are members of the same patent families as pre-2019 patents. No new patent search for 2019 was carried out.

Figures 1-3 focus on DOE-funded feedstock patent families. Figure 4 broadens the scope, and shows the overall number of feedstock patent families by priority year (based on USPTO, EPO, and WIPO filings). In the earliest time periods, there was relatively little patent activity in feedstock technology, with fewer than 50 patent families in each 5-year period through 1994. The number of feedstock patent families then grew slowly through 2004, before increasing sharply to 572 families in 2005-2009 and 980 families in 2010-2014 (i.e. twenty times as many feedstock patent families were filed in 2010-2014 as in 1990-1994). The number of patent families declined to 281 in 2015-2018, although data for this time period are incomplete. Comparing Figure 4 with Figure 1 suggests that the trend in BETO-funded and Other DOE-funded feedstock patenting is in line with the broader trend in this technology. Both figures show relatively little patent activity in the earliest years, before a sharp increase from 2005 onwards.

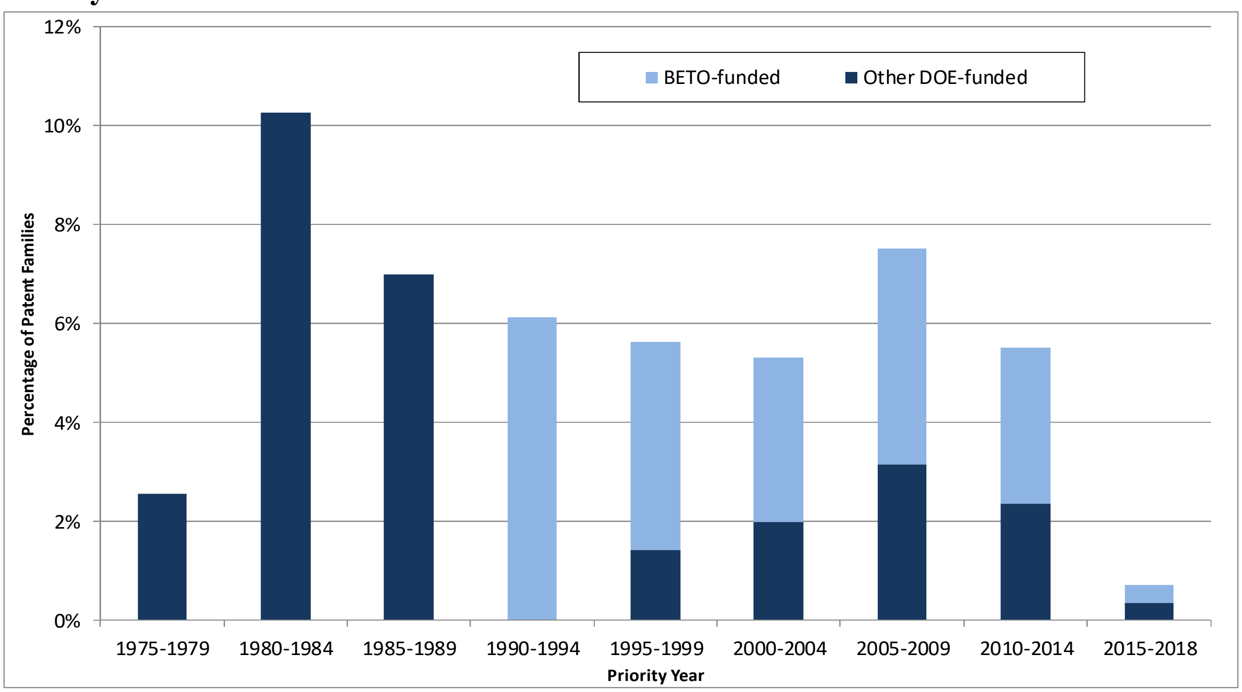
Figure 5 shows the percentage of feedstock patent families that were funded by DOE (BETO plus Other DOE) in each time period. In most of the time periods, these percentages are not particularly robust, since they are based on low numbers of patents (e.g. over 10% of patent families in 1980-1984 were funded by BETO, but this represents four out of 39 families). Of more interest are the recent time periods, where the numbers of patents are higher. For example, in 2005-2009, 8.5% of the 572 patent families were DOE-funded (with 4.4% BETO-funded), while in 2010-2014, 5.5% of families were DOE funded (with 3.2% BETO-funded). Overall, 5.5% of feedstock patent families filed in 1976-2018 were funded by DOE (3.1% by BETO).

Figure 4 - Total Number of Feedstock 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 - Percentage of Feedstock Patent Families Funded by BETO/Other DOE by Priority Year



Leading Feedstock Assignees

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

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

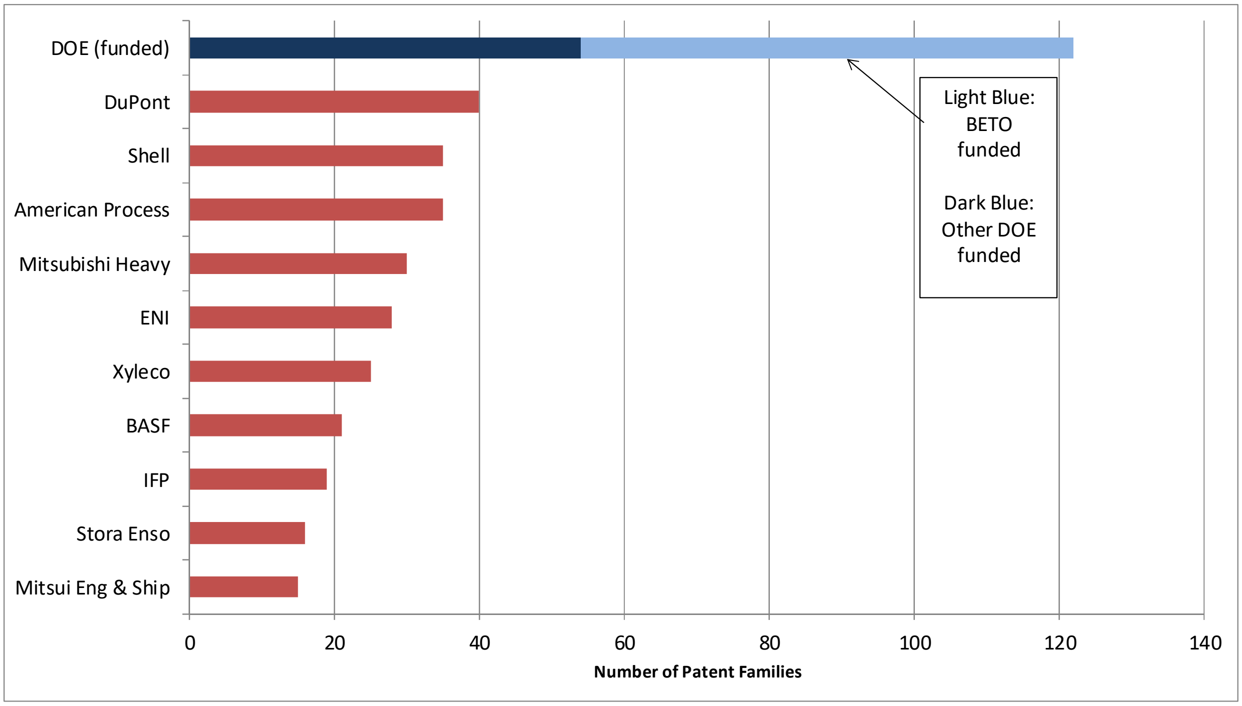


Figure 6 reveals that the portfolio of 122 DOE-funded feedstock patent families (68 BETO-funded; 54 Other DOE-funded) is larger than the feedstock patent portfolios associated with each of the ten leading feedstock organizations. DuPont has the largest portfolio among these organizations, containing 40 patent families, followed by Shell (35 families), American Process Incorporated (35 families) and Mitsubishi Heavy Industries (30 families). All of the other organizations in Figure 6 have feedstock patent portfolios containing fewer than 30 patent families. In assessing the impact of BETO-funded and Other DOE-funded feedstock 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 feedstock organizations in Figure 6. Out of these ten organizations, five are based in Europe, three in North America and two in Asia.

It should be noted that there is some double-counting of feedstock 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, there are five DuPont patent families and two American Process families that were funded by BETO, plus one Other DOE-funded Stora Enso patent family. 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 Feedstock Patents

The DOE-funded feedstock patent portfolios are constructed somewhat differently from the portfolios of the top ten organizations listed in Figure 6. Specifically, DOE's 122 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 DuPont, American Process and Stora Enso patent families discussed above).

Figure 7 shows the leading assignees on BETO-funded feedstock patent families. This chart is headed by Forest Concepts, which has twelve patent families funded by BETO. MRIGlobal (formerly Midwest Research Institute) is in second place in this figure with eight patent families, through its management of the National Renewable Energy Laboratory (NREL). Four organizations share third place in Figure 7 with five BETO-funded feedstock patent families each – Elevance, Michigan State University, DuPont, and the Alliance for Sustainable Energy (again through its management of NREL).

Figure 7 - Assignees with Largest No. of BETO-Funded Feedstock Patent Families

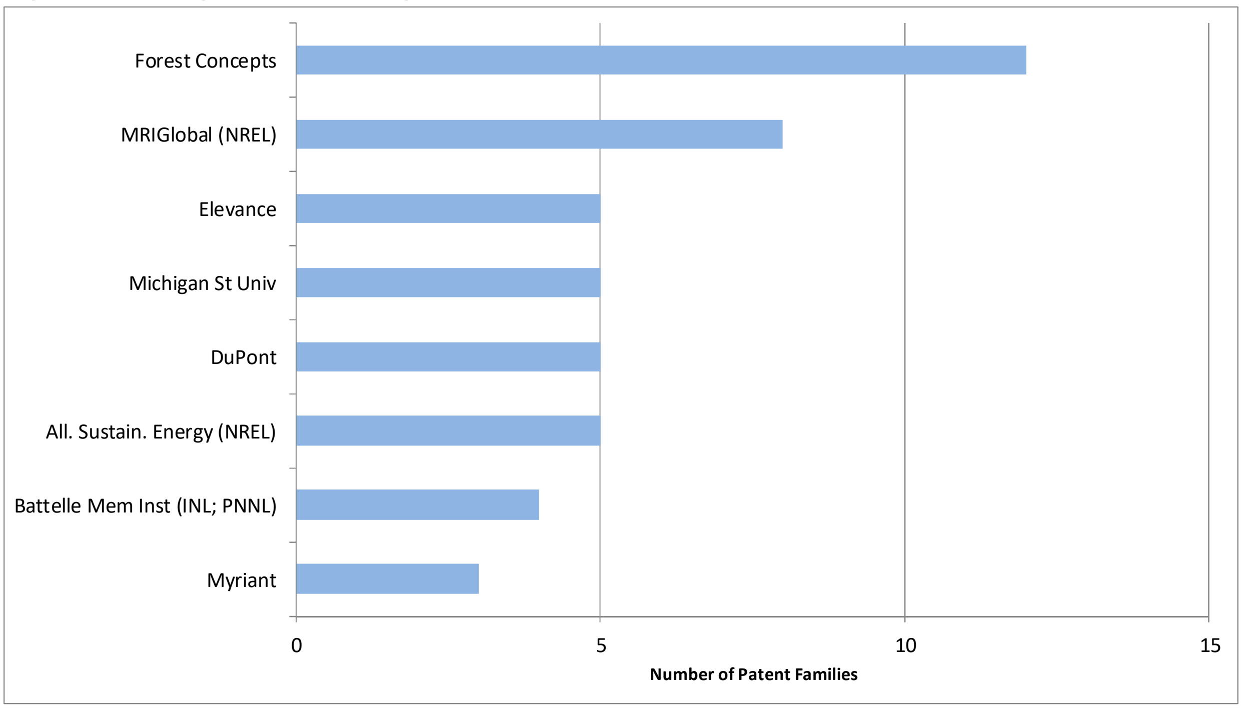
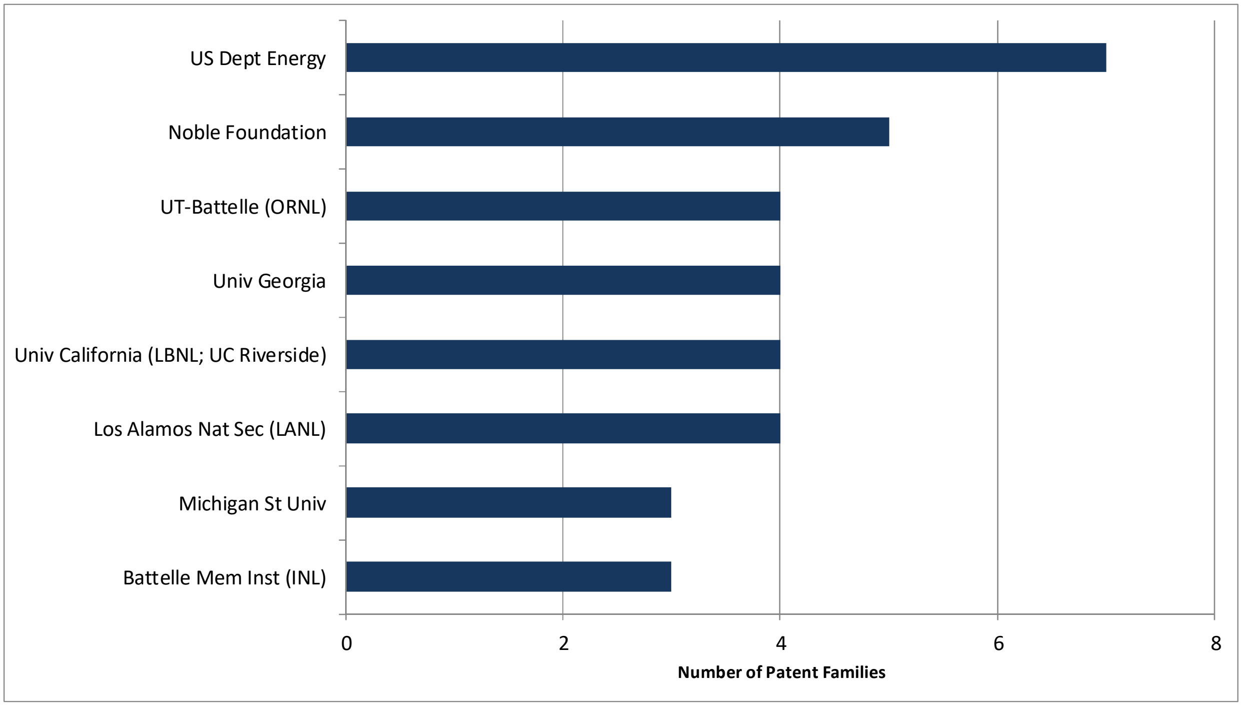


Figure 8 shows the leading assignees on Other DOE-funded feedstock patent families. This figure is headed by DOE itself with seven patent families. Patents may be assigned to DOE for various reasons, including where the inventors are federal employees; where the funding recipient elects not to pursue 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. The Samuel Noble Foundation is in second place in Figure 8 with five Other DOE-funded patent families, followed by four organizations with four patent families each – UT-Battelle, University of Georgia, University of California and Los Alamos National Security LLC.

Figure 8 - Assignees with Largest No. of Other DOE-funded Feedstock Patent Families



Distribution of Feedstock Patents across Patent Classifications

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

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 seven CPCs that are most prevalent among BETO-funded feedstock patents. The purpose of this chart is thus to show the main focus areas of BETO-funded feedstock research, and the extent to which these areas translate to other portfolios (Other DOE-funded; leading feedstock organizations; all feedstock patents).

Figure 9 shows that BETO-funded research includes relatively balanced coverage across the seven 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 feedstock patents is Y02E 50/16, which appears on 27% of these patents. This CPC is related to cellulosic ethanol, and reflects the fact that a number of the BETO-funded patents describe the chemical pretreatment of biomass for improved ethanol production (biomass pretreatment is also the focus of another CPC in Figure 9 – C12P 2201/00). Figure 9 also includes CPCs related to cellulosic materials (C12P 7/10) and the saccharification of these materials (C13K 1/02 and

[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.

C12P 19/02). This again reflects the focus of BETO-funded feedstock patents on treatment of biomass for use in biofuel production. There is also a CPC in Figure 9 for cutting fibrous materials (D21B 1/061), which is related to BETO-funded patents for wood and crop comminution processes. This CPC is largely absent from the other portfolios, suggesting that BETO-funded research has helped fill a research gap not addressed by the leading companies.

