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

FUEL CELL TECHNOLOGIES OFFICE

Pathways to Commercial Success:

Technologies and Products Supported by the Fuel Cell Technologies Office

September 2013

Prepared by Pacific Northwest National Laboratory
for the U.S. Department of Energy Fuel Cell Technologies Office

Notice

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Summary

The purpose of the project described in this report is to identify and document the commercial and emerging (projected to be commercialized within the next 3 to 5 years) hydrogen and fuel cell technologies and products that resulted from Department of Energy support through the Fuel Cell Technologies Office (FCTO) in the Office of Energy Efficiency and Renewable Energy (EERE). Pacific Northwest National Laboratory (PNNL) undertook two efforts simultaneously to accomplish this project. The first effort was a patent search and analysis to identify patents related to hydrogen and fuel cells that are associated with FCTO-funded projects (or projects conducted by DOE-EERE predecessor programs) and to ascertain the patents' current status, as well as any commercial products that may have used the technology documented in the patent. The second effort was a series of interviews with current and past FCTO personnel, a review of relevant program annual reports, and an examination of grants made under the Small Business Innovation Research and Small Business Technology Transfer Programs that are related to hydrogen and fuel cells.

The patent analysis identified 455 patents associated with research supported by FCTO dating back to 1977. The 455 FCTO patents include: 230 fuel cell patents, 167 hydrogen production/delivery patents, and 58 hydrogen storage patents. Three types of organizations received the patents: national laboratories (179 patents), private companies (223 patents), and universities (53 patents). Private companies received the greatest number of patent awards in the fuel cell and production/delivery areas, accounting for 56% of the fuel cell patents and 50% of the production/delivery patents. The national laboratories had 60% of the awards in the storage area.

The patent award status by use indicated that 20 patents are currently used in commercial products and 63 are part of research now taking place on emerging technologies. In addition, 245 awarded patents are still being utilized via continuing research and/or active attempts to license the patent. Of all the patents reviewed, 72% are still actively being pursued through use in continuing research, emerging technologies, or commercially available products.

In addition, PNNL identified 41 commercial technologies that have entered the market, of which 39 are still commercially available. From 2000 – 2006, one to three commercial technologies entered the market per year. For 2007 through 2012, an average of five technologies per year entered into the market. In 2013, one technology has entered the market to date. Commercial technologies also supported the creation/retention of 447 direct jobs in FY 2013. This effort also identified 66 emerging technologies that are anticipated to be commercially available in 3 to 5 years. Of the 66 emerging technologies, 48% are in the fuel cell area, 38% are in the production/delivery area, and 14% are in the storage area.

This report documents the methodology and results of this study, including the specific patents as well as commercial and emerging technologies that resulted from FCTO funding.

1.0 Introduction

This report documents the methodology and results of an effort to identify and characterize commercial and emerging[1] technologies and products that resulted from the support of the Fuel Cell Technologies Office[2] (FCTO) within the U.S. Department of Energy's (DOE's) Office of Energy Efficiency and Renewable Energy (EERE). Commercialization of technologies that are cultivated in a government research and development (R&D) program is viewed as one measure of success. PNNL has been conducting similar technology tracking activities for other EERE offices for over two decades.

The results presented in this report represent the findings from the PNNL effort. The information presented on commercial and emerging technologies fulfills the primary objective – to assess the commercialization status of EERE-developed hydrogen and fuel cell technologies. The effort is expected to continue, with an updated report produced annually.

This chapter presents a brief overview of the FCTO's research that is leading to commercial technologies and products. The chapter concludes with a summary of the contents of this report.

1.1 Organization of the FCTO

The FCTO is focused on key technical challenges associated with fuel cells and hydrogen production, delivery, and storage, as well as institutional barriers, such as hydrogen safety, codes and standards, technology validation, market transformation, and public awareness. The FCTO is currently conducting applied research, technology development, and learning demonstrations, as well as safety research, systems analysis, and public outreach and education activities. Because the research involved in solving critical technological barriers is often high risk, and can benefit from leveraging resources and skills, the FCTO encourages public-private partnerships, which include the supply chain industry, automotive and power equipment manufacturers, energy and chemical companies, electric and natural gas utilities, building designers, standards development organizations, other federal agencies, state government agencies, universities, national laboratories, and other national and international stakeholder organizations.

The FCTO is currently conducting R&D, demonstration, analysis, and other efforts to support development of hydrogen and fuel cell technologies for stationary power (including back-up emergency power and residential electric power generation), transportation (including materials handling equipment, fuel cell vehicles and hydrogen refueling infrastructure), and portable power applications (including consumer electronics such as cellular phones, hand-held computers, radios, and laptop computers). The FCTO subprograms that are relevant to technology development represented in this report include the following:

- Hydrogen Production
- Hydrogen Delivery
- Hydrogen Storage
- Fuel Cells
- Manufacturing R&D.

The first four subprograms are the primary focus of this report because they are focused on technology R&D that would result in patents and other intellectual property that could be incorporated into commercial technologies and products. Manufacturing R&D is a relatively new subprogram that is likely to lead to commercial technologies in the future.

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[1] "Commercial" technologies, as defined in this report, are those available for purchase and that have been sold to at least one party. "Emerging" technologies, as defined in this report, are technologies that are projected to be commercialized within the next 3 to 5 years, based on the opinion of the technology developer.

[2] Formerly the Hydrogen, Fuel Cells & Infrastructure Technologies Program, 2002-2009, and the Fuel Cell Technologies Program, 2009-2012.

The current goals of these four subprograms are briefly summarized below.

Hydrogen Production. The goal of the Hydrogen Production subprogram is to develop low-cost, highly efficient hydrogen production technologies from diverse domestic sources, including natural gas and renewable sources. The subprogram objectives include lowering the cost of distributed production (at the pump) of hydrogen from natural gas, biomass, and electrolysis; developing high-temperature thermo-chemical cycles driven by concentrated solar energy; and developing advanced renewable photo-electrochemical and biological hydrogen generation technologies. Hydrogen separation is a key technology that cross-cuts hydrogen production options, and various separation membranes are being developed as part of distributed and central hydrogen production systems. In addition, work in the subprogram includes developing better catalysts needed in production systems and coordinating with the Office of Science on basic research, such as hydrogen production from algae and other biological systems. The subprogram also coordinates with the Office of Fossil Energy (FE) on coal gasification (with sequestration) and separation processes, and with the Office of Nuclear Energy (NE) on hydrogen production from thermochemical processes.

Hydrogen Delivery. The goal of the Hydrogen Delivery subprogram is to develop hydrogen delivery technologies that enable the introduction and long-term viability of hydrogen as an energy carrier for transportation and stationary power. Some of the current objectives include reducing the cost of compression, storage, and dispensing at refueling stations and stationary power facilities; reducing the cost of hydrogen transport from central and semi-central production facilities to the gate of refueling stations and other end users; and reducing the cost of hydrogen delivery from the point of production to the point of use in vehicles or stationary power units. Some of the technical challenges that must be addressed include resolving hydrogen embrittlement concerns and developing new and improved materials for pipeline delivery of hydrogen, developing novel liquid and solid carrier technologies, improving compression and bulk storage technologies, and improving hydrogen liquefaction approaches.

Hydrogen Storage. The goal of the Hydrogen Storage subprogram is to develop and demonstrate viable hydrogen storage technologies for transportation and stationary applications, as well as early market applications, with the primary objectives focused on developing and verifying on-board hydrogen storage systems for transportation applications. Various research activities are being pursued, such as those related to lightweight composite tanks with high-pressure ratings and conformability and high-capacity metal hydrides, including boron-based materials, adsorbent-based and nanostructured materials, chemical carriers, and other promising materials with potential for hydrogen storage. Coordination with the Office of Science is also noteworthy, particularly in developing a fundamental understanding of hydrogen-material interactions.

Fuel Cells. The goal of the Fuel Cells subprogram is to develop and demonstrate fuel cell power system technologies for transportation, stationary, and portable power applications. The subprogram emphasizes polymer electrolyte membrane (PEM) fuel cells as replacements for internal combustion engines in light-duty vehicles as well as fuel cells for stationary power, portable power, and auxiliary power applications. Research focus areas include work on membranes, electrocatalysts and electrode design, membrane electrode assemblies, gas diffusion layers, bipolar plates, seals, and other aspects of fuel cell design including water management and balance-of-plant components. Over the last several years, the subprogram has included small-scale solid oxide fuel cell (SOFC) R&D to complement the Department Office of Fossil Energy's Solid State Energy Conversion Alliance (SECA) Program[3] on megawatt-scale SOFC power systems. The portfolio has been broadened to include other work as well, such as alkaline fuel cells. Work on fundamental catalysis is coordinated with the Office of Science. More recently, coordination with the Advanced Research Projects Agency - Energy (ARPA-E) has been initiated, particularly in innovative areas such as alkaline exchange membranes.

More information on program goals, objectives, research thrusts, and activities can be found in the FCT Multi-Year Program Plan (http://www1.eere.energy.gov/hydrogenandfuelcells/mypp/).

[3] FE's SECA Program is supporting the development of large-scale SOFCs that can be mass produced in modular form at $400/kW. The objective of the SECA Program is to put reliable fuel cells into a more modular and affordable design to allow wide-spread penetration into stationary and utility-scale markets.

The objectives of, and R&D activities funded by, the FCTO and its predecessor programs have changed over the years as the Office has become more focused on the goals described above and as advancements have been made in R&D. Because this report looks retrospectively at commercial successes over the history of hydrogen and fuel cell research within EERE, the patents and commercial/emerging technologies and products described in the remainder of this report may be broader than one would expect from examining the current FCTO efforts.

1.2 Contents of this Report

The remaining chapters explain in more detail the methodology used and provide the results of the effort in tables and charts. The appendices provide detail related to the data-gathering techniques and descriptions of each of the commercial and emerging technologies and products that were identified in the study, as well as the list of patents resulting from the R&D efforts undertaken by the FCTO and its predecessors. Note that in this report, the delivery technologies have been grouped with production technologies because of the overlap between the two categories. A new area tracked since FY 2011 is an estimate for the number of jobs directly related to FCTO funding. These estimates are based on recipient interviews and may be refined as more information and validation becomes available.

2.0 Approach

Two efforts were undertaken simultaneously by PNNL in August 2007 under FCTO's System Analysis Subprogram, to start the FCTO technology tracking project. The first effort was a patent search and analysis to identify hydrogen- and fuel-cell-related patents that are associated with FCTO-funded projects (or projects conducted by DOE-EERE predecessor programs) and to ascertain the patents' current status, as well as any commercial products that may have used the technology documented in the patent. The second effort was a series of interviews and document reviews to identify and characterize commercial and emerging technologies that have benefited in a direct way as a result of direct funding from the FCTO (or funding from EERE predecessor programs) or from grants under programs such as the Small Business Innovation Research and Small Business Technology Transfer. These initial efforts resulted in the August 2009 EERE report entitled: *Pathways to Commercial Success: Technologies and Products Supported by the Hydrogen, Fuel Cells & Infrastructure Technologies Program*. PNNL subsequently updated this report in FY 2010, FY 2011, FY 2012 and FY 2013. The approach taken for these efforts is summarized in Sections 2.1 and 2.2 below.

2.1 Patent Search and Analysis

PNNL conducted several patent searches using the United States Patent Office (USPTO) database. The searches included key words related to the hydrogen program[1] and focused exclusively on patents for which DOE had a "Government Interest."[2] The resulting list contained 118 fuel cell patents (mostly related to PEMs) and 239 hydrogen production, storage and delivery patents dating back to 1977. The PNNL team then conducted an initial screening analysis to winnow the patent list to those likely to be associated with EERE research. (Other parts of DOE, including FE, NE, and Office of Science, also conduct research on hydrogen and fuel cells, but those patents were not included in this study.)

In addition, PNNL obtained the list of patents that were cited in the Hydrogen and Fuel Cells Program's Annual Progress Reports for 2002 – 2007[3] and included them in the patent list. The list was sent to FCT staff to review, and some patents were removed or recategorized (e.g., from fuel cells to production). The resulting list contained patents for 77 fuel-cell-related and 103 hydrogen-related technologies or inventions (180 total).

The next step was to obtain more information about the government's role in developing the patent and to determine the current status. The PNNL team contacted patent holders by phone or email. For large organizations (e.g., national laboratories, universities, and multinational corporations), PNNL team members were often referred to a central office within the organization, such as a technology transfer, commercialization, or legal affairs office.

The PNNL team members asked the patent holders or central offices whether the FCTO or EERE (or its predecessors) funded the research resulting in the patent. Patents not related to the FCTO or EERE funding were removed from the list. If a patent had received such funding, the PNNL team attempted to ascertain the current status of the patent and placed it in one of the following categories: no longer being pursued for commercialization nor used in research, still being used in research, used in a commercial product, or licensed to another company. If the patent is still being used in research, PNNL asked if it was part of an emerging technology for which PNNL was gathering data. If the technology was licensed to another company, PNNL asked for the name of the company and tried to ascertain whether a commercial product had resulted from the patent. As PNNL gathered technology data, other patents associated with FCTO/EERE funding were sometimes identified and added to the list. Figure 2.1 depicts the initial patent analysis process for the hydrogen and fuel cell technologies.

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[1] One search used the following search terms: "hydrogen" AND "storage" OR "transport" OR "delivery" OR "dispensing" AND "government/energy." The other search used the following search terms: "fuel cell" AND "pem" OR "membrane" AND "government/energy."

[2] Note that the patent database has a separate field that designates whether there is a "Government Interest" in the patent. If DOE has an interest, that field says, for example, "The United States Government has rights in this invention pursuant to Contract No. […] between the United States Department of Energy and [….a national laboratory or other party]." It is possible that not all of the parties with EERE-related patents correctly indicated that their patents had a "Government Interest."

[3] These reports can be found at http://www.hydrogen.energy.gov/annual_progress.html.

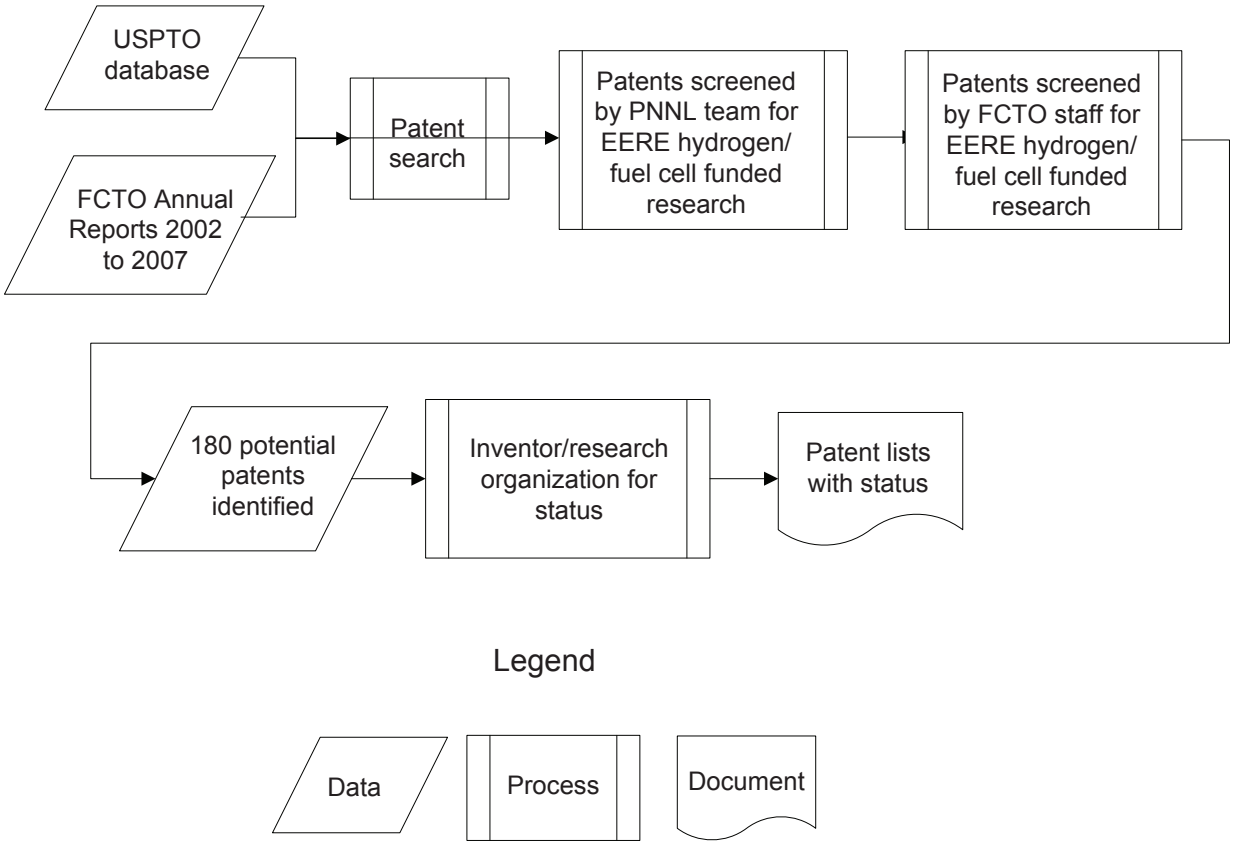

Figure 2.1. Initial Patent Analysis Process for Hydrogen and Fuel Cell Technologies

In FY 2010, PNNL began updating the August 2009 *Pathways to Commercial Success* report. As part of the updating process, the PNNL team conducted a search through FY 2008 and 2009 Hydrogen and Fuel Cells Program Annual Progress Reports to identify any new patents issued during those years. In addition, principal investigators for FCTO-funded emerging technologies and commercial products were asked if they had been awarded any new patents as a result of their research and development work. In June 2010, EERE launched a Technology Commercialization Portal on their website (http://techportal.eere.energy.gov/), which features a portfolio of EERE-funded technologies available for licensing, including patents. Using the EERE Portal, the PNNL team conducted a search for patents which employed similar screening strategies to those used in the original USPTO database searches. The PNNL team contacted patent holders via phone and e-mail to determine whether or not the underlying research associated with a patent was FCTO-funded. If a patent had received such funding, its current status was obtained. In subsequent years, PNNL conducted patent searches using the same methodology as in FY 2010.

The combined results of all the patent searches are discussed in Chapter 3. Some of the intellectual property in the patents on the list was used in technologies or products that were commercialized or that are soon to be commercialized. The section below describes the effort, conducted in parallel with the patent analysis, to identify and describe commercialized and emerging technologies. Chapter 3 provides information on these technologies and the patents related to them.

2.2 Technology Tracking to Identify and Describe Commercial and Emerging Technologies

In 2007, the PNNL team identified FCTO-funded projects that may have led to commercial or emerging technologies. To accomplish this, a series of one-on-one meetings was held with FCTO personnel and former FCTO personnel in which the lists of all FCTO-funded projects, obtained from the Hydrogen and Fuel Cells Program Annual Progress Reports for 2002 – 2007, were reviewed. Also, PNNL reviewed earlier annual reports from FCTO predecessor programs. From these meetings, the PNNL team obtained a preliminary list of projects that the FCTO personnel indicated may have led to commercial or emerging technologies. The government personnel also provided information about points of contact (POCs) or principal investigators (PIs) at each relevant research organization and, where available, hard copies of reports or presentations pertinent to the technologies. The resulting list of projects from these meetings was separated into three categories according to the following research areas: fuel cells, hydrogen production/delivery, and hydrogen storage.

The PNNL team contacted the POCs or PIs for the technologies to determine whether they were commercially available, emerging, still in the research stage but more than 3 to 5 years from commercialization, or no longer being pursued. For technologies identified as commercial or emerging, the POCs/PIs for each technology were contacted to gather data on the technology.

The Hydrogen and Fuel Cells Program Annual Progress Report also includes descriptions of hydrogen and fuel cell projects from the annually funded Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) grants. The SBIR grants are funded in two phases: Phase 1 grants focus on the feasibility of an idea and are funded at a low level (typically up to $100K), and Phase 2 grants focus on principal R&D and are funded at a higher level (typically up to $500K). To receive a SBIR Phase 2 grant, a small business would have to have successfully completed a Phase 1 grant and have been selected to continue their research. The STTR grants are similar to SBIR grants as far as having small business participation, but a nonprofit research institution, such as a university or national laboratory, must also be involved. The PNNL team focused on the SBIR Phase 2 and STTR grant projects and contacted the PIs for all of these grants to determine the status of the technologies being developed. Any identified as commercial or emerging were added to the technology tracking list.

Data gathered about the technologies were then entered into a FCTO Technology Tracking Database, a Lotus Notes database. The database is divided into commercial and emerging technology sections and into three types of research within each section: fuel cells, production/delivery, and storage. In addition, hard copy files are kept that include the template (database) information and other supporting data such as annual progress reports, presentations, and information from the organization's website. The database was created and populated by PNNL and is stored at PNNL, and FCTO personnel have access to it. Periodically, PNNL transmits an updated version of the database to DOE to replace the older version on the DOE system.

For each of the commercial and emerging hydrogen technologies in the database, the PNNL team prepared and edited a summary description and sent it to the industry/research organization POC for review and subsequent approval before sending it to FCTO personnel to review. Figure 2.2 depicts the initial technology tracking process. In subsequent years, the PNNL team employed a similar technology tracking process to identify new emerging and commercially available technologies and ascertain the current status of technologies identified in previous years. Beginning in FY 2011, the PNNL team also asked commercial technology POCs to estimate the number of jobs created or retained by the sales of their technologies. The current listing of commercially available and emerging technologies is shown in Appendix A. The results of the technology tracking effort are discussed in Chapter 3.