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

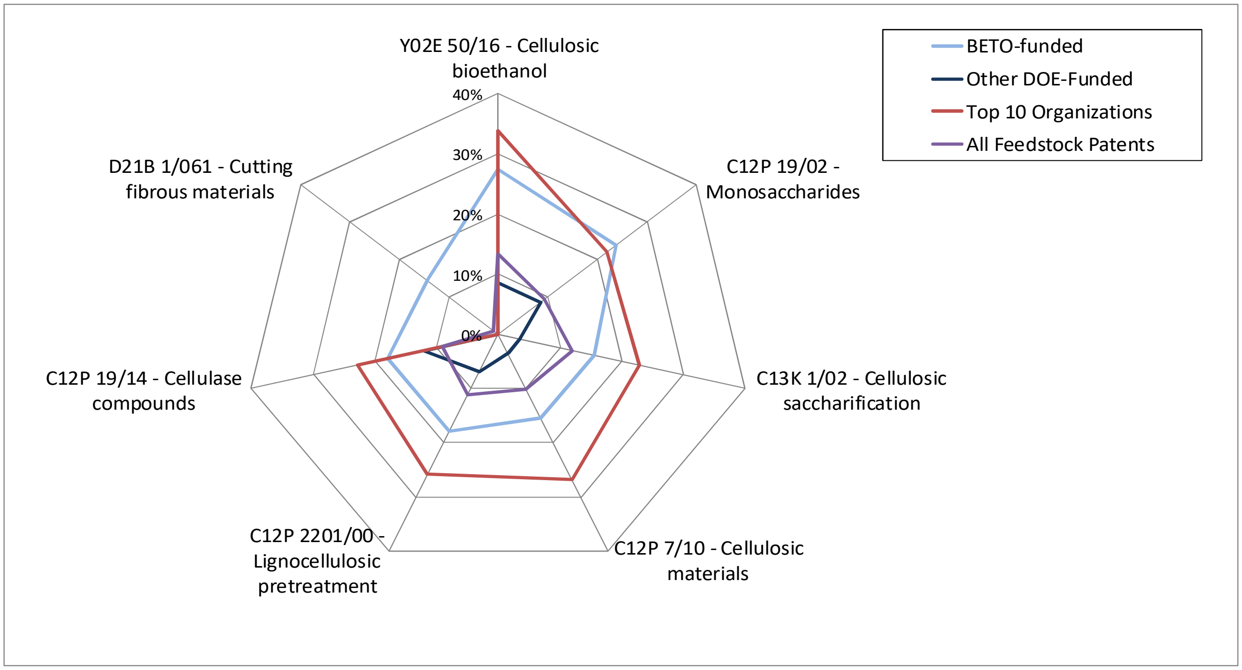


Figure 10 - Percentage of Feedstock U.S. Patents in Most Common Cooperative Patent Classifications (Among All Feedstock Patents)

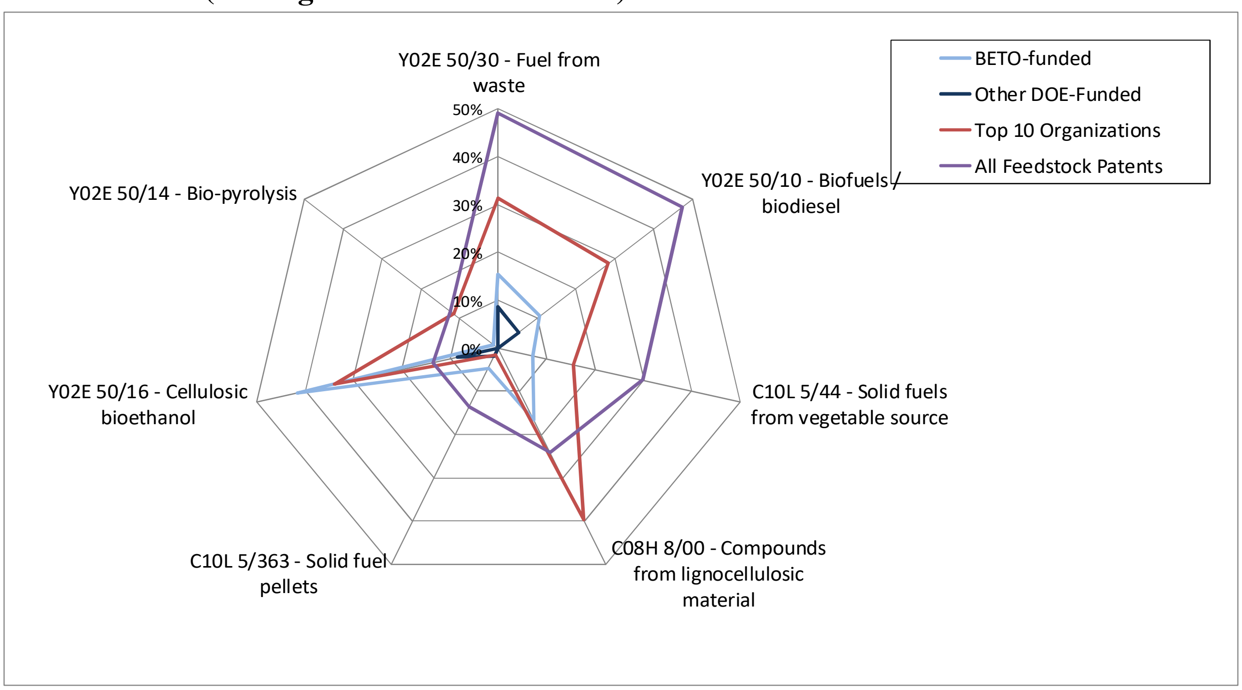
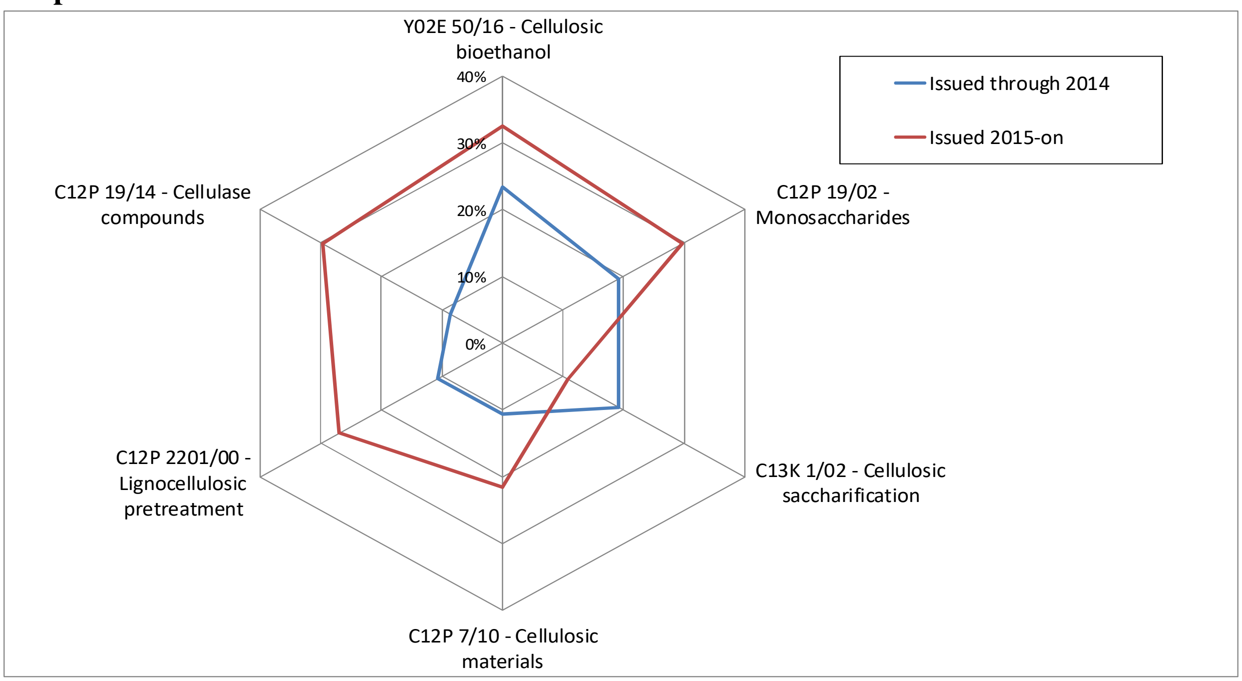


Figure 10 is similar to Figure 9, except that it is from the perspective of the most common CPCs among all feedstock patents. Hence, the purpose of this chart is to show the main research areas within feedstock technology as a whole, and how these areas are represented in selected feedstock portfolios (BETO-funded; Other DOE-funded; leading feedstock organizations). The two most-common CPCs among all feedstock patents are Y02E 50/30 (energy generation from waste) and Y02E 50/10 (biofuels and biodiesel). These CPCs each appear on almost half of all feedstock patents. There are also patents for solid fuels (C10L 5/44), including solid fuel pellets (C10L 5/363), plus lignocellulose-based compounds (C08H 8/00). BETO-funded patents have a presence in each of these CPCs, although with a lesser focus in solid fuels.

Figure 11 compares the CPC distribution of BETO-funded feedstock 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 similar focus across the two time periods, although in the more recent period there is a slight shift towards biomass pretreatment (C12P 2201/00) and cellulase compounds (C12P 19/14) and away from cellulosic saccharification (C13K 1/02).

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



Tracing Backwards from Feedstock Patents Owned by Leading Organizations

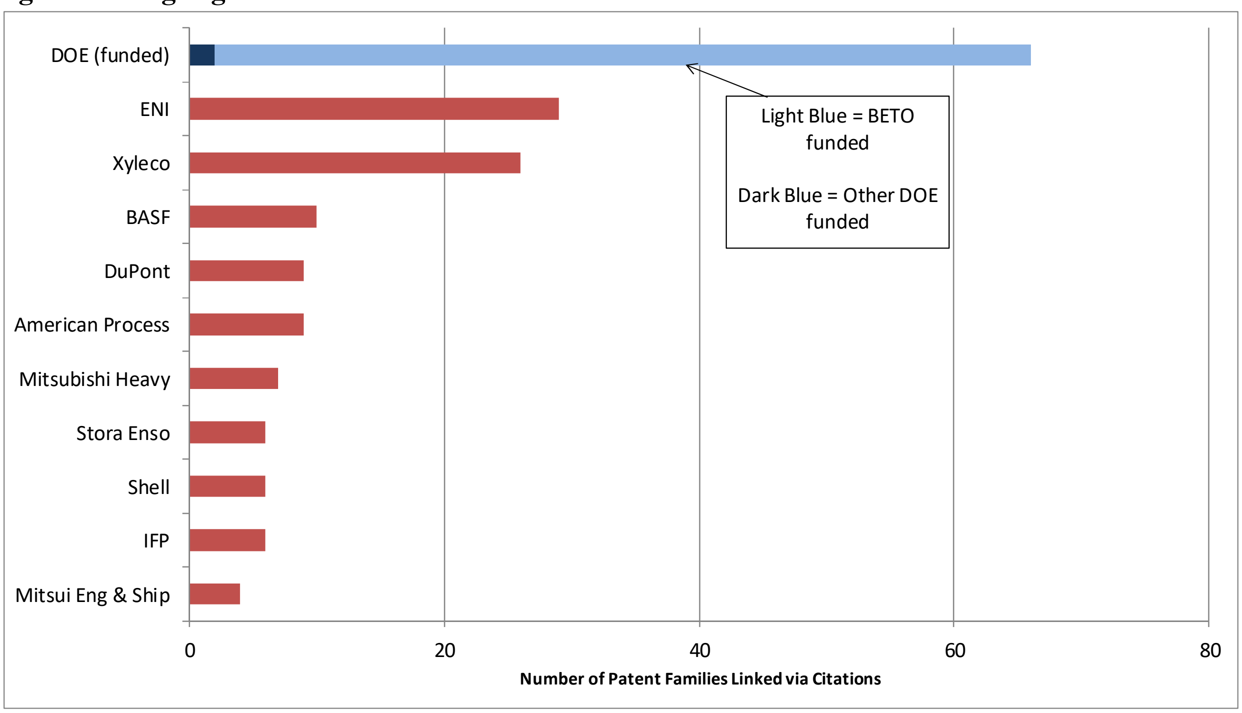
This section reports the results of an analysis tracing backwards from feedstock patents owned by leading organizations in this technology to earlier research, including that funded by DOE. The results in this section are examined at two levels. First, we report results at the organizational level. These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

Figure 12 compares the influence of DOE-funded feedstock research to the influence of research carried out by the top ten feedstock organizations. Specifically, this figure shows the number of feedstock patent families owned by the leading organizations that are linked via citations to earlier feedstock patent families owned by each of the leading organizations (plus patent families funded by DOE). In other words, this figure shows the organizations whose patents have had the strongest influence on subsequent innovations associated with leading feedstock organizations.[8]

Figure 12 - Number of Leading Organization Feedstock Patent Families Linked via Citations to Earlier Feedstock Patents from each Leading Organization
e.g. 66 leading organization families are linked to earlier BETO/Other DOE-funded families

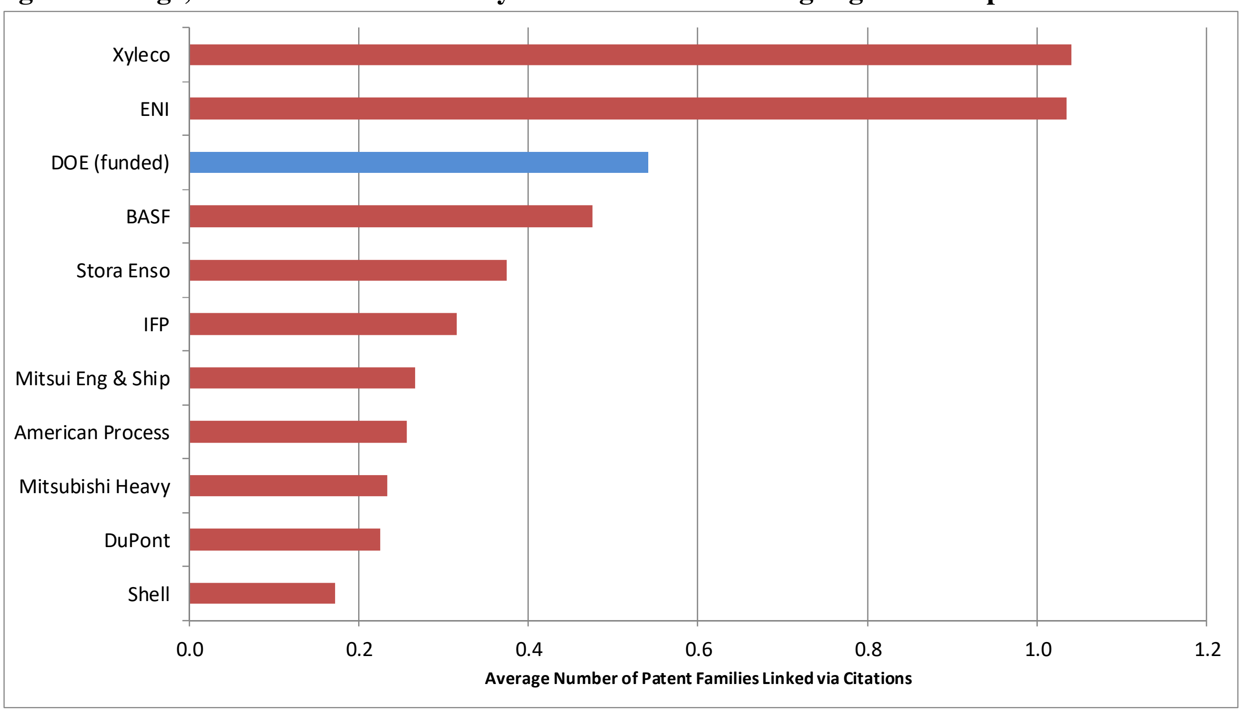


[8] This figure compares the influence of patents *funded* by BETO/DOE against patents *owned* by (i.e. assigned to) organizations. Such a comparison is reasonable, since patents funded by organizations through their research budgets will be assigned to those organizations. Also, organizations (notably 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 DuPont, American Process and Stora Enso 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, 66 feedstock patent families owned by the leading organizations (i.e. 25% of these 264 families) are linked via citations to earlier DOE-funded feedstock patents, out of which 64 are linked to BETO-funded feedstock patents. This finding puts DOE-funded patents at the head of Figure 12. It means that more leading organization feedstock patent families are linked via citations to earlier DOE-funded feedstock patents than are linked to the feedstock 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) feedstock 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, DOE-funded feedstock patent families are each linked to an average of 0.54 patent families assigned to the leading organizations. This puts DOE in third place in Figure 13, which is headed by Xyleco and ENI, whose patent families are each linked to an average of just over one family owned by the leading organizations. DOE's position in Figure 13 suggests that its prominence in Figure 12 is due in part to its portfolio size, with its influence being slightly above-average once this size is taken into account.