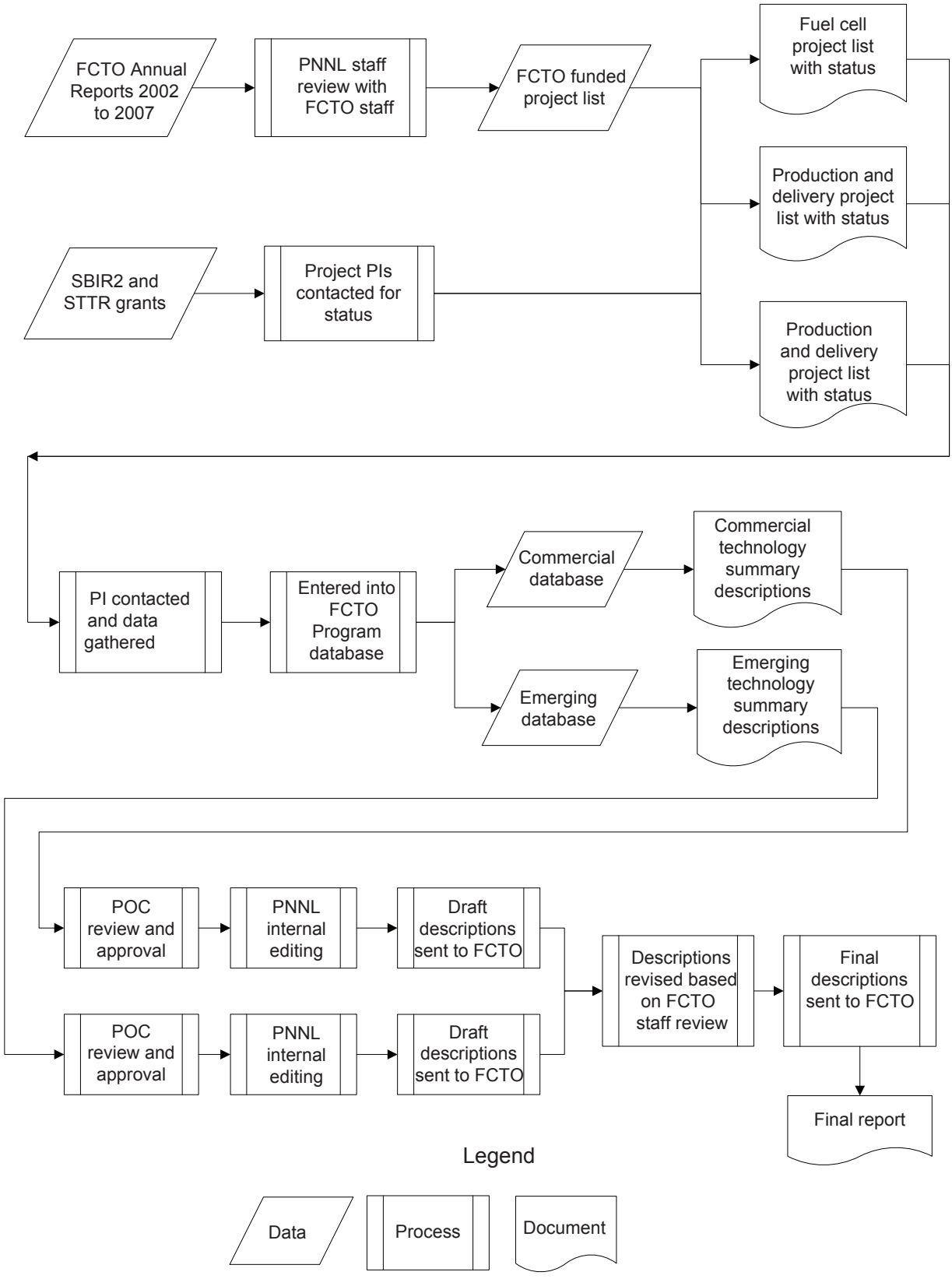

Figure 2.2. Initial Technology Tracking Process for Hydrogen and Fuel

3.0 Results

The results of the efforts undertaken in the FCTO technology tracking project are summarized in this chapter. Section 3.1 describes the patent search and analysis and Section 3.2 describes the results of the commercial and emerging technology identification and tracking effort.

3.1 Patent Search and Analysis

The results of the patent search are shown in tables in Appendix B: the 230 fuel cell patents are listed in Appendix B-1, the 167 hydrogen production/delivery patents are listed in Appendix B-2, and the 58 hydrogen storage patents are listed in Appendix B-3. The patents are listed in chronological order from the most recent to the oldest patent for each group. The tables list the patent number, award date, organization receiving the patent, patent title, patent description, and patent status.

Figure 3.1 shows the cumulative number of patents awarded over time, starting with 2007 patent awards through 2013. (At the time of this report, data for 2013 are only partially available.) From 2007 through 2012, an average of 43 patents per year were awarded. During the same time frame, fuel cell, production/delivery, and storage patents were awarded at an average rate of 21, 16, and 6 patents per year, respectively. As the figure shows, the number of patents awarded per year increased significantly in 2009 and 2010. To date, 2010 had the largest number of patents awarded in an individual year, with 34 fuel cell patents, 20 production/delivery patents, and 11 storage patents.

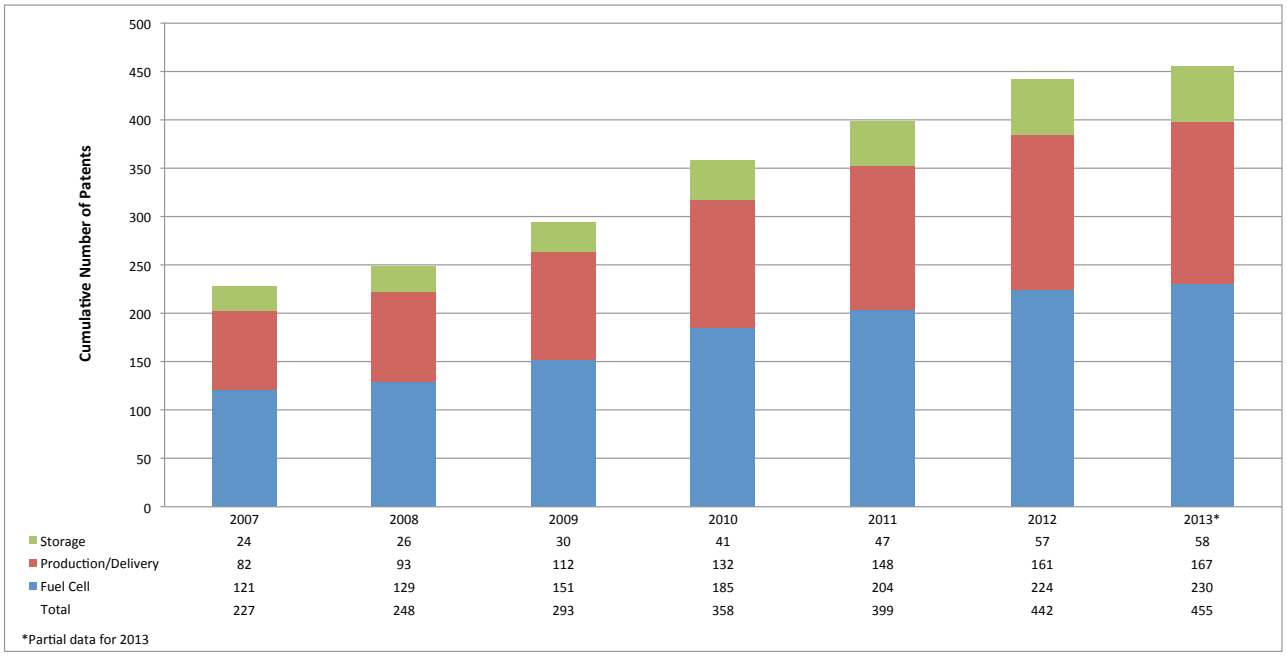

Figure 3.1. Cumulative Number of Patents Awarded Over Time

Another way to view the patent awards, shown in Figure 3.2, is by the type of organization that received the patent or the inventor's employer. Three types of organizations were identified: national laboratories (179 patents), private companies (223 patents), and universities (53 patents). National laboratories and private companies account for 93% of all patents awarded for fuel cell technologies, with private companies receiving 56% of the awards. Private companies had more patent awards in the production/delivery area (50%) than national laboratories (34%), while universities had 16% of the production/delivery patents. National laboratories account for 60% of the storage patents, followed by private companies with 21% and universities with 19%.

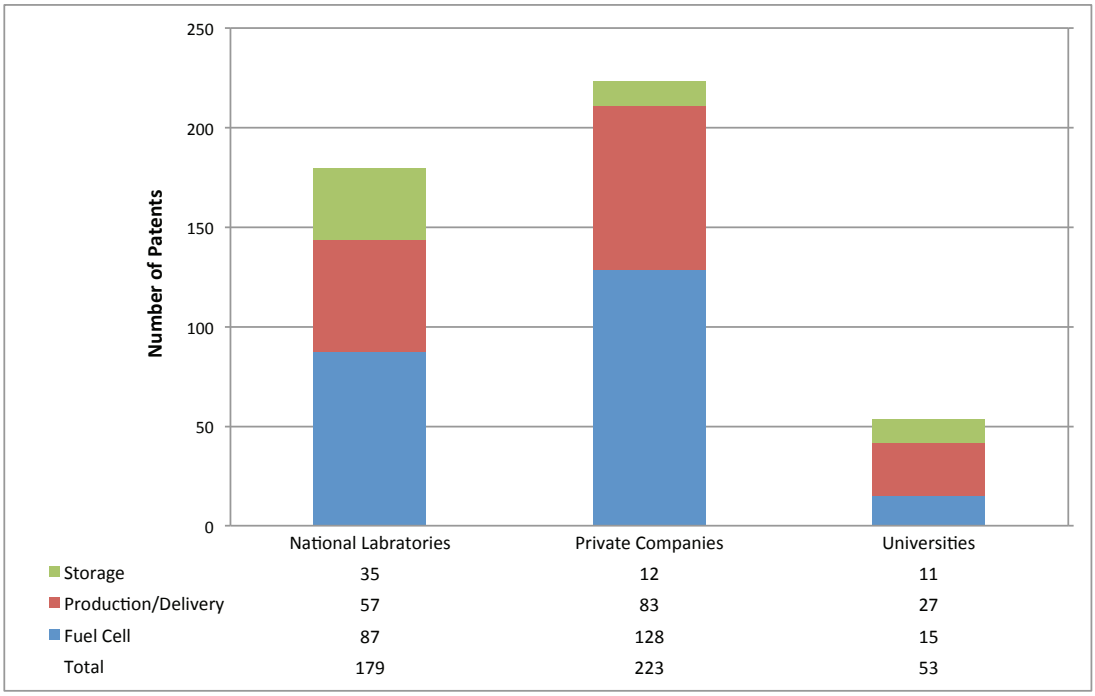

Figure 3.2. Types of Organization Receiving Patent Awards

Figure 3.3 shows the patent award status by use. As the figure shows, 20 patents are used in commercially available products, including:

- Bipolar plate/diffuser for a proton exchange membrane fuel cell (Patent number 6,171,720, Oak Ridge National Laboratory, 2001)
- Composite bipolar plate for electrochemical cells (Patent number 6,248,467, Los Alamos National Laboratory, 2001)
- Corrosion test cell for bipolar plates (Patent number 6,454,922, Los Alamos National Laboratory, 2002)
- Chemical microreactor and method thereof (Patent number 6,960,235 LLNL, 2005)
- Control method for high-pressure hydrogen vehicle fueling station dispensers (Patent number 7,059,364, Gas Technology Institute, 2006)
- Fuel cell and fuel cell coolant compositions (Patent number 7,138,199, Dynalene, Inc., 2006)
- Gas diffusion electrodes, membrane-electrode assemblies and method for the production thereof (Patent numbers 7,419,546 (2008), 7,601,216 (2009), and 7,785,454 (2010), BASF Corporation)
- Fuel cell electrolyte membrane with acidic polymer (Patent number 7,517,604, 3M Company, 2009)
- Fuel cell membrane electrode assembly (Patent number 7,572,534, 3M Company, 2009)
- System and method for detecting gas (Patent number 7,678,251, Proton Energy Systems, Inc., 2010)
- Gas venting system (Patent number 7,744,733, Proton Energy Systems, Inc., 2010)
- Fuel cell electrolyte membrane with basic polymer (Patent numbers 7,838,138 (2010), and 8,323,809 (2012), 3M Company)
- Cold weather hydrogen generation system and method of operation (Patent number 7,850,838, Proton Energy Systems, Inc., 2010).
- Hybrid adsorptive membrane reactor (Patent number 7,897,122 Media and Process Technology, 2011)
- Proton conducting materials (Patent numbers 8,481,227 (2013), and 8,227,140 (2012), 3M Company)
- Electroplating cell with hydrodynamics facilitating more uniform deposition across a workpiece during plating (Patent number 8,329,006, Faraday Technology, Inc., 2012)

Sixty-three patents are part of research now taking place on emerging technologies identified on the technology tracking list in Appendix A. In addition, 245 awarded patents are still being utilized via continuing research and/or active attempts to license the patent. Of all the patents reviewed, 72% are still actively being pursued through use in continuing research, emerging technologies, or commercially available products.

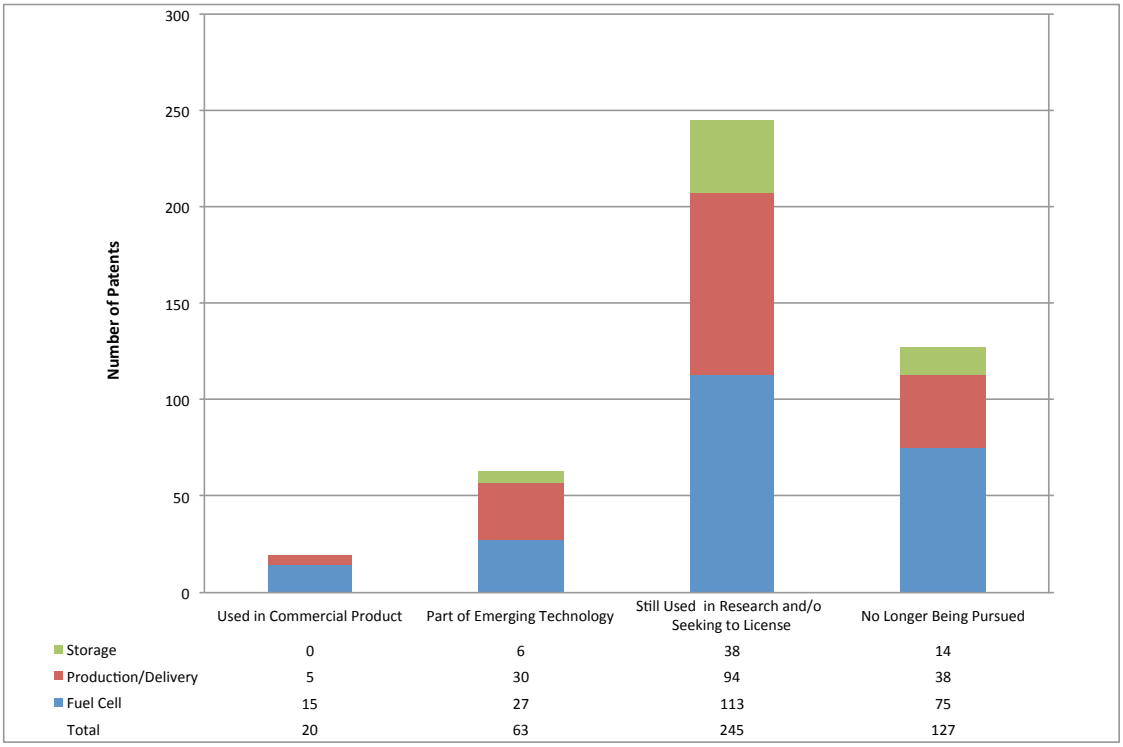

Figure 3.3. Status of Awarded Patents

3.2 Commercial and Emerging Technology Identification and Tracking Results

The FCTO Technology Tracking Database contains 38 commercially available technologies, all of which are described in Appendix C. These descriptions were reviewed and approved by the industry POC for each technology. Figure 3.4 shows the cumulative number of commercial technologies entering the market. Of the 41 technologies that have entered the market two of them are no longer commercially available and one company decided not to continue to participate in the technology tracking effort. From 2000 through 2012, approximately three technologies per year entered the market. The years 2000 through 2006 showed a steady addition of technologies entering the market of one to three per year. For 2007 through 2012, an average of five technologies per year entered the market. In 2013, one technology has entered the market to date.

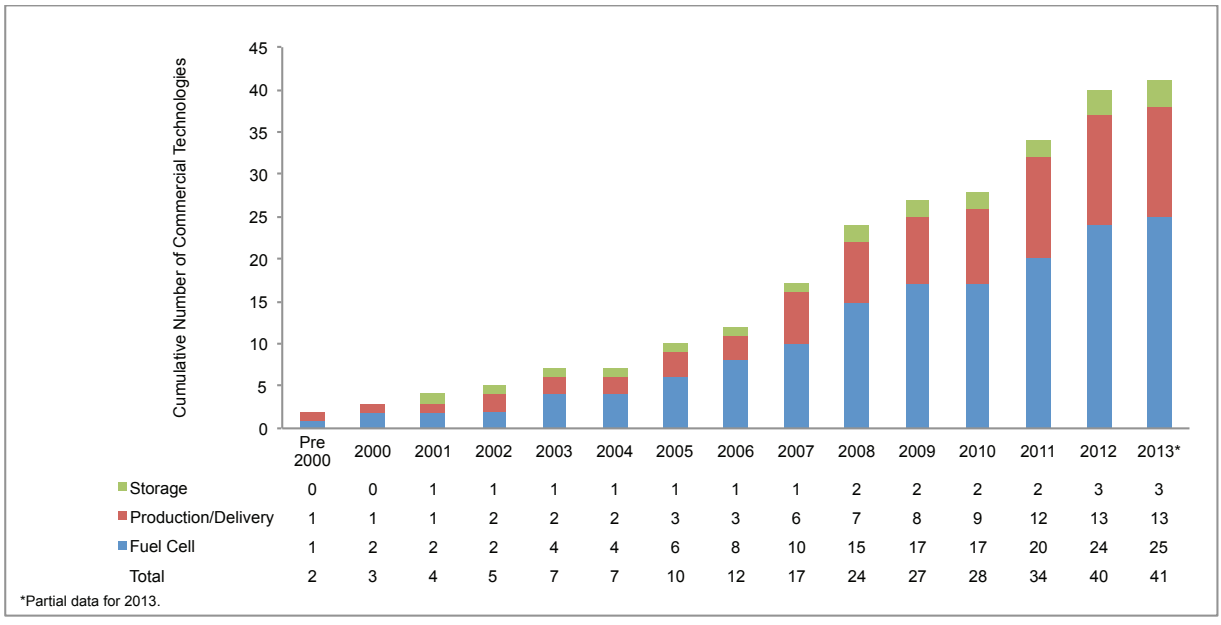

Figure 3.4. Cumulative Number of Commercial Technologies Entering the Market

Table 3.1 briefly describes each of the 24 commercially available fuel cell technologies and their benefits. The full descriptions of these technologies are provided in Appendix C-1. These technologies range from an analysis tool to manufacturing processes for fuel cells and their components, to entire fuel cell systems that can be used in vehicles or stationary applications.

Table 3.2 briefly describes each of the 12 commercially available production/delivery technologies and their benefits. The full descriptions of these technologies are provided in Appendix C-2. These technologies include improved catalysts, hydrogen generation systems for fueling vehicles, and technologies for providing high purity hydrogen.

Table 3.3 briefly describes the 2 commercially available storage technologies and their benefits. The full descriptions of these technologies are provided in Appendix C-3. One of the technologies is a composite tank, and the other is a method to store hydrogen in powder form.

FCTO's Multi-Year Research, Development and Demonstration Plan, which was last updated in October 2007 (and is currently in the process of being revised), was examined to see how the commercially available technologies align with FCTO's objectives and goals. The plan lists challenges and approaches for the research areas funded by the FCTO. The fuel cell area listed 19 challenges. The 24 commercially available technologies in Table 3.1 are aligned with 13 of these challenges, as shown in Table 3.4. Similarly, the 12 commercially available production/delivery technologies in Table 3.2 were found to align with 4 of the 13 challenges in that area, as shown in Table 3.5. The 2 commercially available storage technologies in Table 3.3 were found to align with 2 of the 7 storage approaches, as shown in Table 3.6.

The technology tracking database currently contains 66 emerging technologies for which descriptions are provided in Appendix D. These were reviewed and approved by the industry POC for each technology. Figure 3.5 shows the number of emerging technologies in each FCTO research area over the past five years of the technology tracking effort. Since 2009, the number of fuel cell emerging technologies has been about half of the total, with emerging storage technologies making up a very small percentage. Figure 3.6 shows the FY 2013 distribution of the emerging technologies in the three FCTO research areas.