Figure 13 – Average Number of Leading Organization Feedstock Patent Families Linked via Citations to Feedstock Families from Each Leading Organization
e.g. on average, each DOE-funded family is linked to 0.54 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 feedstock 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 feedstock organizations, nine (i.e. all except Mitsui) have at least one patent family linked to earlier DOE-funded feedstock patents. DuPont is at the head of Figure 14, with 23 feedstock patent families linked via citations to earlier DOE-funded feedstock patents, all of which are linked to BETO-funded patents. ENI is in second place in this figure, with 12 patent families linked via citations to DOE (all linked to BETO), followed by Xyleco (10 families linked to DOE; 9 to BETO).

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

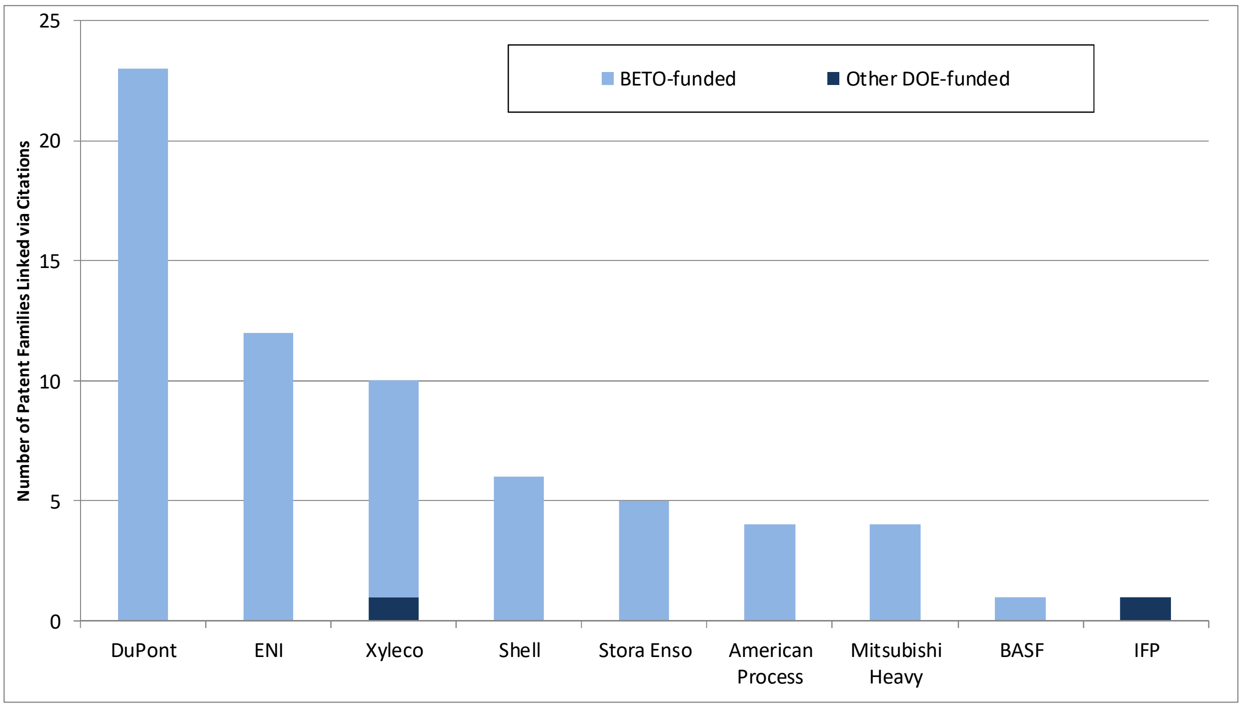


Figure 15 counts the total number of citation links from leading organizations to earlier DOE-funded patents. This differs slightly from the count of linked families in Figure 14, since a single patent family may be linked to multiple earlier DOE-funded patents. That said, the same organizations are again prominent in Figure 15. DuPont is at the head of Figure 15, with a total of 83 citation links to DOE-funded patents (71 being links to BETO-funded patents). Xyleco is in second place (32 citation links to DOE; 24 to BETO), followed by Stora Enso (30 citation links to DOE; 26 to BETO) and EMI (29 citation links to DOE; 26 to BETO).

There is an element of portfolio size bias in the patent family counts in Figures 14 and 15. Organizations with larger feedstock 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 feedstock patent families that are linked via citations to earlier DOE-funded feedstock 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 reveals that more than half of DuPont's feedstock patent families are linked via citations to earlier DOE-funded (with all of them linked to BETO-funded patents). Meanwhile, more than 40% of ENI and Xyleco patent families, and more than 30% of Stora Enso families, are linked via citations to DOE-funded patents (primarily BETO-funded patents). Figure 16 thus further emphasizes the extensive citation links between DOE-funded feedstock patents and subsequent DuPont, Xyleco, Stora Enso and ENI patents.

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

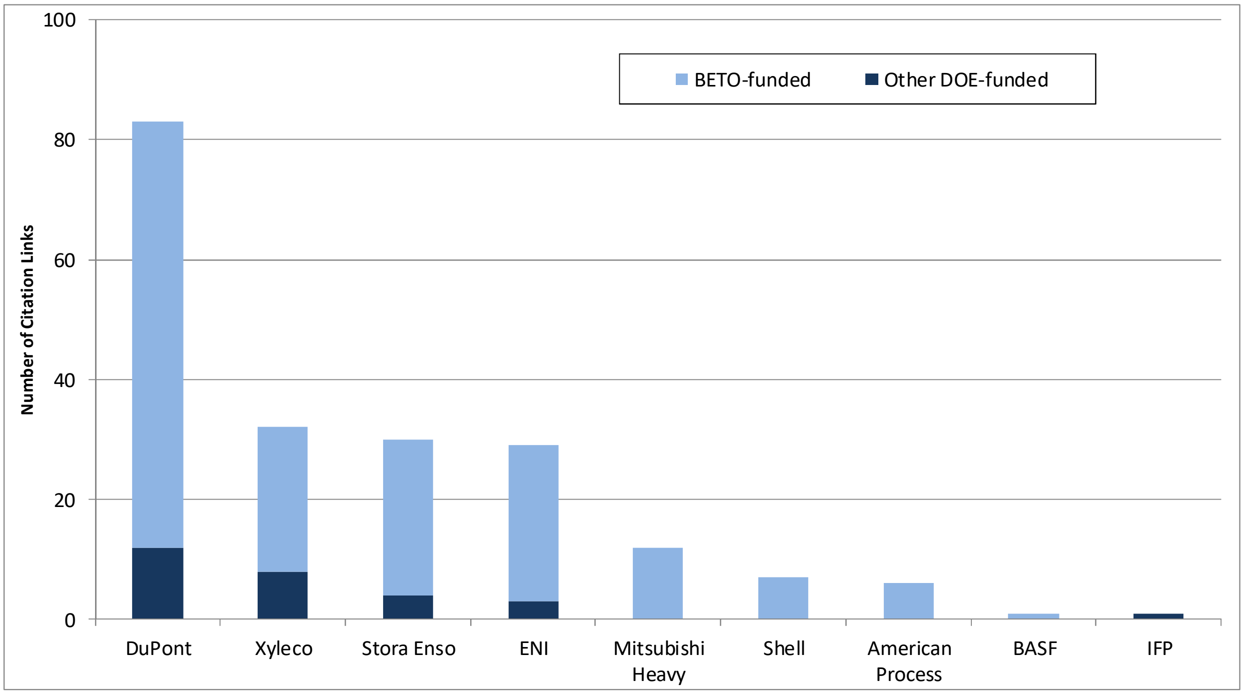
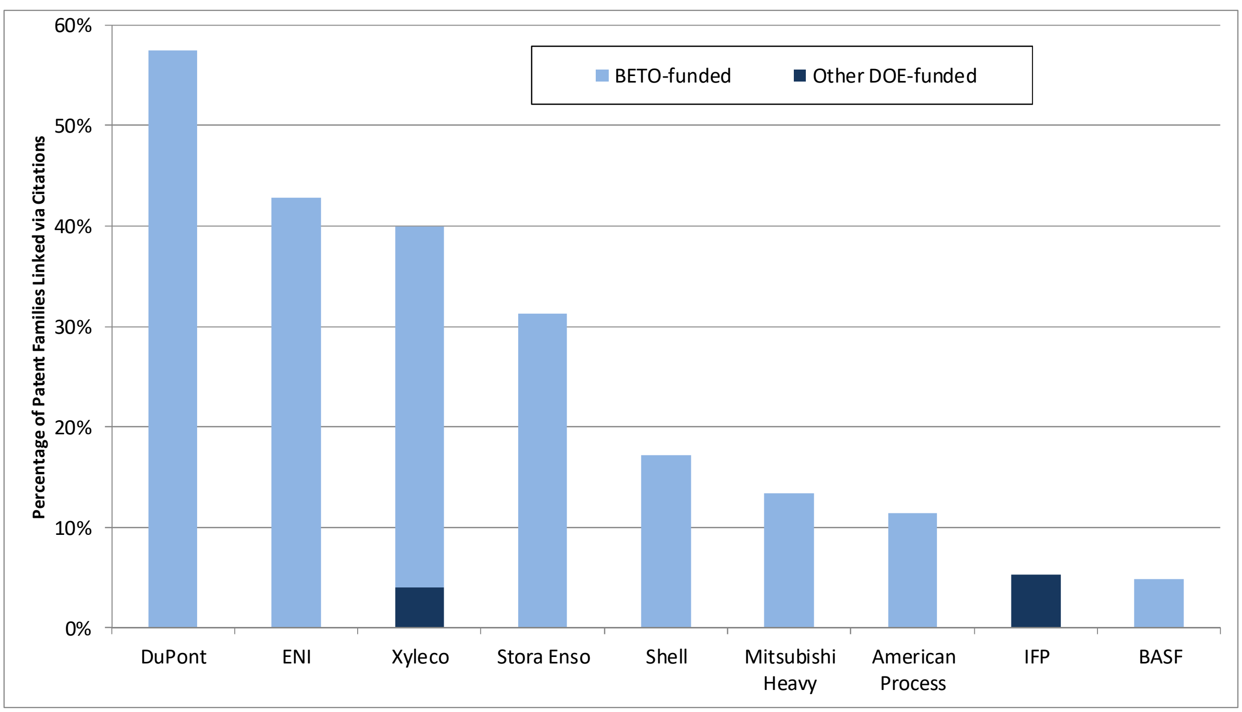


Figure 16 - Percentage of Leading Feedstock Organization Patent Families Linked via Citations to Earlier BETO/Other DOE-funded Feedstock Patents



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

Table 5 shows the BETO-funded feedstock 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 numerous innovations associated with leading organizations in the feedstock industry.

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

Patent Family #	Representative Patent #	Priority Year	# Linked Families	Assignee	Title
22426685	5424417	1993	43	MRIGlobal (NREL)	Prehydrolysis of lignocellulose
23435036	5705369	1994	40	MRIGlobal (NREL)	Prehydrolysis of lignocellulose
24906095	6022419	1996	36	MRIGlobal (NREL)	Hydrolysis and fractionation of lignocellulosic biomass
23368184	5730837	1994	10	MRIGlobal (NREL)	Method of separating lignocellulosic material into lignin, cellulose and dissolved sugars
38668077	7915017	2006	9	Michigan St Univ	Process for the lignocellulosic treatment of biomass
32961095	7449550	2003	8	Alliance Sustainable Energy (NREL)	Superactive cellulase formulation using cellobiohydrolase-1 from Penicillium funiculosum

Three BETO-funded patent families stand out in Table 5, in terms of the number of leading organization families linked to them via citations. These three patent families (see for example representative patent[9] US #5,424,417) are all assigned to MRIGlobal, formerly Midwest Research Institute, through its management of the National Renewable Energy Laboratory (NREL). They were all filed in the mid-1990s, and describe the pre-hydrolysis of lignocellulosic materials, in order to fractionate them into different components, with selected components then available for fermentation into products such as biofuels. These three NREL patent families are respectively linked via citations to 43, 40 and 36 subsequent families owned by the leading feedstock organizations. This includes families assigned to seven out of the ten leading organizations (i.e. all except BASF, IFP and Mitsui). NREL is also responsible for two of the other three patent families in Table 5, with the remaining family (representative patent US #7,915,017) being assigned to Michigan State University, and also concerned with pretreatment of biomass.

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

Table 5 lists BETO-funded patents linked to large numbers of subsequent feedstock patent families owned by leading organizations. Table 6 looks in the opposite direction, and lists the feedstock patent families owned by leading organizations that are linked to multiple earlier families funded by BETO. The two patent families at the head of this table are both assigned to DuPont. These DuPont patent families (for example, representative patent US #9,873,846) describe the use of lignocellulose-based syrups that can be used as binders for solid fuels or soil conditioners. They are both linked via citations to the BETO-funded NREL and Michigan State University patent families listed in Table 5. Table 6 also includes Xyleco biomass treatment patent families (e.g. representative patent #8,637,284) that are linked via citations to the same NREL and Michigan State University patents. In addition, Table 6 includes a patent family assigned to Stora Enso, through its acquisition of Virdia. This families (representative patent US #9,631,246) describes biomass processing, and is linked via citations to earlier BETO-funded families from a range of organizations, including NREL, Pacific Northwest National Laboratory (PNNL) and American Process Incorporated.

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

Patent Family #	Representative Patent #	Priority Year	# BETO Fams	Assignee	Title
51753492	9873846	2013	7	DuPont	Fuel compositions containing lignocellulosic biomass fermentation process syrup
51844859	9499451	2013	7	DuPont	Soil conditioner compositions containing lignocellulosic biomass fermentation process syrup
49515049	9631246	2012	6	Stora Enso	Methods for treating lignocellulosic materials
43823351	8637284	2008	5	Xyleco	Processing biomass
43923159	9587258	2008	5	Xyleco	Processing biomass
42828781	9234224	2009	4	ENI	Biomass pretreatment process

We also identified high-impact feedstock patents owned by leading organizations that have citation links back to BETO-funded patents.[10] The idea is to highlight important technologies developed by leading organizations that are linked to earlier feedstock research funded by BETO. Table 7 lists feedstock patents owned by leading organizations that have Citation Index

[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 C12P 2201/00 (Lignocellulosic pretreatment) 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 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.

values of four or over (i.e. they have been cited at least four times as frequently as expected), and are linked via citations to earlier BETO-funded feedstock patents. The patents are listed in descending order based on their Citation Index.

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

Patent	Issue Year	# Cites Received	Citation Index	Assignee	Title
7932065	2011	97	16.84	Xyleco	Processing biomass
8651403	2014	10	6.67	DuPont	Anhydrous ammonia treatment for improving milling of biomass
8404355	2013	12	4.48	Stora Enso	Methods and systems for processing lignocellulosic materials and related compositions

The patent at the head of Table 7 (US #7,932,065) is assigned to Xyleco. It describes a method for changing the molecular structure of biomass, in order to make it more productive. Since this patent was issued in 2011, it has been cited as prior art by 97 subsequent patents, which is more than sixteen times as many citations as expected given its age and technology (although it should be noted that this citation count is due in part to citations from subsequent patents assigned to Xyleco itself, thus increasing the Citation Index). In turn, this patent is linked via citations to the earlier BETO-funded NREL biomass pre-hydrolysis patents highlighted above in Table 5. The second patent in Table 7 (US #8,651,403) is assigned to DuPont and describes the pretreatment of biomass using ammonia. This patent is linked via citations to the BETO-funded NREL patent listed in second place in Table 5 (representative patent US #5,705,369). In turn, the DuPont patent has been cited as prior art by ten subsequent patents since it was issued in 2014, more than six times as many citations as expected. The third patent in Table 7 (US #8,404,355) is a biomass processing patent assigned to Stora Enso (Virdia). It is also linked via citations to the early NREL biomass pre-hydrolysis patents in Table 5.

While the patent-level results focus on BETO-funded feedstock patent families, we also identified Other DOE-funded feedstock 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 #8,486,680) is assigned to BP (it was originally co-assigned to BP and Verenium, but the latter subsequently assigned its rights to BP). It describes methods for breaking down hemicellulose, which is a major component of the cell wall of plants. This BP family is linked via citations to seven subsequent patent families assigned to the leading organizations, notably families assigned to DuPont and ENI. There are three patent families in Table 8 that are each linked to four subsequent families owned by the leading feedstock organizations. These include a 1989 family co-assigned to the University of North Texas and Arch Development Corporation (representative patent US #5,562,743) outlining refuse derived fuel pellets. They also include more recent families filed in 2006 by Edenspace Systems and UT-Battelle (through its management of Oak Ridge National Laboratory). The first of these (representative patent US #8,237,014) describes transgenic plants for increasing biofuel yields, while the second (representative patent US #7,699,958) details a method for separating carbohydrates from wood or biomass.

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

Patent Family #	Representative Patent #	Priority Year	# Linked Families	Assignee	Title
40526901	8486680	2007	7	BP Plc	Xylanases, nucleic acids encoding them and methods for making and using them
26807988	5562743	1989	4	Univ North Texas / Arch Dev Corp	Binder enhanced refuse derived fuel
38459673	8237014	2006	4	Edenspace Systems	Energy crops for improved biofuel feedstocks
39462456	7699958	2006	4	UT-Battelle (ORNL)	Method for improving separation of carbohydrates from wood pulping and wood or biomass hydrolysis liquors
24741184	4127447	1976	3	US Dept Energy	Biomass growth restriction in a packed bed reactor
22863901	6812377	2000	2	Michigan Tech Univ	Genetic engineering of syringyl-enriched lignin in plants
23964675	4540664	1983	2	US Dept Energy	Method of saccharifying cellulose

Overall, the backward tracing element of the analysis suggests that the portfolios of BETO-funded and Other DOE-funded feedstock patents have had an important influence on subsequent innovations associated with the leading feedstock 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 Feedstock Patents

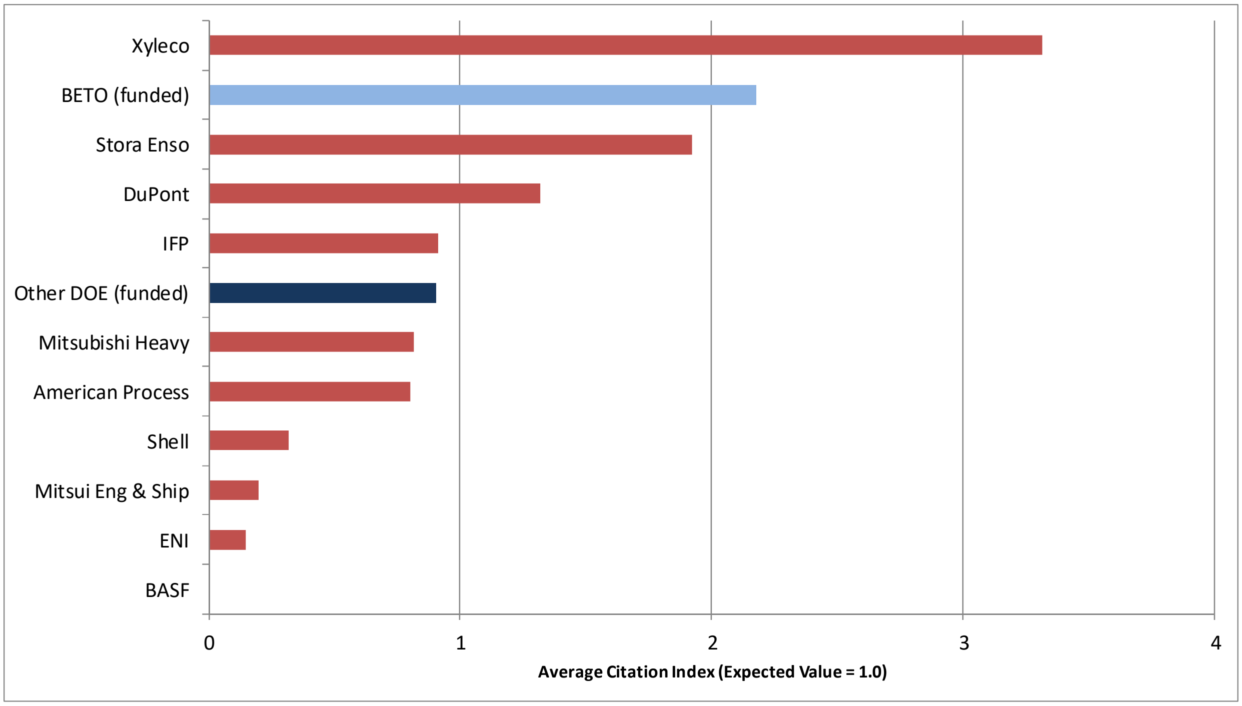
The previous section of the report examined the influence of DOE-funded feedstock research upon technological developments associated with leading feedstock organizations. That analysis was based on tracing backwards from the patents of leading organizations to previous generations of research. This section reports the results of an analysis tracing in the opposite direction – starting with BETO-funded (and Other DOE-funded) feedstock 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 feedstock organizations), this section of the report examines the broader influence of BETO-funded (and Other DOE-funded) feedstock research, both within and beyond feedstock technology. Also, in order to avoid repeating earlier results, the forward tracing concentrates primarily on patents that are linked to DOE-funded feedstock research, but are not owned by the leading feedstock organizations.

Organizational Level Results

We first generated average Citation Index values for the portfolios of BETO-funded and Other DOE-funded feedstock patents. We then compared these Citation Indexes against those of the ten leading feedstock organizations. The results are shown in Figure 17. This figure reveals that BETO-funded feedstock patents have an average Citation Index value of 2.17. This means that they have been cited as prior art more than twice as frequently as expected by subsequent patents, given their age and technology. BETO-funded patents are in second place in Figure 17, behind only Xyleco with a Citation Index of 3.31. However, as discussed earlier, Xyleco's high

Citation Index is due in part to citations from its own later patents. Other DOE-funded feedstock patents have lower Citation Index of 0.90, showing that they have been cited slightly less frequently than expected, given their age and technology.

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



The Citation Index measures the overall influence of the DOE-funded feedstock 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 feedstock patent families.[11] These CPCs reflect the influence of DOE-funded research across technologies.

Figure 18 shows the CPCs with the largest number of patent families linked to BETO-funded feedstock patents. These CPCs are presented in two different colors – i.e. those related to feedstocks and those beyond this technology. The former represent the influence of BETO-funded patents on feedstock technology itself, while the latter represent spillovers of the influence of BETO-funded feedstock research into other technology areas. The CPCs in Figure 18 are a mix of feedstock-related and other technologies (although it should be noted that are many overlaps between feedstocks and adjacent technologies such as bioenergy conversion). The three CPCs at the head of this figure are concerned with cellulosic bioethanol (Y02E 50/16), cellulase compounds (C12P 19/14) and monosaccharides (C12P 19/02). These three CPCs are all defined as being outside feedstock technology. As such, they are examples of BETO-funded feedstock patents being linked to subsequent developments in adjacent technologies. Also prominent in Figure 18 are CPCs defined as within feedstock technology, such as C12P 7/10

[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 feedstock patent families.

(Cellulosic materials), Y02P 30/20 (Feedstocks for oil and gas) and C12P 2201/00 (Lignocellulosic pretreatment). These are examples of BETO-funded patents influencing subsequent developments within feedstock technology.

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

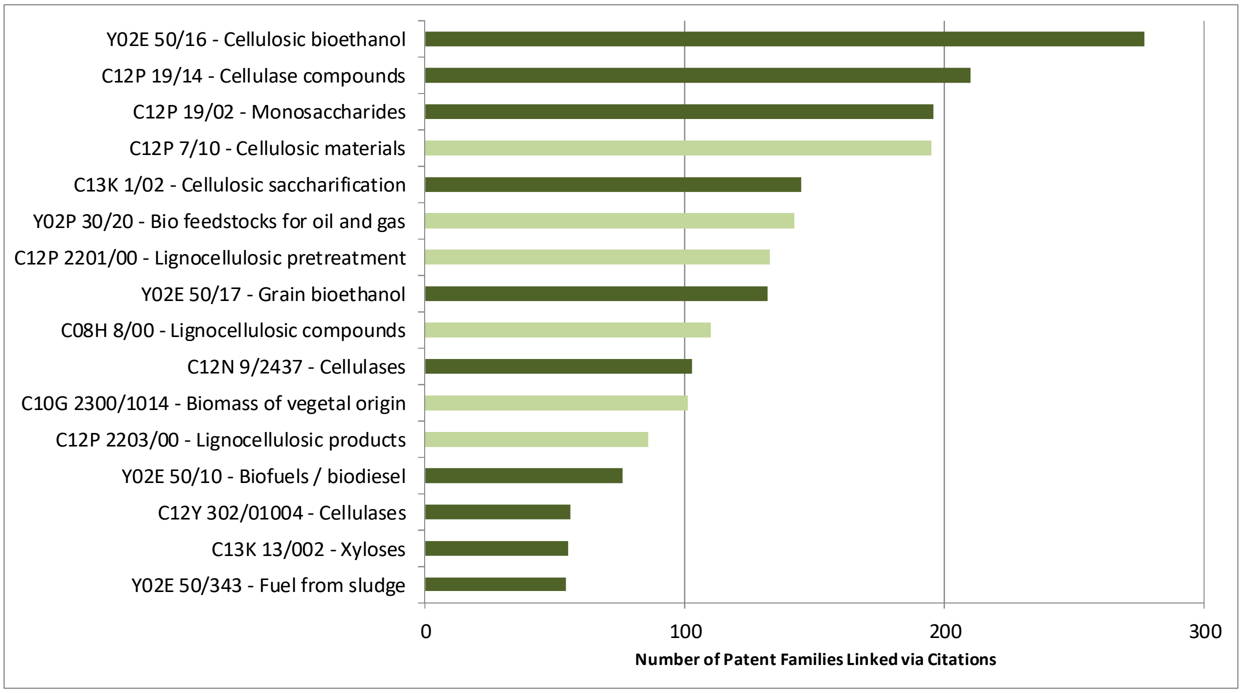


Figure 19 - Number of Patent Families Linked via Citations to Earlier Other DOE-Funded Feedstock Patents by CPC (Light Green = Feedstock-related; Dark Green = Other)

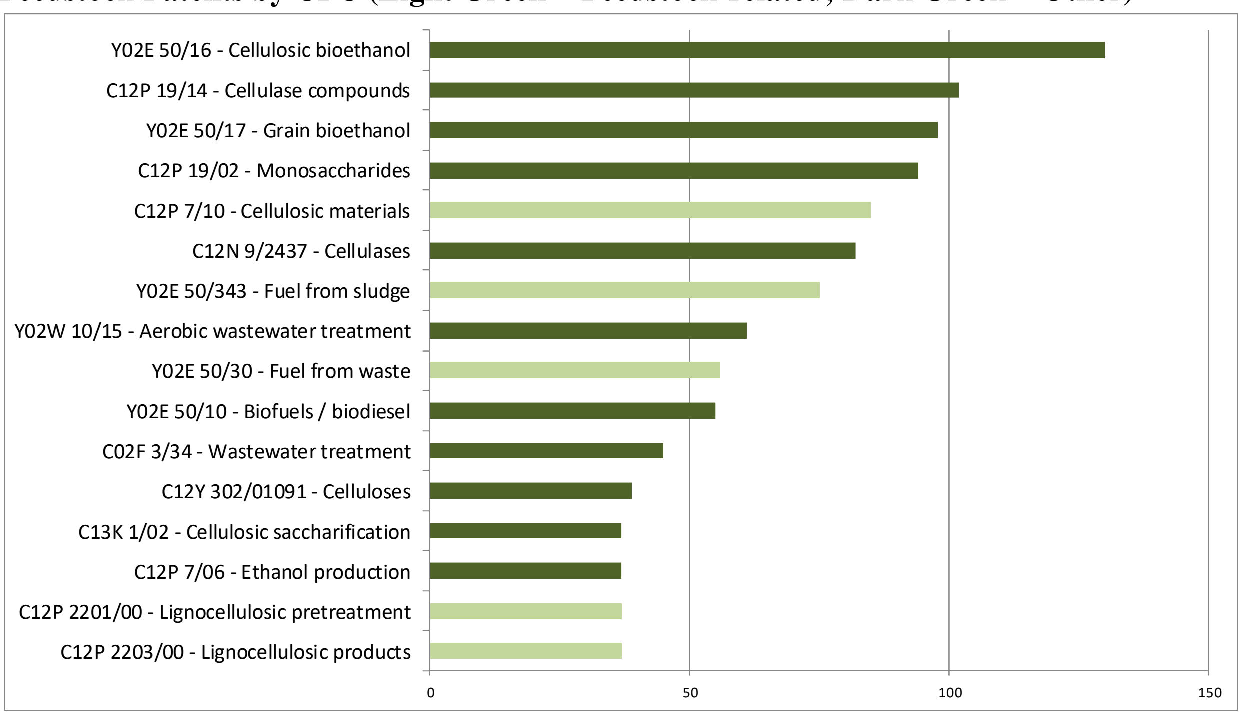
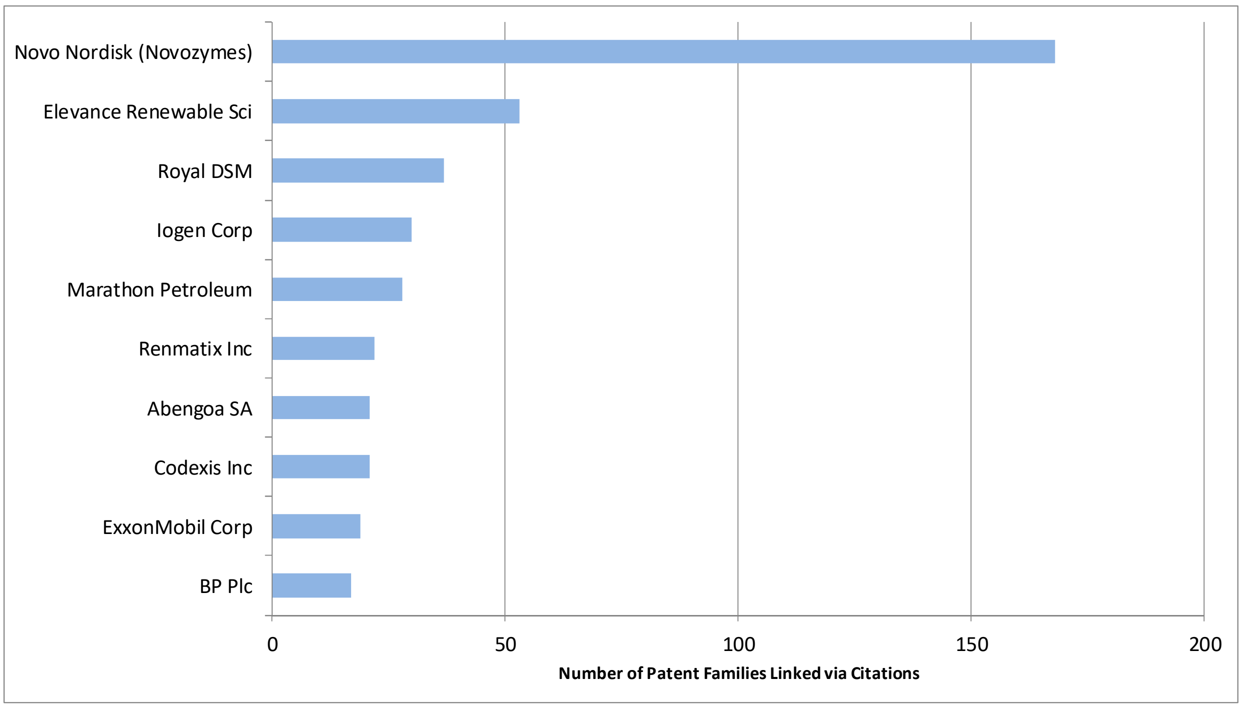


Figure 19 is similar to Figure 18, but is based on patent families linked to Other DOE-funded feedstock patents, rather than to BETO-funded feedstock patents. The list of CPCs in the two figures is similar. The CPC for cellulosic bioethanol (Y02E 50/16) is again at the head of Figure 19, with cellulase compounds (C12P 19/14) and monosaccharides (C12P 19/02) also prominent. Within feedstocks, one difference between the CPCs in the two figures is the greater prominence in Figure 19 of CPCs related to fuels from sludge (Y02E 50/343) and from waste (Y02E 50/30).