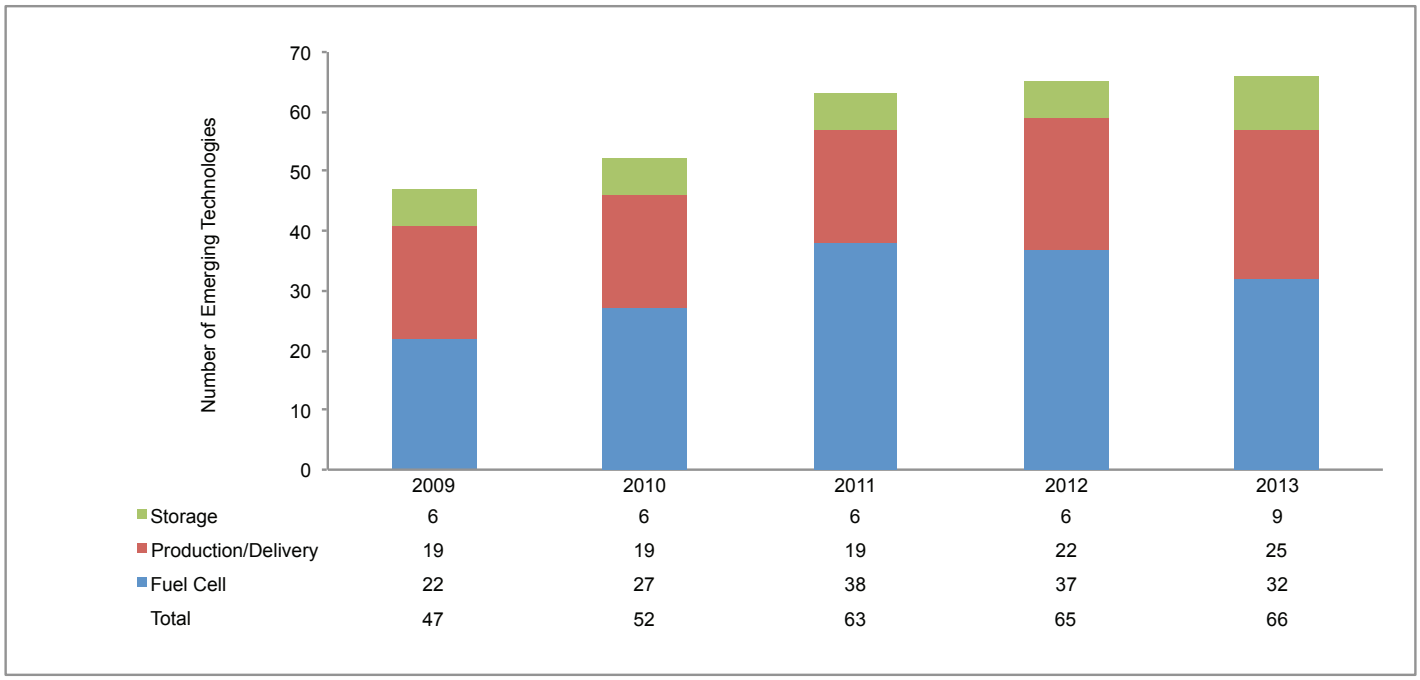

Figure 3.5. Number of Emerging FCTO Technologies

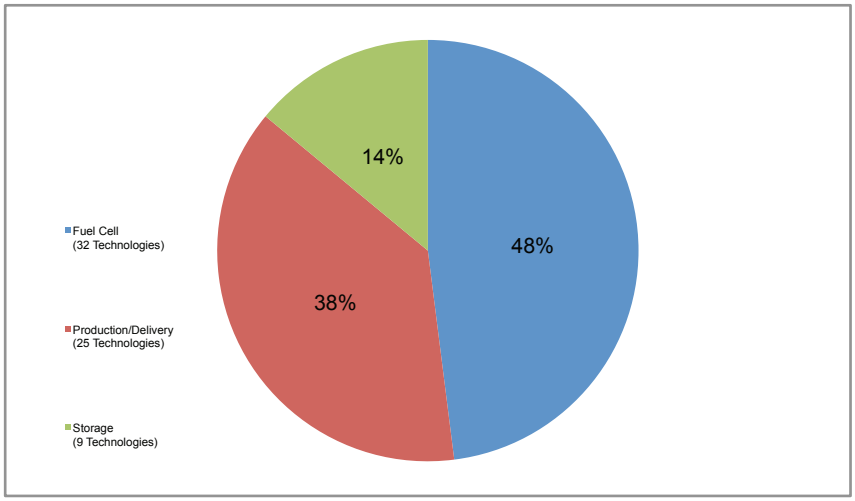

Figure 3.6. Distribution of Emerging FCTO Technologies in FY 2013

Table 3.7 briefly describes each of the 32 emerging fuel cell technologies and their benefits. The full descriptions of these technologies are provided in Appendix D-1. These technologies are quite diverse and include improved fuel cell components, such as membranes, plates, assemblies, cathodes and sensors, as well as entire systems for various uses.

Table 3.8 briefly describes each of the 25 emerging production/delivery technologies and their benefits. The full descriptions of these technologies are provided in Appendix D-2. These technologies include improved membranes, reformers, and compressors, as well as novel methods and fuels to produce hydrogen.

Table 3.9 briefly describes each of the 9 emerging storage technologies and their benefits. The full descriptions of these technologies are provided in Appendix D-3. These technologies include improved tanks or cylinders, as well as new approaches for storing hydrogen.

The 32 emerging fuel cell technologies in Table 3.7 are aligned with 11 of the 19 fuel cell challenges in the FCTO Program Plan, as Table 3.10 shows. Also, 3 challenges in the manufacturing research area of the plan for PEM fuel cells are aligned with 4 emerging fuel cell technologies. Similarly, the 25 emerging production/delivery technologies in Table 3.8 are aligned with 9 of the 13 production and delivery challenges in the plan, as shown in Table 3.11. The 9 emerging storage technologies in Table 3.9 are aligned with 4 of the 7 approaches in the storage area, as shown in Table 3.12.

An alphabetized directory of the organizations that developed the commercial and emerging technologies described in Appendices C and D is provided in Appendix E.

3.3 Jobs Created or Retained as a Result of Commercially Available Technologies

Beginning in FY 2011, the PNNL team asked commercial technology POCs to estimate the number of jobs created or retained by the sales of their technologies. Figure 3.7 shows the number of jobs created or retained in FY 2011, FY 2012 and FY 2013 based on the responses from the POCs.[1] These numbers do not include estimates for indirect jobs. For example, the associated supply chain jobs (e.g., balance-of-plant components, stack materials, etc.) for a fuel cell system are excluded. Figure 3.8 shows the FY 2013 distribution of jobs created or retained in the three FCTO research areas.

[1] Some POCs declined to provide an estimate of the number of jobs created/retained due to business confidentiality.

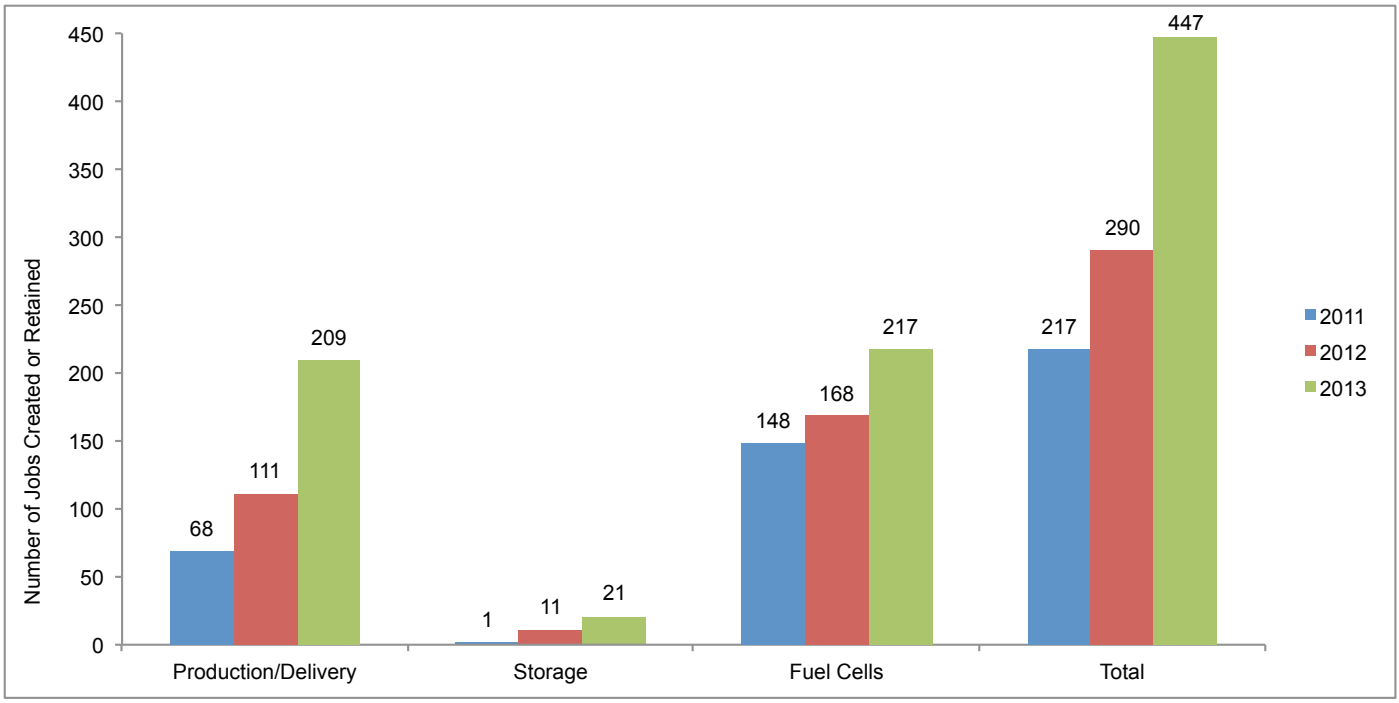

Figure 3.7. Jobs Created or Retained as a Direct Result of Commercially Available Technologies