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

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



Novo Nordisk (through its majority ownership of the voting rights in Novozymes) is at the head of Figure 20 by a wide margin, with 168 patent families linked via citations to earlier BETO-funded feedstock patents. These Novozymes patent families describe enzymes designed to enhance the conversion of lignocellulosic feedstocks into ethanol. They are linked via citations to earlier BETO-funded NREL patents for biomass pre-hydrolysis (e.g. US #5,424,417), plus PNNL patents (e.g. US #8,304,212) outlining enzymes for treating biomass. Elevance is in second place in Figure 20, with 53 patent families linked via citations to earlier BETO-funded patents. Many of these Elevance families describe feedstocks based on natural oils, and are linked via citations to earlier BETO-funded Dow Chemical patents (e.g. US #7,576,227) outlining seed oil feedstocks for use in the chemical industry. The third-place organization in Figure 20 is Royal DSM, which has 37 patent families describing biomass pretreatment that are linked via citations to the BETO-funded NREL and PNNL patents for biomass treatment and pre-hydrolysis referred to above.

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

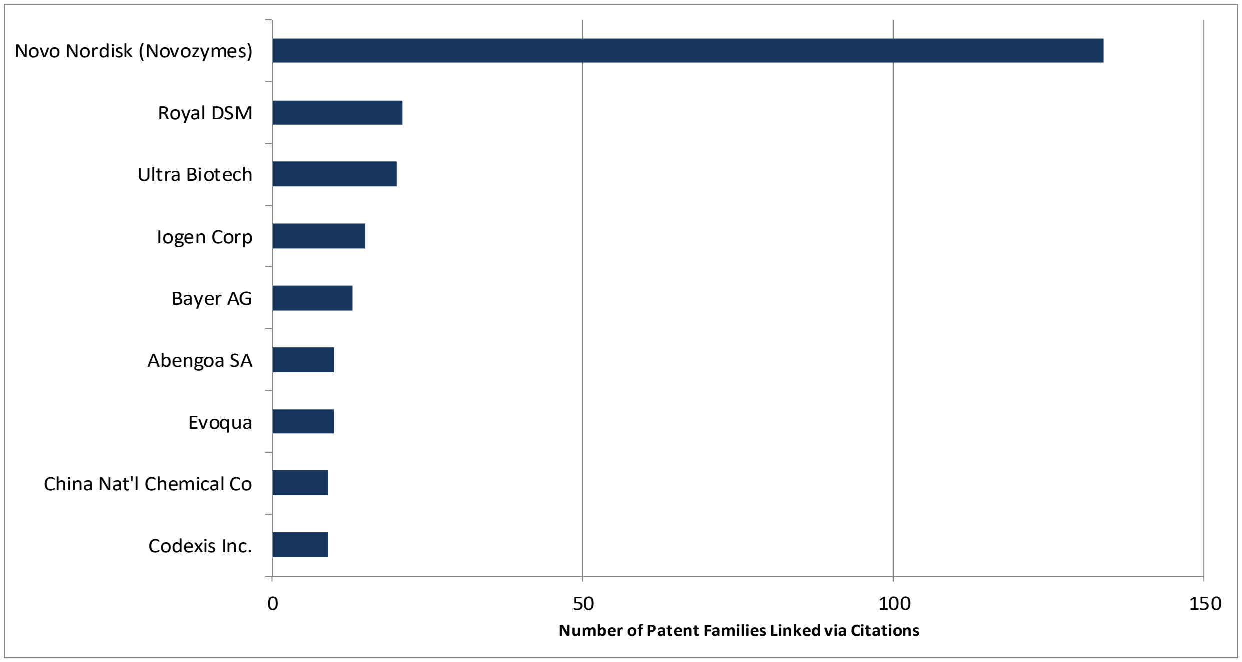


Figure 21 shows the organizations with the largest number of patent families linked to earlier Other DOE-funded feedstock patents. Novo Nordisk (Novozymes) is again at the head of this figure by a wide margin, with 134 of its enzyme patent families being linked via citations to earlier Other DOE-funded feedstock patents. These earlier Other DOE-funded patents include a BP patent for breaking down hemicellulose (US #8,486,680) and an Edenspace Systems patent (US #8,237,014) describing transgenic plants for increasing biofuel yields. Royal DSM is in second place in Figure 21, with 21 patent families linked via citations to earlier Other DOE-funded feedstock patents. These DSM patent families describe improved methods for degrading lignocellulose, and are also linked via citations to the Other DOE-funded BP and Edenspace patents. Ultra Biotech is in third place in Figure 21. It has 20 patent families describing applications for yeast cells that are linked via citations to an early Other DOE-funded patent (US #4,127,447) describing biomass reactors for controlling micro-organisms such as yeast.

Patent Level Results

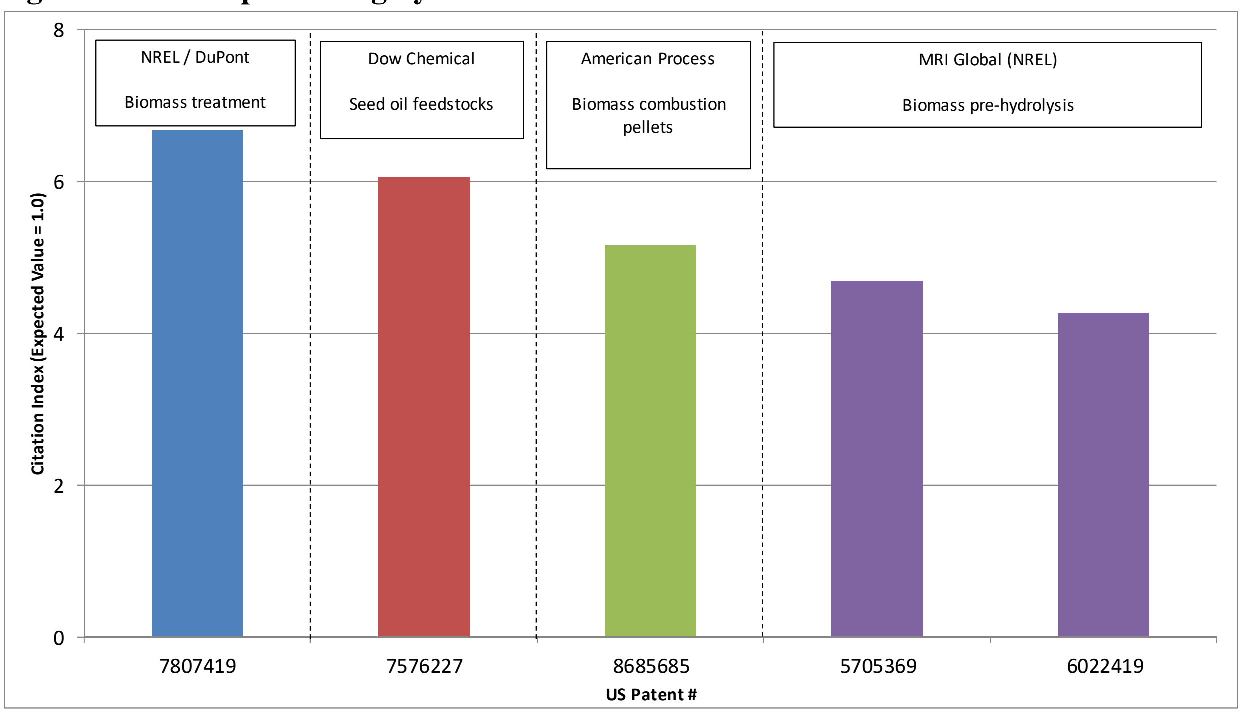
This section of the report drills down to identify individual DOE-funded (and particularly BETO-funded) feedstock patents whose influence on subsequent technological developments has been particularly strong. Looking in the opposite direction, it also highlights patents that have extensive citation links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

The simplest way of identifying high-impact BETO-funded feedstock 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.

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

Patent #	Issue Year	# Cites Received	Citation Index	Assignee	Title
7807419	2010	34	6.67	All. Sustain Energy (NREL) / DuPont	Process for concentrated biomass saccharification
7576227	2009	63	6.04	Dow Chemical Co.	Integrate chemical processes for industrial utilization of seed oils
8685685	2014	12	5.16	American Process Inc.	Processes for producing fermentable sugars and low-ash biomass for combustion or pellets
5705369	1998	112	4.69	MRIGlobal (NREL)	Prehydrolysis of lignocellulose
6022419	2000	113	4.27	MRIGlobal (NREL)	Hydrolysis and fractionation of lignocellulosic biomass
5730837	1998	58	3.74	MRIGlobal (NREL)	Method of separating lignocellulosic material into lignin, cellulose and dissolved sugars
5424417	1995	118	3.43	MRIGlobal (NREL)	Prehydrolysis of lignocellulose
6982328	2006	25	2.16	Archer Daniels / Battelle Mem Inst (PNNL)	Methods of producing compounds from plant material

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



The patent at the head of Table 9 (US #7,807,419) is co-assigned to the Alliance for Sustainable Energy (through its management of NREL) and DuPont. This patent describes pretreated biomass for use in the production of ethanol. Since being issued in 2010, this patent has been cited as prior art by 34 subsequent patents, more than six times as many citations as expected given its age and technology. Dow Chemical has the patent in second place in Table 9. This patent (US #7,576,227) was highlighted above in Figure 20. It outlines seed oil feedstocks, and has been cited as prior art by 63 subsequent patents, more than six times as many citations as expected. The third patent in Table 9 is more recent, having been issued in 2014. This patent, assigned to American Process and describing biomass pellets for combustion, has been cited by 12 subsequent patents, more than five times as many as expected. Table 9 also includes a number of highly-cited older MRIGlobal (NREL) patents (e.g. US #5,705,369) related to pre-hydrolysis of biomass that were highlighted in the backward tracing element of the analysis.

The Citation Indexes in Table 9 are based on a single generation of citations to BETO-funded feedstock patents. Tables 10 and 11 extend this by examining a second generation of citations – i.e. they show the BETO-funded feedstock patents linked directly or indirectly to the largest number of subsequent patent families.[12] These subsequent families are divided into two groups, based on whether they are within or beyond feedstock technology (i.e. whether or not they are in the universe of feedstock patents defined in the first stage of this project). This highlights which BETO-funded patent families have been particularly influential within feedstock technology, and which have had a wider impact beyond feedstocks.

Table 10 contains older BETO-funded feedstocks patent families (i.e. with priority dates prior to 2000) linked to the largest number of subsequent patent families. This table is dominated by the MRIGlobal (NREL) biomass pre-hydrolysis patent families highlighted throughout this report. For example, the patent family at the head of Table 10 (representative patent US #5,424,417) is linked via citations to 643 subsequent patent families, 125 of which are related to feedstocks technology. Meanwhile the second family in this table (representative patent US #5,705,369) is also assigned to MRIGlobal, and is linked via citations to 532 subsequent patent families, 107 of them within feedstock technology. Table 10 does include two patent families not assigned to MRIGlobal. The first (representative patent US #6,013,860) is assigned to Bayer and describes genetic engineering of plant cells, while the second (representative patent US #6,485,774) is assigned to Agtec Development, and describes crop harvesting for bioenergy applications.

Table 10 – Pre-2000 BETO-funded Feedstock Patent Families Linked via Citations to Largest Number of Subsequent Feedstock/Other Patent Families

Family #	Priority Year	Rep. Patent #	# Linked Families	# Linked Feedstock Fams	Assignee	Title
22426685	1993	5424417	643	125	MRIGlobal (NREL)	Prehydrolysis of lignocellulose
23435036	1994	5705369	532	107	MRIGlobal (NREL)	Prehydrolysis of lignocellulose
24906095	1996	6022419	310	84	MRIGlobal (NREL)	Hydrolysis and fractionation of lignocellulosic biomass
23368184	1994	5730837	166	48	MRIGlobal (NREL)	Method of separating lignocellulosic material into lignin, cellulose and dissolved sugars
22403255	1998	6013860	128	15	Bayer AG	Expression of enzymes involved in cellulose modification
26848307	1999	6485774	46	4	Agtec Development LLC	Method of preparing and handling chopped plant materials

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

Table 11 contains more recent BETO-funded patent families, with priority dates from 2000 onwards. This table is headed by a patent family (representative patent US #8,304,212) from PNNL, in co-operation with the Iowa Corn Promotion Board and Dyadic Incorporated. This patent family describes enzymes for treating biomass. It is linked via citations to 258 subsequent patent families, 22 of which are within feedstocks technology. The second patent family in Table 11 (representative patent US #7,576,227) is the Dow Chemical seed oil family discussed earlier in Table 9. It is linked via citations to 159 subsequent patent families, only five of which are related to feedstocks. The third patent family in this table (representative patent US #6,982,328) is co-assigned to Archer-Daniels-Midland and Battelle Memorial Institute (PNNL) and describes processing of plant fiber materials. It is also linked primarily to subsequent patent families outside feedstocks, with only six of these 121 linked families being within feedstocks.

Table 11 – Post-1999 BETO-funded Feedstock Patent Families Linked via Citations to Largest Number of Subsequent Feedstock/Other Patent Families

Family #	Priority Year	Rep. Patent #	# Linked Families	# Linked Feedstock Fams	Assignee	Title
38924113	2006	8304212	258	22	Iowa Corn Board / Dyadic / Battelle Mem Inst (PNNL)	Methods and compositions for degradation of lignocellulosic material
29401376	2002	7576227	159	5	Dow Chemical Co.	Integrated chemical processes for industrial utilization of seed oils
32926649	2003	6982328	121	6	Archer Daniels / Battelle Mem Inst (PNNL)	Methods of producing compounds from plant material
32961095	2003	7449550	96	12	All. Sustain Energy (NREL)	Superactive cellulase formulation using cellobiohydrolase-1 from Penicillium funiculosum
40382552	2007	7807419	72	9	All. Sustain Energy (NREL) / DuPont	Process for concentrated biomass saccharification
40002778	2006	9120742	63	2	Elevance Renewable Sciences Inc	Methods of making organic compounds by metathesis
38668077	2006	7915017	55	21	Michigan State University	Process for the treatment of lignocellulosic biomass

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

The patent at the head of Table 12 (US #8,669,393) was granted in 2014 to Rennovia Incorporated, which subsequently ceased operations and its intellectual property acquired by

Archer-Daniels-Midland. This patent describes the use of renewable feedstocks in place of oil, for example in nylon production. It has been cited as prior art by 18 subsequent patents, which is more than fourteen times as many citations as expected for a patent of its age and technology. The second patent in Table 12 (US #7,176,336) is older, having been issued in 2007 to Dow Chemical. This patent describes a method for producing olefin alcohols. It has been cited by 52 subsequent patents, which also more than fourteen times as many as expected. Meanwhile, the third patent in Table 12 (US #8,906,204), assigned to Butamax and describing energy-efficient ethanol production, has been cited by 19 subsequent patents (eleven times as many as expected). Table 12 also includes other patents related to biomass processing, ethanol production and paper manufacturing, reflect the breadth of influence of BETO-funded feedstock research on subsequent high-impact technological developments.

Table 12 - Highly Cited Patents (not from leading feedstock organizations) Linked via Citations to Earlier BETO-funded Feedstock Patents

Patent #	Issue Year	# Cites Received	Citation Index	Assignee	Title
8669393	2014	18	14.23	Archer Daniels (Rennovia)	Adipic acid compositions
7176336	2007	52	14.06	Dow Chemical	Process for the synthesis of unsaturated alcohols
8906204	2014	19	11.25	Butamax Advanced Biofuels	Methods for alcohol recovery and concentration of stillage by-products
7465791	2008	80	11.04	Lignol Innovations	Continuous counter-current organosolv processing of lignocellulosic feedstocks
8501989	2013	25	9.72	Rennovia Inc	Production of adipic acid and derivatives from carbohydrate-containing materials
7649086	2010	54	8.17	Biojoule Ltd	Integrated processing of plant biomass
6419788	2002	93	7.38	PureVision Technology	Method of treating lignocellulosic biomass to produce cellulose
7381294	2008	61	6.61	Japan Absorbent Tech Inst	Method and apparatus for manufacturing microfibrillated cellulose fiber

As with the backward tracing element of the analysis, the patent-level results from the forward tracing focus on BETO-funded feedstock patents. That said, within the forward tracing, we did also identify Other DOE-funded feedstock patent families linked to the largest number of subsequent patent families within and beyond feedstock technology. These Other DOE-funded feedstock families are shown in Table 13.

The patent family at the head of Table 13 (representative patent US #4,127,447) is assigned to DOE and describes biomass reactors for controlling micro-organisms. This DOE family is linked via citations to 481 subsequent patent families, only ten of which are related to feedstocks. The second patent family in Table 13 (representative patent US #4,540,664) is also assigned to DOE and describes a method for processing cellulosic materials. It is linked via citations to 131 subsequent families, only 13 of which are related to feedstock technology. Note that both of these DOE patent families were marked as unknown in terms of funding source, so it is possible that they could have been funded by BETO. Out of all the patent families in Table 13, the one with the most extensive citation links within feedstocks is co-assigned to the University of North Texas and Arch Development Corporation, and describes refuse derived fuel pellets. This patent family (representative patent US #5,562,743) is linked via citations to 112 subsequent patent families, 39 of them related to feedstocks. It is also marked as unknown for DOE funding source.

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

Family #	Priority Year	Rep. Patent #	# Linked Families	# Linked Feedstock Fams	Assignee	Title
24741184	1976	4127447	481	10	US Dept Energy	Biomass growth restriction in a packed bed reactor
23964675	1983	4540664	131	13	US Dept Energy	Method of saccharifying cellulose
38459673	2006	8237014	123	9	Edenspace Systems	Energy crops for improved biofuel feedstocks
26807988	1989	5562743	112	39	Univ North Texas / Arch Dev Corp	Binder enhanced refuse derived fuel
40526901	2007	8486680	91	8	BP Plc	Xylanases, nucleic acids encoding them and methods for making and using them
24647996	1984	4630535	64	4	Univ Minnesota	Method and apparatus for de-watering biomass materials in a compression drying process
23062411	1988	5200338	53	11	Univ Idaho	Bacterial extracellular lignin peroxidase

Overall, the forward tracing element of the analysis shows that BETO-funded and Other DOE-funded feedstock research has had a strong influence on subsequent technologies. This influence can be seen most extensively in feedstock technology, but can also be traced in other technologies such as biofuel production, chemical manufacturing and waste treatment.

5.0 Conclusions

This report describes the results of an analysis tracing links between feedstock research funded by DOE (BETO plus Other DOE) and subsequent developments both within and beyond feedstock 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 feedstock organizations. The purpose of the forward tracing is to examine the influence of BETO-funded (and Other DOE-funded) feedstock patents both within and outside feedstock technology.

The backward tracing element of the analysis suggests that the portfolios of BETO-funded and Other DOE-funded feedstock patents have had an important influence on subsequent innovations associated with the leading feedstock 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 feedstock research has had a strong influence on subsequent technologies. This influence can be seen most extensively within feedstock technology, but can also be traced in other technologies such as biofuel production, chemical manufacturing and waste treatment.

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

Appendix A. Feedstock Patents in Families Associated with BETO Funding

Patent #	Application Year	Issue / Publication Year	Original Assignee	Title
5424417	1993	1995	MIDWEST RESEARCH INSTITUTE	PREHYDROLYSIS OF LIGNOCELLULOSE
WO1995008648	1994	1995	MIDWEST RESEARCH INSTITUTE	PREHYDROLYSIS OF LIGNOCELLULOSE
5503996	1994	1996	MIDWEST RESEARCH INSTITUTE	PREHYDROLYSIS OF LIGNOCELLULOSE
EP0715657	1994	1996	MIDWEST RESEARCH INSTITUTE	PREHYDROLYSIS OF LIGNOCELLULOSE
5705369	1995	1998	MIDWEST RESEARCH INSTITUTE	PREHYDROLYSIS OF LIGNOCELLULOSE
5730837	1994	1998	MIDWEST RESEARCH INSTITUTE	METHOD OF SEPARATING LIGNOCELLULOSIC MATERIAL INTO LIGNIN, CELLULOSE AND DISSOLVED SUGARS
WO1998014270	1997	1998	MIDWEST RESEARCH INSTITUTE	HYDROLYSIS AND FRACTIONATION OF LIGNOCELLULOSIC BIOMASS
EP0951347	1997	1999	MIDWEST RESEARCH INSTITUTE	HYDROLYSIS AND FRACTIONATION OF LIGNOCELLULOSIC BIOMASS
6013860	1998	2000	BAYER AG	EXPRESSION OF ENZYMES INVOLVED IN CELLULOSE MODIFICATION
6022419	1996	2000	MIDWEST RESEARCH INSTITUTE	HYDROLYSIS AND FRACTIONATION OF LIGNOCELLULOSIC BIOMASS
EP1017824	1999	2000	BAYER AG	EXPRESSION OF ENZYMES INVOLVED IN CELLULOSE MODIFICATION
WO2000005381	1999	2000	BAYER AG	EXPRESSION OF ENZYMES INVOLVED IN CELLULOSE MODIFICATION
6485774	2000	2002	UNASSIGNED	METHOD OF PREPARING AND HANDLING CHOPPED PLANT MATERIALS
WO2003093215	2003	2003	DOW CHEMICAL CO.	INTERGRATED CHEMICAL PROCESSES FOR INDUSTRIAL UTILIZATION OF SEED OILS
WO2004078919	2003	2004	MIDWEST RESEARCH INSTITUTE	SUPERACTIVE CELLULASE FORMULATION USING CELLOBIOHYDROLASE-1 FROM PENICILLIUM

				FUNICULOSUM
6973883	2002	2005	TEXAS A&M UNIVERSITY	REBURN SYSTEM WITH FEEDLOT BIOMASS
EP1501784	2003	2005	DOW CHEMICAL CO.	INTEGRATED CHEMICAL PROCESSES FOR INDUSTRIAL UTILIZATION OF SEED OILS
WO2005092021	2005	2005	ARCHER DANIELS MIDLAND CO.	ETHANOL EXTRACTION OF PHYTOSTEROLS FROM CORN FIBER
6982328	2003	2006	ARCHER DANIELS MIDLAND CO. / BATTELLE MEMORIAL INST	METHODS OF PRODUCING COMPOUNDS FROM PLANT MATERIAL
EP1747000	2005	2007	ARCHER DANIELS MIDLAND CO.	ETHANOL EXTRACTION OF PHYTOSTEROLS FROM CORN FIBER
WO2007130337	2007	2007	MICHIGAN STATE UNIVERSITY / DARTMOUTH COLLEGE	PROCESS FOR THE TREATMENT OF LIGNOCELLULOSIC BIOMASS
7449550	2003	2008	ALLIANCE FOR SUSTAINABLE ENERGY LLC	SUPERACTIVE CELLULASE FORMULATION USING CELLOBIOHYDROLASE-1 FROM PENICILLIUM FUNICULOSUM
WO2008008793	2007	2008	DYADIC INTERNATIONAL INC	METHODS AND COMPOSITIONS FOR DEGRADATION OF LIGNOCELLULOSIC MATERIAL
WO2008085356	2007	2008	DUPONT DE NEMOURS INC.	CONDITIONING BIOMASS FOR MICROBIAL GROWTH
WO2008140468	2007	2008	ELEVANCE RENEWABLE SCIENCES INC	METHODS OF MAKING ORGANIC COMPOUNDS BY METATHESIS
7576227	2004	2009	DOW CHEMICAL CO.	INTEGRATE CHEMICAL PROCESSES FOR INDUSTRIAL UTILIZATION OF SEED OILS
EP2013368	2007	2009	MICHIGAN STATE UNIVERSITY / DARTMOUTH COLLEGE	PROCESS FOR THE TREATMENT OF LIGNOCELLULOSIC BIOMASS
EP2099899	2007	2009	DUPONT DE NEMOURS INC.	CONDITIONING BIOMASS FOR MICROBIAL GROWTH
EP2121546	2007	2009	ELEVANCE RENEWABLE SCIENCES INC	METHODS OF MAKING ALPHA, OMEGA-DICARBOXYLIC ACID ALKENE DERIVATIVES BY METATHESIS
WO2009045651	2008	2009	MIDWEST RESEARCH INSTITUTE / DU POINT NEMOURS	PROCESS FOR CONCENTRATED BIOMASS SACCHARIFICATION
WO2009045653	2008	2009	MIDWEST	BIOMASS TREATMENT

			RESEARCH INSTITUTE / DU POINT NEMOURS	METHOD
WO2009045654	2008	2009	MIDWEST RESEARCH INSTITUTE / DU POINT NEMOURS	IMPROVED BIOMASS PRETREATMENT
7652131	2004	2010	BATTELLE MEMORIAL INSTITUTE	METHODS OF PRODUCING COMPOUNDS FROM PLANT MATERIALS
7744450	2006	2010	BATTELLE MEMORIAL INSTITUTE	PARTICULATE RESIDUE SEPARATORS FOR HARVESTING DEVICES
7745652	2008	2010	DOW CHEMICAL CO.	INTEGRATED CHEMICAL PROCESSES FOR INDUSTRIAL UTILIZATION OF SEED OILS
7807419	2007	2010	ALLIANCE FOR SUSTAINABLE ENERGY / DUPONT DE NEMOURS	PROCESS FOR CONCENTRATED BIOMASS SACCHARIFICATION
7819976	2007	2010	ALLIANCE FOR SUSTAINABLE ENERGY / DUPONT DE NEMOURS	BIOMASS TREATMENT METHOD
7833994	2005	2010	ARCHER DANIELS MIDLAND CO.	ETHANOL EXTRACTION OF PHYTOSTEROLS FROM CORN FIBER
EP2179048	2008	2010	ALLIANCE FOR SUSTAINABLE ENERGY / DUPONT DE NEMOURS	PROCESS FOR CONCENTRATED BIOMASS SACCHARIFICATION
EP2179085	2008	2010	ALLIANCE FOR SUSTAINABLE ENERGY / DUPONT DE NEMOURS	IMPROVED BIOMASS PRETREATMENT
EP2190883	2008	2010	ALLIANCE FOR SUSTAINABLE ENERGY / DUPONT DE NEMOURS	BIOMASS TREATMENT METHOD
7887672	2007	2011	UNIVERSITY OF NEBRASKA	METHOD FOR MAKING NATURAL CELLULOSIC FIBER BUNDLES FROM CELLULOSIC SOURCES
7915017	2007	2011	MICHIGAN STATE UNIVERSITY	PROCESS FOR THE TREATMENT OF LIGNOCELLULOSIC BIOMASS
7918721	2010	2011	BATTELLE MEMORIAL INSTITUTE	METHODS OF SEPARATING PARTICULATE RESIDUE STREAMS

8034449	2010	2011	FOREST CONCEPTS LLC	ENGINEERED PLANT BIOMASS FEEDSTOCK PARTICLES
8039106	2010	2011	FOREST CONCEPTS LLC	ENGINEERED PLANT BIOMASS FEEDSTOCK PARTICLES
WO2011022644	2010	2011	AUBURN UNIVERSITY	FERMENTATION AND CHEMICAL TREATMENT OF PULP AND PAPER MILL SLUDGE
WO2011028543	2010	2011	MICHIGAN STATE UNIVERSITY	PRETREATED DENSIFIED BIOMASS PRODUCTS AND METHODS OF MAKING AND USING SAME
WO2011112824	2011	2011	UNIVERSITY OF FLORIDA	METHODS OF USING CELLULASE FOR REDUCING THE VISCOSITY OF FEEDSTOCK
WO2011123154	2010	2011	MYRIANT CORP	METABOLIC EVOLUTION OF ESCHERCHIA COLI STRAINS THAT PRODUCE ORGANIC ACIDS
WO2011133865	2011	2011	FOREST CONCEPTS LLC	ENGINEERED PLANT BIOMASS FEEDSTOCK PARTICLES
8143040	2009	2012	METNA CO	PROCESS FOR WHOLE CELL SACCHARIFICATION OF LIGNOCELLULOSES TO SUGARS USING A DUAL BIOREACTOR SYSTEM
8158256	2011	2012	FOREST CONCEPTS LLC	ENGINEERED PLANT BIOMASS FEEDSTOCK PARTICLES
8283150	2008	2012	ALLIANCE FOR SUSTAINABLE ENERGY LLC	SUPERACTIVE CELLULASE FORMULATION USING CELLOBIOHYDROLASE-1 FROM PENICILLIUM FUNICULOSUM
8304212	2007	2012	BATTELLE MEMORIAL INSTITUTE / DYADIC INC / IOWA CORN PROMOTION BOARD	METHODS AND COMPOSITIONS FOR DEGRADATION OF LIGNOCELLULOSIC MATERIAL
EP2411492	2010	2012	MICHIGAN STATE UNIVERSITY	PRETREATED DENSIFIED BIOMASS PRODUCTS AND METHODS OF MAKING AND USING SAME
EP2501798	2010	2012	MYRIANT CORP	METABOLIC EVOLUTION OF ESCHERCHIA COLI STRAINS THAT PRODUCE ORGANIC ACIDS
WO2012012734	2011	2012	UNASSIGNED	SYSTEM AND METHOD FOR CONDITIONING A HARDWOOD PULP LIQUID

				HYDROLYSATE
WO2012018699	2011	2012	MYRIANT CORP	IMPROVED FERMENTATION PROCESS FOR THE PRODUCTION OF ORGANIC ACIDS
WO2012088429	2011	2012	MICHIGAN STATE UNIVERSITY	METHODS FOR PRETREATING BIOMASS
WO2012103220	2012	2012	ABENGOA SA	METHOD AND APPARATUS FOR TREATING A CELLULOSIC FEEDSTOCK
WO2012106040	2011	2012	UNIVERSITY OF MAINE	PROCESS FOR IMPROVING THE ENERGY DENSITY OF FEEDSTOCKS USING FORMATE SALTS
WO2012135375	2012	2012	TEXAS A&M UNIVERSITY	BIOMASS SHOCK PRETREATMENT
WO2012151275	2012	2012	MARATHON PETROLEUM CORPORATION	APPARATUS AND METHOD FOR CONVERTING BIOMASS TO FEEDSTOCK FOR BIOFUEL AND BIOCHEMICAL MANUFACTURING PROCESSES
WO2012155074	2012	2012	MARATHON PETROLEUM CORPORATION	PROCESS FOR PURIFYING LIGNOCELLULOSIC FEEDSTOCKS
8394611	2007	2013	MICHIGAN STATE UNIVERSITY	PROCESS FOR THE TREATMENT OF LIGNOCELLULOSIC BIOMASS
8445236	2007	2013	ALLIANCE FOR SUSTAINABLE ENERGY / DUPONT DE NEMOURS INC	BIOMASS PRETREATMENT
8481160	2012	2013	FOREST CONCEPTS LLC	BIMODAL AND MULTIMODAL PLANT BIOMASS PARTICLE MIXTURES
8487159	2009	2013	CYMABAY THERAPEUTICS INC	PRODUCTION OF POLYHYDROXYBUTYRATE IN SWITCHGRASS
8496033	2012	2013	FOREST CONCEPTS LLC	COMMINUTION PROCESS TO PRODUCE ENGINEERED WOOD PARTICLES OF UNIFORM SIZE AND SHAPE WITH DISRUPTED GRAIN STRUCTURE FROM VENEER
8497019	2012	2013	FOREST CONCEPTS LLC	ENGINEERED PLANT BIOMASS PARTICLES COATED WITH BIOACTIVE AGENTS
8497020	2013	2013	FOREST CONCEPTS LLC	PRECISION WOOD PARTICLE FEEDSTOCKS
8507093	2013	2013	FOREST CONCEPTS LLC	COMMINUTION PROCESS TO PRODUCE PRECISION WOOD PARTICLES OF UNIFORM