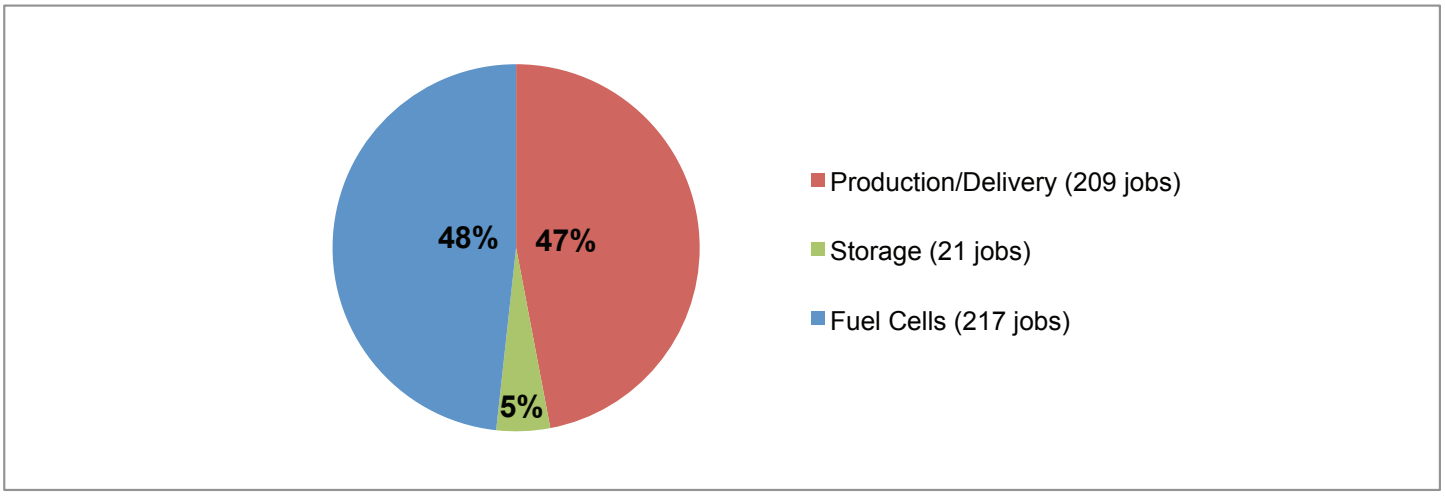

Figure 3.8. Distribution of Jobs Created or Retained in FY 2013

Table 3.1. Commercial Products Summary – Fuel Cells

Technology	Organization	Description	Benefits	Commercial Status
A Silicon-Based Solid Oxide Fuel Cell for Portable Consumer Electronics	Lilliputian Systems, Inc.	A miniature SOFC for the consumer portable power market is fabricated on a silicon chip and is fueled by butane from an on-board cartridge. The device delivers 2.5 watts of power with a run time of more than 30 hours per cartridge and plugs into various portable electronics via a USB cable connection.	The technology can be used as an alternative to conventional wall outlet and battery-based devices for charging portable consumer electronics. It provides convenient, on-the-go power and has been approved by the Federal Aviation Administration for passenger use on airplanes.	Commercially available in 2013 through Brookstone.
Bio-Fuled Solid Oxide Fuel Cells (SBIR Project)	TDA Research, Inc.	A novel catalyst and high-capacity sorbent were developed that allows biogas to be used in SOFCs.	This new technology allows SOFCs to operate on biogas as an alternative to natural gas.	Commercialized in 2011.
Cathode Catalysts and Supports for PEM Fuel Cells	3M Company	The advanced MEA uses a carbon-free nanostructured thin-film catalyst and an ion exchange membrane to achieve longer lifetimes using fewer precious metals.	The technology reduces costs because of lower precious metal loading and manufacturing costs, improved durability, and smaller fuel cell size. It can operate at higher temperatures and lower humidity.	Commercialized in 2007 and selling to select fuel cell developers.
Compact, Multi-Fuel Solid Oxide Fuel Cell (SOFC) System	Technology Management, Inc.	The 1-kW modular, multi-fuel SOFC system is designed to produce electricity and heat for multiple mobile and on-site stationary applications.	The SOFC system is inherently flexible and sulfur tolerant and can operate on multiple renewable and conventional fuels, including biodiesel, vegetable oils, ethanol, diesel, kerosene, natural gas, and propane.	Commercialized in 2012 with demonstration units provided to several potential customers.
Complex Coolant for Polymer Electrolyte Membrane (PEM) Fuel Cells	Dynalene, Inc.	The advanced, complex coolant fluid consists of a base mixture and additives of non-ionic corrosion inhibitors and ion-suppressing nanoparticles, which maintain low electrical conductivity.	The technology eliminates de-ionizing filters, thereby reducing the overall cost and maintenance of the fuel cell while increasing the amount of time the cell can run continuously.	Commercialized in 2009 with approximately 950 gallons of coolant sold.
Conductive Compound for Molding Fuel Cell Bipolar Plates	Bulk Molding Compounds, Inc.	The compound is a graphitized thermoset vinyl-ester, which is molded and used in producing bipolar plate (BPP) assemblies. (This technology was based on a technology licensed from Los Alamos National Laboratory.)	The compound allows thinner and less-expensive BPP assemblies to be produced; eliminates the need for expensive corrosion-resistant coatings; provides greater part flatness, creep resistance, and dimensional stability; and facilitates large-volume commercial production.	Commercialized in 2000.
Corrosion Test Cell for PEM Bipolar Plate Materials	Fuel Cell Technologies, Inc.	To screen materials that could be used in producing corrosion-resistant bipolar plates (BPPs), the test cell simulates, as closely as possible, the conditions at the anode and cathode of a PEM fuel cell. (This technology was based on a technology licensed from Los Alamos National Laboratory.)	The test cell reduces the costs of traditional fuel cell corrosion tests, shortens the fuel cell development time, and allows for an intermediate level of BPP material screening between potentiostatic measurements and long-term fuel cell tests.	Commercialized in 2008, with two units sold.

Table 3.1. Commercial Products Summary – Fuel Cells (Cont'd)

Technology	Organization	Description	Benefits	Commercial Status
Cost-Effective, High-Efficiency, Advanced Reforming Module (CHARM)	Nuvera Fuel Cells, Inc.	The steam reforming module for producing hydrogen is designed to be cyclable (daily start/stop for 5 years) and runs at low pressure.	The system produces a low-cost supply of hydrogen (compared with bottles) and can minimize thermal cycling induced stress and exposure, thus increasing the lifetime of the module.	Commercialized in 2009 and being used to supply hydrogen for material-handling equipment.
FARADAYIC ElectroEtching of Stainless Steel Bipolar Plates (SBIR Project)	Faraday Technology, Inc.	The new manufacturing process, FARADAYIC ElectroEtching, is based on electrochemical through-mask etching and is producing stainless steel bipolar plates with advanced flow channel designs that cannot be manufactured cost-effectively using more conventional machining techniques.	The new manufacturing process reduces the overall manufacturing cost of bipolar plates through use of a high-volume batch process with low capital equipment and tooling costs.	Commercialized in 2012 and a patent awarded in December 2012.
GCtool: Fuel Cell Systems Analysis Software Model	Argonne National Laboratory	The GCtool allows designers to model, analyze, and manipulate different configurations of fuel cell propulsion systems without building a functional prototype in order to address issues such as thermal and water management, design-point and part-load operations, and fuel economies.	The model saves users time and money while exploring various fuel cell system configurations. It provides developers with a library of models for subcomponents and allows them to incorporate their own models.	Sold 67 licenses since 1999.
GenDrive™ Fuel Cell Power System (ARRA Project)	Plug Power Inc.	A fuel-cell-based power source for electric forklift fleets that increases fleet productivity and improves forklift performance compared with conventional lead-acid batteries.	The system can be refueled with hydrogen in less than 3 minutes (compared with 10 minutes or more for a battery change), allowing operators to spend more time moving product out on the floor. Constant voltage is provided throughout the entire shift, eliminating the performance degradation experienced with batteries.	More than 2,500 units are currently in use.
High Speed, Low Cost Fabrication of Gas Diffusion Electrodes for Membrane Electrode Assemblies	BASF Fuel Cell, Inc.	A new fabrication process for gas diffusion electrodes for MEAs allows the use of innovative catalyst electrodes and membranes.	The new process is higher speed and lower cost and the new components result in increased durability and superior performance.	Commercialized in 2012.
Improved Catalyst Coated Membrane (CCM) Manufacturing	IRD Fuel Cells LLC	The spray deposition technology uses special electrocatalyst inks and a simple manufacturing process that allows for high-volume production with a lower platinum content compared with other techniques.	The system reduces manufacturing and raw material costs. It can be used with existing spray deposition systems and allows quick changeover to different materials.	Manufacturing line for improved MEAs sold to IRD Fuel Cells, LLC in 2009, and the associated electrocatalyst inks and catalyst powders were made commercially available in 2008.

Table 3.1. Commercial Products Summary – Fuel Cells (Cont'd)

Technology	Organization	Description	Benefits	Commercial Status
Improved Fuel Cell Cathode Catalysts Using Combinatorial Methods (SBIR Project)	NuVant Systems Inc.	The MEA testing equipment is composed of two devices, an array potentiostat (Arraystat™) and a parallel array flow-field fuel cell, which allow rapid, accurate testing under realistic operating conditions.	The equipment allows for the preparation and testing of various MEAs in a single test stand with high throughput under realistic catalyst loadings and reactant flow rates. This eliminates random error introduced by multiple test stands and reduces the costs associated with testing MEAs.	The Arraystat was commercialized in 2006 and the parallel array fuel cell in 2007. To date seven Arraystats and seven parallel array fuel cell test units have been sold.
Integrated Manufacturing for Advanced Membrane Electrode Assemblies	BASF Fuel Cell, Inc.	The advanced MEA fabrication process uses a new gas diffusion electrode to develop assemblies that run longer with stable voltages.	The process decreases the amount of precious metal used and reduces fabrication costs. The resulting assemblies exhibit improved stability and allow operation at extreme temperatures.	Currently marketing the Celtec® -P MEA for high temperature PEM fuel cells.
Lifetime Improvements for PEM Fuel Cells	DuPont Fuel Cells	The Nafion® polymer technology, which can be used for both PEM fuel cells and water electrolyzers, reduces the reactive centers within the polymer to combat chemical degradation, leading to increased stability and longer life.	The technology reduces costs because of greater membrane durability and lifetime.	Commercialized in 2005.
Low-Cost PEM Fuel Cell Metal Bipolar Plates	TreadStone Technologies, Inc.	A low-cost fabrication process produces durable, low-contact resistance metallic bipolar plates for use in PEM fuel cells for automotive, stationary and portable power applications.	The new process reduces costs by using commercially available, stainless steel, low-cost carbon steel or aluminum as substrate materials and by reducing or eliminating the use of more expensive electrically conductive materials.	Commercialized in 2011 with small volumes sold to date.
Manufacture of Durable Seals for PEM Fuel Cells	Freudenberg-NOK General Partnership	The seals, used in fuel cell assemblies, use a custom elastomer and carrier material that provide an advanced interfacial design that exhibits superior chemical and mechanical properties compared with conventional silicons.	The seals increase durability, which reduces fuel cell operation and maintenance costs, and eliminates catalyst poisoning concerns in the fuel cell. The system can be mass-produced and leads to shorter fuel cell assembly time.	Commercialized in 2009 with more then 30,000 seals sold to date.
Membranes and Membrane Electrode Assemblies for Dry, Hot Operating Conditions	3M Company	The advanced MEAs use a low equivlent weight, perfluorinated sulfonic acid-based membrane with improved chemical and mechanical stability, and proton conductivity.	The new MEA has improved durability and performance with increased lifetimes while operating under hot (up to 120°C), dry conditions.	Commercialized in 2006 with sales to a wide variety of fuel cell customers for stationary and automotive applications.
Novel Manufacturing Process for PEM Fuel Cell Stacks	Protonex Technology Corporation	The one-step molding process creates the structure necessary to seal the stack and five layer MEAs. Two portable power system product lines for military customers are now using it.	The process lowers costs because fewer components with lower tolerances are used. It reduces part count and manufacturing time and improves stack fabrication reliability.	Delivered over 30 M250-CX and M300-CX systems through 2011.

Table 3.1. Commercial Products Summary – Fuel Cells (Cont'd)

Technology	Organization	Description	Benefits	Commercial Status
Portable Reformed Methanol Fuel Cells	UltraCell Corporation	The XX25 fuel cell, using methanol as a fuel source, is a self-contained, 25-watt output power system that can be used by individual soldiers for portable power. Fuel cartridges can be hot swapped for continuous operation, and the fuel cell can be hybridized with external batteries for high power peaks or with a 5-gallon fuel tank for long run time.	The fuel cell features a rugged, lightweight (1.24 kg), reliable power system that uses a contained fuel with no toxic byproducts during use. It contains no moving parts that can fail.	Commercialized in 2007, with more than 400 units sold.
PureMotion® Model 120 Fuel Cell Power Plant	UTC Power	The powerplant can be used as a power source for hydrogen-powered vehicles or as a stationery, 120-kW power source.	The power system reduces costs through mass manufacturing, produces only water as a byproduct, and uses hydrogen produced from various sources, including renewables.	First unit deployed in 2005 with one older unit still in use on a bus and 16 next generation buses delivered in 2010.
Reduction in Fabrication Costs of Gas Diffusion Layers	Ballard Material Products, Inc.	The new gas diffusion layer (GDL) manufacturing process produces continuous rolls of GDL material and reduces GDL fabrication costs by 60%. Cost-saving measures used in the process include replacing batch processes with continuous ones, implementing on-line control systems, and reducing the number of process steps.	The new process reduces GDL costs through high-volume manufacturing and improves GDL quality and uniformity by using real-time process monitoring.	New process now being used to manufacture GDLs at Ballard.
Scale-Up of Carbon-Carbon Composite Bipolar Plates	Porvair Advanced Materials, Inc.	A carbon-carbon composite bipolar plate (BPP) formation technology was licensed and transferred from laboratory to full-scale production to produce low-cost BPPs using high-volume manufacturing with no machining. (This technology was based on a technology licensed from Oak Ridge National Laboratory.)	The resulting BPPs minimize contact resistance between cells, resist corrosion, are lightweight (1.2 grams per cc), and cost <$4 per kW. The process allows for molding a wide variety of product designs.	Manufactured more than 52,000 BPPs since 2003.