				SIZE AND SHAPE WITH DISRUPTED GRAIN STRUCTURE FROM WOOD CHIPS
8512979	2010	2013	ALLIANCE FOR SUSTAINABLE ENERGY / DUPONT DE NEMOURS	SYSTEM AND PROCESS FOR BIOMASS TREATMENT
8598378	2009	2013	UNIVERSITY OF HAWAII	METHODS AND COMPOSITIONS FOR EXTRACTION AND TRANSESTERIFICATION OF BIOMASS COMPONENTS
8608970	2011	2013	UNIVERSITY OF MAINE / RED SHIELD ACQUISITIONS	SYSTEM AND METHOD FOR CONDITIONING A HARDWOOD PULP LIQUID HYDROLYSATE
EP2596003	2011	2013	UNIVERSITY OF MAINE / RED SHIELD ACQUISITIONS	SYSTEM AND METHOD FOR CONDITIONING A HARDWOOD PULP LIQUID HYDROLYSATE
EP2655638	2011	2013	MICHIGAN STATE UNIVERSITY	METHODS FOR PRETREATING BIOMASS
EP2670819	2011	2013	UNIVERSITY OF MAINE	PROCESS FOR IMPROVING THE ENERGY DENSITY OF FEEDSTOCKS USING FORMATE SALTS
WO2013090430	2012	2013	UNIVERSITY OF MINNESOTA	LIGNIN DEGRADING METHODS
WO2013142317	2013	2013	API INTELLECTUAL PROPERTY HOLDINGS LLC	PROCESSES AND APPARATUS FOR PRODUCING FERMENTABLE SUGARS AND LOW-ASH BIOMASS FOR COMBUSTION AT REDUCED EMISSIONS
WO2013142320	2013	2013	API INTELLECTUAL PROPERTY HOLDINGS LLC	PROCESSES AND APPARATUS FOR PRODUCING ENERGY-DENSE BIOMASS FOR COMBUSTION AND FERMENTABLE SUGARS FROM THE BIOMASS
WO2013142352	2013	2013	STATE UNIVERSITY OF NEW YORK	FLOCCULATION OF LIGNOCELLULOSIC HYDROLYZATES
WO2013163271	2013	2013	THE MICHIGAN BIOTECHNOLOGY INSTITUTE	PROCESS FOR TREATING BIOMASS
8673031	2010	2014	MICHIGAN STATE UNIVERSITY	PRETREATED DENSIFIED BIOMASS PRODUCTS
8685685	2013	2014	API INTELLECTUAL PROPERTY HOLDINGS LLC	PROCESSES FOR PRODUCING FERMENTABLE SUGARS AND LOW-ASH BIOMASS FOR COMBUSTION OR PELLETS

8709742	2010	2014	APPLIED BIOTECHNOLOGY INSTITUTE INC	METHODS OF SACCHARIFICATION OF POLYSACCHARIDES IN PLANTS
8709761	2011	2014	APPLIED BIOTECHNOLOGY INSTITUTE INC	METHODS OF SACCHARIFICATION OF POLYSACCHARIDES IN PLANTS
8734947	2013	2014	FOREST CONCEPTS LLC	MULTIPASS COMMINUTION PROCESS TO PRODUCE PRECISION WOOD PARTICLES OF UNIFORM SIZE AND SHAPE WITH DISRUPTED GRAIN STRUCTURE FROM WOOD CHIPS
8758895	2013	2014	FOREST CONCEPTS LLC	ENGINEERED PLANT BIOMASS PARTICLES COATED WITH BIOLOGICAL AGENTS
8765429	2012	2014	TEXAS A&M UNIVERSITY	BIOMASS SHOCK PRETREATMENT
8771425	2012	2014	MICHIGAN STATE UNIVERSITY	PROCESS FOR THE TREATMENT OF LIGNOCELLULOSIC BIOMASS
8871346	2012	2014	FOREST CONCEPTS LLC	PRECISION WOOD PARTICLE FEEDSTOCKS WITH RETAINED MOISTURE CONTENTS OF GREATER THAN 30% DRY BASIS
8871489	2010	2014	MYRIANT CORP	METABOLIC EVOLUTION OF ESCHERICHIA COLI STRAINS THAT PRODUCE ORGANIC ACIDS
8900457	2010	2014	AUBURN UNIVERSITY	FERMENTATION AND CHEMICAL TREATMENT OF PULP AND PAPER MILL SLUDGE
8906657	2013	2014	API INTELLECTUAL PROPERTY HOLDINGS LLC	PROCESSES FOR PRODUCING FERMENTABLE SUGARS AND ENERGY-DENSE BIOMASS FOR COMBUSTION
EP2691531	2012	2014	TEXAS A&M UNIVERSITY	BIOMASS SHOCK PRETREATMENT
WO2014035458	2013	2014	MASCOMA CORP	EXPRESSION OF ENZYMES IN YEAST FOR LIGNOCELLULOSE DERIVED OLIGOMER CBP
WO2014150470	2014	2014	ELEVANCE RENEWABLE SCIENCES INC	METHODS FOR TREATING A METATHESIS FEEDSTOCK WITH METAL ALKOXIDES
8945245	2012	2015	THE MICHIGAN BIOTECHNOLOGY INSTITUTE / MICHIGAN STATE	METHODS OF HYDROLYZING PRETREATED DENSIFIED BIOMASS PARTICULATES

			UNIVERSITY	AND SYSTEMS RELATED THERETO
8968515	2010	2015	MICHIGAN STATE UNIVERSITY	METHODS FOR PRETREATING BIOMASS
8993267	2007	2015	DUPONT DE NEMOURS INC.	CONDITIONING BIOMASS FOR MICROBIAL GROWTH
9000246	2012	2015	ELEVANCE RENEWABLE SCIENCES INC	METHODS OF REFINING AND PRODUCING DIBASIC ESTERS AND ACIDS FROM NATURAL OIL FEEDSTOCKS
9005758	2014	2015	FOREST CONCEPTS LLC	MULTIPASS ROTARY SHEAR COMMINUTION PROCESS TO PRODUCE CORN STOVER PARTICLES
9039792	2013	2015	MICHIGAN STATE UNIVERSITY	METHODS FOR PRODUCING AND USING DENSIFIED BIOMASS PRODUCTS CONTAINING PRETREATED BIOMASS FIBERS
9061286	2013	2015	FOREST CONCEPTS LLC	COMMINUTION PROCESS TO PRODUCE PRECISION WOOD PARTICLES OF UNIFORM SIZE AND SHAPE WITH DISRUPTED GRAIN STRUCTURE FROM WOOD CHIPS
9068291	2013	2015	UNIVERSITY OF MAINE / RED SHIELD ACQUISITIONS	SYSTEM AND METHOD FOR CONDITIONING A HARDWOOD PULP LIQUID HYDROLYSATE
9085494	2014	2015	API INTELLECTUAL PROPERTY HOLDINGS LLC	PROCESSES FOR PRODUCING LOW-ASH BIOMASS FOR COMBUSTION OR PELLETS
9102964	2012	2015	THE MICHIGAN BIOTECHNOLOGY INSTITUTE	PROCESS FOR TREATING BIOMASS
9109049	2013	2015	IOWA STATE UNIVERSITY	METHOD FOR PRETREATING LIGNOCELLULOSIC BIOMASS
9120712	2011	2015	UNIVERSITY OF MAINE	PROCESS FOR IMPROVING THE ENERGY DENSITY OF FEEDSTOCKS USING FORMATE SALTS
9120742	2009	2015	ELEVANCE RENEWABLE SCIENCES INC	METHODS OF MAKING ORGANIC COMPOUNDS BY METATHESIS
9127325	2011	2015	ABENGOA SA	METHOD AND APPARATUS FOR TREATING A CELLULOSIC FEEDSTOCK
9145529	2014	2015	API INTELLECTUAL PROPERTY HOLDINGS LLC	PROCESSES FOR PRODUCING ENERGY-DENSE BIOMASS FOR COMBUSTION
9175323	2013	2015	THE MICHIGAN BIOTECHNOLOGY	PROCESS FOR TREATING BIOMASS

			INSTITUTE	
9212328	2012	2015	MARATHON PETROLEUM CORPORATION	APPARATUS AND METHOD FOR CONVERTING BIOMASS TO FEEDSTOCK FOR BIOFUEL AND BIOCHEMICAL MANUFACTURING PROCESSES
EP2826869	2007	2015	MICHIGAN STATE UNIVERSITY	PROCESS FOR THE LIGNOCELLULOSIC TREATMENT OF BIOMASS
EP2828393	2013	2015	API INTELLECTUAL PROPERTY HOLDINGS LLC	PROCESSES AND APPARATUS FOR PRODUCING FERMENTABLE SUGARS AND LOW-ASH BIOMASS FOR COMBUSTION AT REDUCED EMISSIONS
EP2828394	2013	2015	API INTELLECTUAL PROPERTY HOLDINGS LLC	PROCESSES AND APPARATUS FOR PRODUCING ENERGY-DENSE BIOMASS FOR COMBUSTION AND FERMENTABLE SUGARS FROM THE BIOMASS
EP2841586	2013	2015	THE MICHIGAN BIOTECHNOLOGY INSTITUTE	PROCESS FOR TREATING BIOMASS
EP2890784	2013	2015	MASCOMA CORP	EXPRESSION OF ENZYMES IN YEAST FOR LIGNOCELLULOSE DERIVED OLIGOMER CBP
WO2015031889	2014	2015	COORSTEK INC	HYDROGEN UTILIZATION AND CARBON RECOVERY
9282747	2013	2016	UNIVERSITY OF TENNESSEE	ANTIMICROBIAL AND ANTI-INFLAMMATORY ACTIVITY OF SWITCHGRASS-DERIVED EXTRACTIVES
9284512	2015	2016	ELEVANCE RENEWABLE SCIENCES INC	METHODS OF REFINING AND PRODUCING DIBASIC ESTERS AND ACIDS FROM NATURAL OIL FEEDSTOCKS
9322043	2011	2016	UNIVERSITY OF FLORIDA	METHODS OF USING CELLULASE FOR REDUCING THE VISCOSITY OF FEEDSTOCK
9365487	2013	2016	ELEVANCE RENEWABLE SCIENCES INC	METHODS OF REFINING AND PRODUCING DIBASIC ESTERS AND ACIDS FROM NATURAL OIL FEEDSTOCKS
9382502	2013	2016	ELEVANCE RENEWABLE SCIENCES INC	METHODS OF REFINING AND PRODUCING ISOMERIZED FATTY ACID ESTERS AND FATTY ACIDS FROM NATURAL OIL FEEDSTOCKS
9440237	2015	2016	FOREST CONCEPTS LLC	CORN STOVER BIOMASS FEEDSTOCKS WITH UNIFORM PARTICLE SIZE

				DISTRIBUTION PROFILES AT RETAINED FIELD MOISTURE CONTENTS
9458482	2014	2016	THE MICHIGAN BIOTECHNOLOGY INSTITUTE / MICHIGAN STATE UNIVERSITY	METHODS OF HYDROLYZING PRETREATED DENSIFIED BIOMASS PARTICULATES AND SYSTEMS RELATED THERETO
EP2970782	2014	2016	ELEVANCE RENEWABLE SCIENCES INC	METHODS FOR TREATING A METATHESIS FEEDSTOCK WITH METAL ALKOXIDES
EP3039099	2014	2016	COORSTEK INC	METHOD FOR UPGRADING BIOMASS MATERIAL
9604387	2012	2017	FOREST CONCEPTS LLC	COMMINUTION PROCESS TO PRODUCE WOOD PARTICLES OF UNIFORM SIZE AND SHAPE WITH DISRUPTED GRAIN STRUCTURE FROM VENEER
9644222	2011	2017	MICHIGAN STATE UNIVERSITY	METHODS FOR PRETREATING BIOMASS
9745560	2013	2017	MASCOMA CORP	EXPRESSION OF ENZYMES IN YEAST FOR LIGNOCELLULOSE DERIVED OLIGOMER CBP
9751781	2013	2017	STATE UNIVERSITY OF NEW YORK	METHOD TO SEPARATE LIGNIN-RICH SOLID PHASE FROM ACIDIC BIOMASS SUSPENSION AT AN ACIDIC PH
9796993	2012	2017	UNIVERSITY OF MINNESOTA	LIGNIN-DEGRADING METHODS
9862893	2012	2018	MARATHON PETROLEUM CORPORATION	PROCESS FOR PURIFYING LIGNOCELLULOSIC FEEDSTOCKS
9938662	2015	2018	THE MICHIGAN BIOTECHNOLOGY INSTITUTE	PROCESS FOR TREATING BIOMASS
9944860	2014	2018	ELEVANCE RENEWABLE SCIENCES INC	METHODS FOR TREATING A METATHESIS FEEDSTOCK WITH METAL ALKOXIDES
9951431	2013	2018	MICHIGAN STATE UNIVERSITY	ELECTROCATALYTIC HYDROGENATION AND HYDRODEOXYGENATION OF OXYGENATED AND UNSATURATED ORGANIC COMPOUNDS
9957532	2015	2018	MYRIANT CORP	FERMENTATION PROCESS FOR THE PRODUCTION OF ORGANIC ACIDS
9969553	2016	2018	BATTELLE MEMORIAL INSTITUTE	HOPPER APPARATUSES FOR PROCESSING A BULK SOLID, AND RELATED SYSTEMS AND METHODS
10017793	2014	2018	MYRIANT CORP	METABOLIC EVOLUTION OF

				ESCHERICHIA COLI STRAINS THAT PRODUCE ORGANIC ACIDS
10105867	2017	2018	FOREST CONCEPTS LLC	COMMINUTION PROCESS TO PRODUCE ENGINEERED WOOD PARTICLES OF UNIFORM SIZE AND SHAPE FROM CROSS-GRAIN ORIENTED WOOD CHIPS
10145020	2014	2018	COORSTEK INC	HYDROGEN UTILIZATION AND CARBON RECOVERY
EP3281931	2007	2018	ELEVANCE RENEWABLE SCIENCES INC	METHODS OF MAKING ORGANIC COMPOUNDS BY METATHESIS

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

Patent #	Application Year	Issue / Publication Year	Original Assignee	Title
4127447	1976	1978	US DEPARTMENT OF ENERGY	BIOMASS GROWTH RESTRICTION IN A PACKED BED REACTOR
4463210	1983	1984	US DEPARTMENT OF ENERGY	PRODUCTION OF CHEMICAL FEEDSTOCK BY THE METHANOLYSIS OF WOOD
4540664	1983	1985	US DEPARTMENT OF ENERGY	METHOD OF SACCHARIFYING CELLULOSE
4597832	1981	1986	US DEPARTMENT OF ENERGY	APPARATUS FOR CONVERTING BIOMASS TO A PUMPABLE SLURRY
4630535	1984	1986	UNIVERSITY OF MINNESOTA	METHOD AND APPARATUS FOR DE-WATERING BIOMASS MATERIALS IN A COMPRESSION DRYING PROCESS
4840904	1987	1989	US DEPARTMENT OF ENERGY	RECOVERY AND REUSE OF CELLULASE CATALYST IN AN EXZYMATIC CELLULOSE HYDROLYSIS PROCESS
5200338	1988	1993	IDAHO RESEARCH FOUNDATION	BACTERIAL EXTRACELLULAR LIGNIN PEROXIDASE
5562743	1995	1996	UNIVERSITY OF NORTH TEXAS	BINDER ENHANCED REFUSE DERIVED FUEL
6114158	1998	2000	UNIVERSITY OF GEORGIA	ORPINOMYCES CELLULASE CELF PROTEIN AND CODING SEQUENCES
WO2002020717	2001	2002	MICHIGAN TECH UNIVERSITY	METHODS FOR SIMULTANEOUS CONTROL OF LIGNIN CONTENT AND COMPOSITION, AND CELLULOSE CONTENT IN PLANTS
WO2002020812	2001	2002	MICHIGAN TECH UNIVERSITY	GENETIC ENGINEERING OF SYRINGYL-ENRICHED LIGNIN IN PLANTS
EP1320617	2001	2003	MICHIGAN TECH UNIVERSITY	GENETIC ENGINEERING OF SYRINGYL-ENRICHED LIGNIN IN PLANTS
6812377	2001	2004	MICHIGAN TECH UNIVERSITY	GENETIC ENGINEERING OF SYRINGYL-ENRICHED LIGNIN IN PLANTS
6855864	2001	2005	MICHIGAN TECH UNIVERSITY	METHODS FOR SIMULTANEOUS CONTROL OF LIGNIN CONTENT AND COMPOSITION, AND CELLULOSE CONTENT IN PLANTS
7311013	2006	2007	US DEPARTMENT	COMPLEX PENDULUM BIOMASS SENSOR

			OF ENERGY	
WO2007100897	2007	2007	EDENSPACE SYSTEMS CORP	ENERGY CROPS FOR IMPROVED BIOFUEL FEEDSTOCKS
WO2007149646	2007	2007	BATTELLE MEMORIAL INSTITUTE	METHOD OF PRODUCING HYDROGEN, AND RENDERING A CONTAMINATED BIOMASS INERT
EP1989303	2007	2008	EDENSPACE SYSTEMS CORP	ENERGY CROPS FOR IMPROVED BIOFUEL FEEDSTOCKS
WO2008005631	2007	2008	WASHINGTON STATE UNIVERSITY	GENES ENCODING CHAVICOL/EUGENOL SYNTHASE FROM THE CREOSOTE BUSH LARREA TRIDENTATA
WO2008014027	2007	2008	BATTELLE MEMORIAL INSTITUTE	OIL SHALE DERIVED POLLUTANT CONTROL MATERIALS AND METHODS AND APPARATUSES FOR PRODUCING AND UTILIZING THE SAME
7514596	2005	2009	MICHIGAN TECH UNIVERSITY	METHODS FOR SIMULTANEOUS CONTROL OF LIGNIN CONTENT AND COMPOSITION, AND CELLULOSE CONTENT IN PLANTS
EP2046110	2007	2009	WASHINGTON STATE UNIVERSITY	GENES ENCODING CHAVICOL/EUGENOL SYNTHASE FROM THE CREOSOTE BUSH LARREA TRIDENTATA
EP2046482	2007	2009	BATTELLE MEMORIAL INSTITUTE	OIL SHALE DERIVED POLLUTANT CONTROL MATERIALS AND METHODS AND APPARATUSES FOR PRODUCING AND UTILIZING THE SAME
WO2009045627	2008	2009	BP P.L.C.	XYLANASES, NUCLEIC ACIDS ENCODING THEM AND METHODS FOR MAKING AND USING THEM
WO2009099858	2009	2009	BATTELLE MEMORIAL INSTITUTE	THERMOPHILIC AND THERMOACIDOPHILIC BIOPOLYMER- DEGRADING GENES AND ENZYMES FROM ALICYCLOBACILLUS ACIDOCALDARIUS AND RELATED ORGANISMS, METHODS
7665328	2006	2010	BATTELLE MEMORIAL INSTITUTE	METHOD OF PRODUCING HYDROGEN, AND RENDERING A CONTAMINATED BIOMASS INERT
7699958	2006	2010	UT-BATTELLE LLC	METHOD FOR IMPROVING SEPARATION OF CARBOHYDRATES FROM WOOD PULPING AND WOOD OR

				BIOMASS HYDROLYSIS LIQUORS
7708964	2006	2010	BATTELLE MEMORIAL INSTITUTE	OIL SHALE DERIVED POLLUTANT CONTROL MATERIALS AND METHODS AND APPARATUSES FOR PRODUCING AND UTILIZING THE SAME
7795460	2006	2010	TDA RESEARCH INC	METHOD OF MAKING ALKYL ESTERS
7858353	2009	2010	BATTELLE MEMORIAL INSTITUTE	THERMOPHILIC AND THERMOACIDOPHILIC BIOPOLYMER-DEGRADING GENES AND ENZYMES FROM ALICYCLOBACILLUS ACIDOCALDARIUS AND RELATED ORGANISMS, METHODS
EP2205744	2008	2010	BP P.L.C.	XYLANASES, NUCLEIC ACIDS ENCODING THEM AND METHODS FOR MAKING AND USING THEM
EP2235174	2009	2010	BATTELLE MEMORIAL INSTITUTE	THERMOPHILIC AND THERMOACIDOPHILIC BIOPOLYMER- DEGRADING GENES AND ENZYMES FROM ALICYCLOBACILLUS ACIDOCALDARIUS AND RELATED ORGANISMS, METHODS
WO2010011680	2009	2010	TEXAS A&M UNIVERSITY	DISCOVERY AND UTILIZATION OF SORGHUM GENES (MA5/MA6)
WO2010060096	2009	2010	UNIVERSITY OF CALIFORNIA	COMPOSITIONS AND METHODS FOR INCREASING CELLULOSE PRODUCTION
EP2377943	2011	2011	MICHIGAN STATE UNIVERSITY	EXTRACTION OF SOLUBLES FROM PLANT BIOMASS FOR USE AS A GROWTH STIMULANT AND METHODS RELATED THERETO
WO2011008698	2010	2011	THE SAMUEL ROBERTS NOBLE FOUNDATION	PLANTS WITH MODIFIED LIGNIN CONTENT AND METHODS FOR PRODUCTION THEREOF
WO2011087947	2011	2011	UT-BATTELLE LLC	BIOCHAR PRODUCTION METHOD AND COMPOSITION THEREFROM
WO2011106794	2011	2011	LOS ALAMOS NATIONAL SECURITY LLC / UNIV OF MAINE	INCREASING PLANT GROWTH BY MODULATING OMEGA-AMIDASE EXPRESSION IN PLANTS
WO2011133691	2011	2011	LOS ALAMOS NATIONAL SECURITY LLC	INCORPORATION OF METAL NANOPARTICLES INTO WOOD SUBSTRATE AND METHODS

8168861	2009	2012	UNIVERSITY OF CALIFORNIA	COMPOSITIONS AND METHODS FOR INCREASING CELLULOSE PRODUCTION
8202716	2010	2012	BATTELLE MEMORIAL INSTITUTE	THERMOPHILIC AND THERMOACIDOPHILIC BIOPOLYMER-DEGRADING GENES AND ENZYMES FROM ALICYCLOBACILLUS ACIDOCALDARIUS AND RELATED ORGANISMS, METHODS
8237014	2007	2012	EDENSPACE SYSTEMS CORP	ENERGY CROPS FOR IMPROVED BIOFUEL FEEDSTOCKS
8278500	2009	2012	OKLAHOMA STATE UNIVERSITY	SWITCHGRASS CULTIVAR
8309793	2009	2012	TEXAS A&M UNIVERSITY	DISCOVERY AND UTILIZATION OF SORGHUM GENES (MA5/MA6)
8314287	2009	2012	UNIVERSITY OF GEORGIA	SWITCHGRASS CULTIVAR EG1102
8319009	2009	2012	UNIVERSITY OF GEORGIA	SWITCHGRASS CULTIVAR EG1101
EP2524020	2011	2012	UT-BATTELLE LLC	BIOCHAR PRODUCTION METHOD AND COMPOSITION THEREFROM
WO2012037107	2011	2012	MICHIGAN STATE UNIVERSITY	COMPOSITIONS AND METHODS FOR XYLEM-SPECIFIC EXPRESSION IN PLANT CELLS
WO2012061615	2011	2012	THE SAMUEL ROBERTS NOBLE FOUNDATION	TRANSCRIPTION FACTORS FOR MODIFICATION OF LIGNIN CONTENT IN PLANTS
WO2012122308	2012	2012	AGRIVIDA INC	CONSOLIDATED PRETREATMENT AND HYDROLYSIS OF PLANT BIOMASS EXPRESSING CELL WALL DEGRADING ENZYMES
8398738	2010	2013	UT-BATTELLE LLC	BIOCHAR PRODUCTION METHOD AND COMPOSITION THEREFROM
8469784	2010	2013	US DEPARTMENT OF ENERGY	AUTONOMOUS GRAIN COMBINE CONTROL SYSTEM
8486680	2008	2013	BP P.L.C.	XYLANASES, NUCLEIC ACIDS ENCODING THEM AND METHODS FOR MAKING AND USING THEM
8604276	2010	2013	UNIVERSITY OF TENNESSEE	SWITCHGRASS UBIQUITIN PROMOTER (PVUBI2) AND USES THEREOF
EP2539456	2011	2013	LOS ALAMOS NATIONAL SECURITY LLC / UNIV OF MAINE	INCREASING PLANT GROWTH BY MODULATING OMEGA-AMIDASE EXPRESSION IN PLANTS

WO2013066842	2012	2013	UT-BATTELLE LLC / DARTMOUTH COLLEGE	FLOW-THROUGH PRETREATMENT OF LIGNOCELLULOSIC BIOMASS WITH INORGANIC NANOPOROUS MEMBRANES
WO2013126230	2013	2013	PURDUE UNIVERSITY	NOVEL LIGNASES AND ALDO-KETO REDUCTASES FOR CONVERSION OF LIGNIN-CONTAINING MATERIALS TO FERMENTABLE PRODUCTS
WO2013130456	2013	2013	MICHIGAN STATE UNIVERSITY	CONTROL OF CELLULOSE BIOSYNTHESIS
WO2013170265	2013	2013	DONALD DANFORTH PLANT SCI CENTER	METHODS FOR HIGH YIELD PRODUCTION OF TERPENES
8709122	2013	2014	UT-BATTELLE LLC	BIOCHAR PRODUCTION METHOD AND COMPOSITION THEREFROM
8790542	2010	2014	UNIVERSITY OF CALIFORNIA / SANDIA CORP	COMPOSITIONS AND METHODS USEFUL FOR IONIC LIQUID TREATMENT OF BIOMASS
8796509	2010	2014	THE SAMUEL ROBERTS NOBLE FOUNDATION	PLANTS WITH MODIFIED LIGNIN CONTENT AND METHODS FOR PRODUCTION THEREOF
8871051	2012	2014	LOS ALAMOS NATIONAL SECURITY LLC	PROCESS FOR DECOMPOSING LIGNIN IN BIOMASS
8901371	2012	2014	THE SAMUEL ROBERTS NOBLE FOUNDATION	COMPOSITIONS AND METHODS FOR IMPROVED PLANT FEEDSTOCK
EP2683799	2012	2014	AGRIVIDA INC	CONSOLIDATED PRETREATMENT AND HYDROLYSIS OF PLANT BIOMASS EXPRESSING CELL WALL DEGRADING ENZYMES
EP2708602	2008	2014	BP P.L.C.	XYLANASES, NUCLEIC ACIDS ENCODING THEM AND METHODS FOR MAKING AND USING THEM
8962333	2012	2015	UNIVERSITY OF GEORGIA	RESTRICTION/MODIFICATION POLYPEPTIDES, POLYNUCLEOTIDES, AND METHODS
8975489	2011	2015	THE SAMUEL ROBERTS NOBLE FOUNDATION	GRASS FUNGAL ENDOPHYTES AND USES THEREOF
9045549	2011	2015	THE SAMUEL ROBERTS NOBLE FOUNDATION	TRANSCRIPTION FACTORS FOR MODIFICATION OF LIGNIN CONTENT IN PLANTS

9068194	2011	2015	LOS ALAMOS NATIONAL SECURITY LLC / UNIV OF MAINE	INCREASING PLANT GROWTH BY MODULATING OMEGA-AMIDASE EXPRESSION IN PLANTS
9131648	2007	2015	WASHINGTON STATE UNIVERSITY	GENES ENCODING CHAVICOL/EUGENOL SYNTHASE FROM THE CREOSOTE BUSH LARREA TRIDENTATA
9174355	2011	2015	LOS ALAMOS NATIONAL SECURITY LLC	INCORPORATION OF METAL NANOPARTICLES INTO WOOD SUBSTRATE AND METHODS
9206446	2010	2015	MICHIGAN STATE UNIVERSITY	EXTRACTION OF SOLUBLES FROM PLANT BIOMASS FOR USE AS MICROBIAL GROWTH STIMULANT AND METHODS RELATED THERETO
EP2850193	2013	2015	DONALD DANFORTH PLANT SCI CENTER	METHODS FOR HIGH YIELD PRODUCTION OF TERPENES
WO2015095399	2014	2015	UNIVERSITY OF WISCONSIN / GLUCAN BIO RENEWABLES	BIOMASS PRE-TREATMENT FOR CO-PRODUCTION OF HIGH-CONCENTRATION C5- AND C6-CARBOHYDRATES AND THEIR DERIVATIVES
9249474	2012	2016	AGRIVIDA INC	CONSOLIDATED PRETREATMENT AND HYDROLYSIS OF PLANT BIOMASS EXPRESSING CELL WALL DEGRADING ENZYMES
9334505	2012	2016	U.S. DEPT OF AGRICULTURE / PURDUE UNIVERSITY	USING CORNGRASS1 TO ENGINEER POPLAR AS A BIOENERGY CROP
9359650	2013	2016	UNIVERSITY OF WISCONSIN / GLUCAN BIO RENEWABLES	BIOMASS PRE-TREATMENT FOR CO-PRODUCTION OF HIGH-CONCENTRATION C5- AND C6-CARBOHYDRATES AND THEIR DERIVATIVES
9394503	2014	2016	UNIVERSITY OF ILLINOIS	SEPARATION PROCESS OF OIL AND SUGARS FROM BIOMASS
9403915	2014	2016	UNIVERSITY OF CALIFORNIA / SANDIA CORP	COMPOSITIONS AND METHODS USEFUL FOR IONIC LIQUID TREATMENT OF BIOMASS
9428705	2014	2016	UNIVERSITY OF KENTUCKY	ENHANCEMENT OF BINDING CHARACTERISTICS FOR PRODUCTION OF AN AGGLOMERATED PRODUCT
9428762	2013	2016	TEXAS A&M UNIVERSITY	METHOD FOR PRODUCTION OF SORGHUM HYBRIDS WITH SELECTED FLOWERING TIMES
9434956	2012	2016	LOS ALAMOS NATIONAL	TRANSGENIC PLANTS WITH ENHANCED GROWTH

			SECURITY LLC / UNIVERSITY OF MAINE	CHARACTERISTICS
9441256	2013	2016	PURDUE UNIVERSITY	LIGNASES AND ALDO-KETO REDUCTASES FOR CONVERSION OF LIGNIN-CONTAINING MATERIALS TO FERMENTABLE PRODUCTS
9534227	2013	2017	DONALD DANFORTH PLANT SCI CENTER	METHODS FOR HIGH YIELD PRODUCTION OF TERPENES
9617558	2013	2017	UNIVERSITY OF WISCONSIN	EXTENDING JUVENILITY IN GRASSES
9650643	2013	2017	MICHIGAN STATE UNIVERSITY	CONTROL OF CELLULOSE BIOSYNTHESIS BY OVEREXPRESSION OF A TRANSCRIPTION FACTOR
9845478	2011	2017	MICHIGAN STATE UNIVERSITY	COMPOSITIONS AND METHODS FOR XYLEM-SPECIFIC EXPRESSION IN PLANT CELLS
9862964	2016	2018	LOS ALAMOS NATIONAL SECURITY LLC / UNIVERSITY OF MAINE	TRANSGENIC PLANTS WITH ENHANCED GROWTH CHARACTERISTICS
9909136	2015	2018	THE SAMUEL ROBERTS NOBLE FOUNDATION	METHODS AND COMPOSITIONS FOR ALTERING LIGNIN COMPOSITION IN PLANTS
9932648	2012	2018	UT-BATTELLE LLC	FLOW-THROUGH PRETREATMENT OF LIGNOCELLULOSIC BIOMASS WITH INORGANIC NANOPOROUS MEMBRANES
9994998	2015	2018	UT-BATTELLE LLC	KEY GENE REGULATING PLANT CELL WALL RECALCITRANCE
10006038	2015	2018	AGRIVIDA INC	CONSOLIDATED PRETREATMENT AND HYDROLYSIS OF PLANT BIOMASS EXPRESSING CELL WALL DEGRADING ENZYMES
10112916	2015	2018	UNIVERSITY OF CALIFORNIA / SANDIA CORP / VIRDIA INC	HMF PRODUCTION FROM GLUCOSE IN IONIC LIQUID MEDIA
10160980	2016	2018	UNIVERSITY OF CALIFORNIA	ARTIFICIAL PHOTOSYNTHESIS SYSTEMS AND METHODS FOR PRODUCING CARBON-BASED CHEMICAL COMPOUNDS
RE46733	2008	2018	BP P.L.C.	XYLANASES, NUCLEIC ACIDS ENCODING THEM AND METHODS FOR MAKING AND USING THEM

An Analysis of the Influence of BETO-funded Feedstock Patents

Report prepared by 1790 Analytics LLC

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