Table 3.2. Commercial Products Summary – Production/Delivery

Technology	Organization	Description	Benefits	Commercial Status
FuelGen® Hydrogen Fueling Systems	Proton Energy Systems, Inc.	The fueling station uses electrolysis to produce 99.999% pure hydrogen from water using electricity, which can come from wind or solar energy. The system can generate over 13 kg per day at pressures up to 400 psi.	The system produces high purity hydrogen without requiring additional cleanup, can be installed and operating within a day, requires only four hours of maintenance per year, and can use renewable energy sources.	Commercialized in 2007, with six units sold and five currently operating.
H2 ProGen: A Total Supply Solution for Hydrogen Vehicles	GreenField Compression	The integrated, on-site hydrogen generation, purification, compression, storage, and dispensing system deploys quickly and produces 20 to 200 kg of hydrogen per day by reforming natural gas, propane, E-85, biodiesel, or other liquids. Alternatively, it can use electrolysis for hydrogen production. The dispenser can be purchased individually or as part of the system.	The system can produce hydrogen from various sources, achieves full-cycle energy savings compared with trucked-in hydrogen, and is delivered as a pre-assembled system, thereby minimizing costs and setup time.	Commercialized in 2007, with one fuel station in use at the University of Texas in Austin.
High Performance Palladium-Based Membrane	Pall Corporation	The palladium-based membrane works as a selective barrier to let only H_2 pass through by using sophisticated high-temperature analysis and inorganic membrane development/manufacturing techniques.	The membrane can be economically integrated into the overall H_2 production process and is easily scalable to industrial applications.	Commercialized the AccuSep® Pd membrane module in 2011 with 24 integrated devices sold.
Hydrogen Distributed Production System	Air Liquide Process and Construction, Inc.	The HGM-2000 uses a built-in pressure swing adsorption system that produces 565 kg of hydrogen per day at 200 to 300 psig at a fuel efficiency of up to 78% (based on the higher heating value).	The system cuts high-purity hydrogen costs by up to 50% compared with trucked-in hydrogen, is highly efficient, and uses a modular design that eliminates the need for large-scale hydrogen infrastructure. It allows remote monitoring without the need for staffing.	Became commercially available in 2008.
Hydrogen Generation from Electrolysis	Proton Energy Systems, Inc.	The HOGEN® electrolysis-based hydrogen generator incorporates a PEM and produces 99.999% pure hydrogen at 90 to 275 grams per hour at pressures up to 400 psi without requiring additional compression.	The system is very compact, can be installed in less than a day, is very reliable, and produces high-purity hydrogen.	Commercialized the HOGEN S series in 1999, selling 187 units in the U.S. and 228 internationally through 2011. Commercialized the HOGEN H series in 2004, selling 88 units in the U.S. and 90 internationally through 2011. Commercialized the HOFEN C series in 2011, selling 2 units in the U.S. and 3 internationally.
Hydrogen Safety Sensor for Advanced Energy Applications	NexTech Materials, Ltd.	A chemi-resistive three-phase ceramic sensor exhibits a highly sensitive (500 ppm to 1%), selective (no interference from CO, CH_4, or VOC), and rapid response to the presence of hydrogen in ambient air, even with varying humidities and background combustible gases.	Because of its low materials and fabrication cost, minimal power consumption, and wide detection range, the sensor lends itself to wide-scale implementation in any application requiring the safe use or handling of hydrogen gas. It is durable and reliable, with fast response and recovery times.	Commercialized in 2010 and sold 100 to 200 units to date.

Table 3.2. Commercial Products Summary – Production/Delivery (Cont'd)

Technology	Organization	Description	Benefits	Commercial Status
ME100 Methanol Reforming Hydrogen Generator (SBIR Project)	REB Research & Consulting	The generator is constructed with palladium-coated membranes within the reactor zone and can produce 99.99995% pure hydrogen independent of back-pressure changes or variable loads at a variable rate of up to 10 kg per day at pressures up to 40 psig.	The generator produces very high purity independent of back pressure changes caused by varying fuel cell demand. It produces hydrogen at costs far lower than bottled gas from a readily available feedstock (methanol). The system is compact, reliable, and ideal for remote and mobile applications.	More than 27 ME100 hydrogen generator systems sold since 2002.
Membrane Structures for Hydrogen Separation (SBIR Project)	Genesis Fueltech, Inc.	The low-cost membrane to separate hydrogen from other gases in the reforming process is used in a purifier module that can be scaled to larger sizes to increase capacity.	The low-cost purifier has improved mechanical support and sealing, as well as improved alloys for higher hydrogen flux.	Commercialized in 2009.
Nanoscale Water Gas Shift Catalysts	NexTech Materials, Ltd.	The water gas shift catalysts are based on ceria-supported precious metals that can be tailored to specific reactions/ conditions (i.e., steam reforming and/or the partial oxidation of various hydrocarbons) and can be used for small reactors and/or reactors with multiple startup-shutdown cycles.	The catalysts are available in multiple forms and allow applications to perform efficiently over a wide range of temperatures.	Commercialized in 2005 with >$300,000 in sales to date.
PEM Electrolyzer Incorporating Low-Cost Membrane	Giner Electrochemical Systems, LLC	An electrolysis system that produces 0.5 kg-H_2/hr at 350 psig and uses an advanced dimensionally stable membrane with improved durability under high-pressure conditions.	The electrolyzer stack capital cost has been reduced to <$500/kW by using low-cost materials, lower catalyst loading, and a reduced part count per cell. The system can make use of renewable electricity sources such as wind and solar.	Commercialized in 2011. GES has delivered 6 stacks and has taken orders for several more.
Stackable Structural Reactor (SSR®) for Low-Cost Hydrogen Production	Catacel Corp.	During hydrogen production via steam reforming, a drop-in replacement for the loose ceramic media eliminates the periodic replacement required in conventional ceramic packed beds.	The drop-in replacements lower costs, increase performance, and minimize maintenance costs and inconveniences.	Commercialized in 2012 with one international sale and one domestic unit being installed
TITAN™: High-Pressure Hydrogen Storage Tank for Gaseous Truck Delivery	Lincoln Composites, Inc.	The large composite tank for storing and transporting compressed hydrogen gas over road, rail, or water has an internal volume of 8,500 liters and contains 150 kg of hydrogen at 3,600 psi. Four of these tanks are mounted in a frame for transport and a system for loading, unloading, and pressure relief has been designed and implemented.	The tank and frame system reduces costs by improving volumetric hydrogen storage capacity compared with conventional tube trailers while meeting strength, environmental, and durability targets.	Commercialized in 2011 with $3.5 million in U.S. sales.

Table 3.3. Commercial Products Summary – Storage

Technology	Organization	Description	Benefits	Commercial Status
Hydrogen Composite Tanks	Quantum Technologies, Inc.	For storage applications at 5,000 and 10,000 psig, the hydrogen tank uses a seamless, one-piece, ultra-high-molecular-weight polymer liner wrapped in layers of a carbon fiber/epoxy laminate and a proprietary external protective layer for impact resistance.	The 10,000-psig tank offers a high-capacity, lightweight, safe hydrogen storage system that exceeds regulatory safety requirements and may increase a hydrogen-powered vehicle's driving range by >55% compared with equivalent-sized 5,000-psig tanks.	Since 2001, sold more than 2,000 storage tank systems, primarily to major automobile manufacturers.
Sodium Silicide (NaSi) Hydrogen Generation System	SiGNa Chemistry, Inc.	The portable power system uses a stable, room-temperature reaction between sodium silicide and water to generate hydrogen at pressures from 2 to 30 psi. When coupled to a fuel cell generator the system provides 300 watts of continuous power and up to 500 watts of peak power.	The system uses two cartridges filled with NaSi powder and an integrated water reservoir that are hot-swappable, enabling extended runtimes without an interruption of power. Power output is consistent over the entire runtime, without the degradation associated with batteries.	Commercialized in the U.S. in 2012 with sales to a producer of a portable fuel-cell-based charger for electronics.

Table 3.4. Fuel Cell Challenges and Related Commercial Technologies

Challenges*	Technology Title	Organization
Develop membranes that meet all targets	Improved Catalyst Coated Membrane (CCM) Manufacturing	IRD Fuel Cells LLC
	Lifetime Improvements for PEM Fuel Cells	DuPont Fuel Cells
Develop electrodes that meet all targets	High Speed, Low Cost Fabrication of Gas Diffusion Electrodes for Membrane Electrode Assemblies	BASF Fuel Cell, Inc.
Develop MEAs that meet all targets	Cathode Catalysts and Supports for PEM Fuel Cells	3M Company
	Improved Fuel Cell Cathode Catalysts Using Combinatorial Methods	NuVant Systems Inc.
	Integrated Manufacturing for Advanced Membrane Electrode Assemblies	BASF Fuel Cell, Inc.
	Membranes and Membrane Electrode Assemblies for Dry, Hot Operating Conditions	3M Company
Develop low-cost, durable GDLs that improve fuel cell performance	Reduction in Fabrication Costs of Gas Diffusion Layers	Ballard Material Products, Inc.
Develop low-cost, durable bipolar plates that meet all targets	A Silicon-Based Solid Oxide Fuel Cell for Portable Consumer Electronics	Lilliputian Systems, Inc.
	Conductive Compound for Molding Fuel Cell Bipolar Plates	Bulk Molding Compounds, Inc.
	FARADAYIC ElectroEtching of Stainless Steel Bipolar Plates	Faraday Technology, Inc.
	Low-Cost PEM Fuel Cell Metal Bipolar Plates	TreadStone Technologies, Inc.
	Scale-Up of Carbon-Carbon Composite Bipolar Plates	Porvair Advanced Materials, Inc.
Develop efficient, cost-effective thermal/water management systems	Complex Coolant for Polymer Electrolyte Membrane (PEM) Fuel Cells	Dynalene, Inc.
Develop reliable, durable, low-cost seals	Manufacture of Durable Seals for PEM Fuel Cells	Freudenberg-NOK General Partnership
Develop cost-effective, efficient, reliable and durable fuel cells for stationary applications that meet all targets	Bio-Fueled Solid Oxide Fuel Cells	TDA Research, Inc.
	Compact, Multi-Fuel Solid Oxide Fuel Cell (SOFC) System	Technology Management, Inc.
	Cost-Effective, High-Efficiency, Advanced Reforming Module (CHARM)	Nuvera Fuel Cells, Inc.
	PureMotion® Model 120 Fuel Cell Power Plant	UTC Power
Develop cost-effective, reliable, durable fuel cells for portable power applications (e.g., cell phones, computers, etc.) that meet all targets	A Silicon-Based Solid Oxide Fuel Cell for Portable Consumer Electronics	Lilliputian Systems, Inc.
	Portable Reformed Methanol Fuel Cells	UltraCell Corporation
Conduct system and tradeoff analysis	GCtool: Fuel Cell Systems Analysis Software Model	Argonne National Laboratory
Develop system to allow PEM fuel cells to operate in off-road applications	GenDrive™ Fuel Cell Power System	Plug Power Inc.
Test and evaluate fuel cell components and systems	Corrosion Test Cell for PEM Bipolar Plate Materials	Fuel Cell Technologies, Inc.
Develop innovative fuel cell designs that provide improved performance, durability and cost	Novel Manufacturing Process for PEM Fuel Cell Stacks	Protonex Technology Corporation

* Note: These challenges are described in the FCT Program Multi-Year Plan at http://www1.eere.energy.gov/hydrogenandfuelcells/mypp/pdfs/fuel_cells.pdf.

Table 3.5. Production/Delivery Challenges and Related Commercial Technologies

Challenges*	Technology Title	Organization
Cost reduction of distributed hydrogen production from natural gas and bio-derived liquids	H2 ProGen: A Total Supply Solution for Hydrogen Vehicles	GreenField Compression
	Hydrogen Distributed Production System	Air Liquide Process and Construction, Inc.
	ME100 Methanol Reforming Hydrogen Generator	REB Research & Consulting
	Nanoscale Water Gas Shift Catalysts	NexTech Materials, Ltd.
	Stackable Structural Reactor (SSR®) for Low-Cost Hydrogen Production	Catacel Corp.
Hydrogen production from water via electrolysis	FuelGen® Hydrogen Fueling Systems	Proton Energy Systems, Inc.
	Hydrogen Generation from Electrolysis	Proton Energy Systems, Inc.
	PEM Electrolyzer Incorporating Low-Cost Membrane	Giner Electrochemical Systems, LLC
Separation and purification systems	High Performance Palladium-Based Membrane	Pall Corporation
	Hydrogen Safety Sensor for Advanced Energy Applications	NexTech Materials, Ltd.
	Membrane Structures for Hydrogen Separation	Genesis Fueltech, Inc.
Develop carriers that can enable low-cost hydrogen delivery	TITAN™: High-Pressure Hydrogen Storage Tank for Gaseous Truck Delivery	Lincoln Composites, Inc.

* Note: These challenges are described in the FCT Program Multi-Year Plan at http://www1.eere.energy.gov/hydrogenandfuelcells/mypp/pdfs/fuel_cells.pdf.

Table 3.6. Storage Approaches and Related Commercial Technologies

Approaches*	Technology Title	Organization
Compressed, cryo-compressed and conformal hydrogen tanks	Hydrogen Composite Tanks	Quantum Technologies, Inc.
Chemical hydrogen storage	Sodium Silicide (NaSi) Hydrogen Generation System	SiGNa Chemistry, Inc.

* Note: The storage approaches are described in the FCT Program Multi-Year Plan at http://www1.eere.energy.gov/hydrogenandfuelcells/mypp/pdfs/storage.pdf.

Table 3.7. Emerging Products Summary – Fuel Cells

Technology	Organization	Description	Benefits
Alternative and Durable High-Performance Cathode Supports for PEM Fuel Cells	Pacific Northwest National Laboratory	An advanced support structure for cathodes used in PEM fuel cells. The technology takes advantage of the stable interface between platinum, a conductive metal oxide, and a honeycombed carbon support.	The support structures increase cathode performance and durability, and are synthesized using a method that can be easily scaled up for high-volume manufacturing.
CIRRUS: Cell Ice Regulation and Removal Upon Start-up	Nuvera Fuel Cells, Inc.	The Orion™ fuel cell exploits higher current density operation to increase the power density of the stack and reduce its thermal mass, enhancing freeze starting ability.	The new fuel cell has improved performance in sub-freezing conditions including increased fuel cell stack power density, improved water purging prior to cold shutdown, and avoidance of significant degradation of stack materials after 200 freeze startup/shutdown cycles.
Dimensionally-Stable High-Performance Membrane (SBIR Project)	Giner Electrochemical Systems, LLC	The robust PEM material uses a high-performance plastic support structure, which allows lower-equivalent-weight ionomers to be used without forfeiting mechanical durability.	Because of its mechanical properties, the new membrane prevents stress-induced failure and improves performance at low humidity and high temperature.
Direct Methanol Fuel Cell (DMFC) Anode Catalysts	National Renewable Energy Laboratory	An improved anode catalyst for direct methanol fuel cells. The catalyst is manufactured using ion implantation and magnetron sputtering of platinum-ruthenium (PtRu) on high-surface-area carbon support materials.	The new PtRu catalyst materials have shown up to 30% improvement in methanol oxidation reaction activity and increase the durability of membrane electrode assemblies.
Direct Methanol Fuel Cell for Handheld Electronics Applications	MTI Micro Fuel Cells, Inc.	The Mobion® direct methanol fuel cell (DMFC) uses passive means for water and air management to simplify the conventional DMFC process, resulting in a smaller and simpler fuel cell for handheld applications. Received American Recovery and Reinvestment Act (ARRA) funding to facilitate commercialization.	The device uses methanol fuel instead of hydrogen, avoiding hydrogen-handling issues. Using micro fuel cells for handheld electronics may extend device operating times between charges and enhance device versatility.
Direct-Write Inkjet Printing for Fabricating Hydrogen Sensors (SBIR Project)	InnoSense, LLC	The hydrogen sensor was developed using high-output, inkjet printing manufacturing techniques and detects hydrogen at concentrations from 1% to 75%.	The high-volume fabrication process produces safe, all-optical sensors and eliminates the individual calibration of sensors by making many identical sensors in one batch.
Durable Catalysts for Fuel Cell Protection During Transient Conditions	3M Company	The new catalyst materials alleviate the damaging effects of transient conditions (e.g., startup, shutdown, and fuel starvation) on fuel cells. The materials are being developed by modifying the catalyst's behavior so that oxidation of water instead of carbon corrosion is the preferred reaction during transient conditions.	Fuel cell durability is improved by controlling catalyst reaction behavior during transient conditions. Low platinum-group-metal loading reduces material costs.
Engineered Nanostructured MEA Technology for Low-Temperature Fuel Cells	Nanosys, Inc.	A nanowire-supported platinum cobalt (PtCo) catalyst for PEM fuel cells increases catalyst mass activity relative to commercially available platinum carbon (Pt/C) catalysts while using reduced amount of precious metal catalyst.	The new catalyst support structure ensures a high catalyst utilization, enables a higher power density using low catalyst loading, and ensures a superior durability compared with conventional carbon-supported catalysts.

Table 3.7. Emerging Products Summary – Fuel Cells (Cont'd)

Technology	Organization	Description	Benefits
Extended, Continuous Pt Nanostructures in Thick, Dispersed Electrodes	National Renewable Energy Laboratory	The nanostructured platinum (Pt) catalysts have extended surface areas and show improved specific activity and durability compared with traditional Pt catalysts supported on carbon (Pt/C). The catalysts are synthesized from metal nanowire templates using the spontaneous galvanic displacement process.	The new catalysts achieve increased performance (specific activity) and durability compared with traditional Pt/C catalysts and reduce material costs by using less Pt.
Fuel Cell Membrane Measurement System for Manufacturing (SBIR Project)	Scribner Associates, Inc.	The Rapid Membrane Measurement System uses a proprietary electrode design for robust long-term operation, custom measurement and control hardware and software, and state-of-the-art electrochemical measurement methods.	The system rapidly (a few minutes per test) and accurately measures the through-thickness ionic resistance of fuel cell membranes under controlled temperatures and humidity and may allow for more consistent results, higher productivity, and lower manufacturing costs because of waste reduction.
Fuel-Cell-Based Mobile Lighting	Sandia National Laboratories	The fuel cell mobile lighting system uses a 5-kW, hydrogen-fueled PEM fuel cell stack to power high-efficiency plasma lighting. The system is an energy-efficient, environmentally-friendly alternative to the diesel-fueled generators currently used to power most portable lighting equipment.	The system produces zero emissions at the point of use, reduces noise compared with diesel generators, and can be used in indoor or outdoor applications. The use of a fuel cell power source and plasma lighting maximizes the unit's overall energy efficiency.
GenSys® Blue: High-Temperature CHP Fuel Cell System (ARRA Project)	Plug Power Inc.	The GenSys® Blue is a high-temperature PEM fuel cell system that provides up to 5 kW of electricity and 28,000 Btu/hr of usable heat for residential and light commercial applications. The system achieves electrical and CHP efficiencies of 30% and 85%, respectively.	The high-efficiency system reduces residential utility bills and CO_2 emissions. The unit can be easily integrated with existing heating systems because it produces waste heat of a sufficient temperature to meet thermal comfort demands.
High-Efficiency Polymer Electrolyte Membrane Fuel Cell Combined Heat and Power System	Intelligent Energy Inc.	The CHP system is composed of two main parts: a fuel processor, that uses hydrocarbon feedstock in a steam-methane reforming reaction and water-gas shift reaction to produce hydrogen, and a PEM fuel cell that uses the hydrogen for electricity production. Heat is recovered from the fuel cell and the fuel processor and can be used for a variety of applications.	The system achieves 35% electrical efficiency with greater than 70% combined efficiency possible, depending on the application. The modular and scalable design allows for easy installation and the unit can be configured to provide emergency backup power in the event of a grid failure.
High-Performance, Low-Pt Cathodes Containing New Catalysts and Layer Structure	Cabot Superior MicroPowders	Applying an approach to formulate and test low-Pt cathodes has led to six Pt-alloy compositions that demonstrate up to a two-fold improvement in performance compared with pure Pt electrocatalysts.	Reducing Pt in cathodes reduces costs (Pt is very expensive), and in some cases, improves performance and durability. The new formulation and testing approach allow rapid synthesis and testing of electrocatalysts, thus reducing research costs.
High-Temperature Membrane with Humidification-Independent Cluster Structure	FuelCell Energy, Inc.	The composite fuel cell membrane has enhanced ionic conductivity and mechanical properties, allowing the fuel cell to retain water and maintain proton conductivity and mechanical integrity at low humidities and elevated temperatures.	The membrane improves fuel cell durability, reduces system costs, and improves performance over extreme and fluctuating humidity and temperature conditions.

Table 3.7. Emerging Products Summary – Fuel Cells (Cont'd)

Technology	Organization	Description	Benefits
Low-Cost 3-10 kW Tubular SOFC Power System	Acumentrics Corporation	The system is a natural gas based SOFC which is being developed for use as a micro CHP unit to provide electricity and hot water in residential applications. The system has demonstrated an electrical efficiency of 35%-40% and a CHP energy efficiency of 85%.	The system handles readily available fuels such as natural gas and propane, without requiring an external reformer to produce hydrogen. On-site simultaneous generation of heat and power will increase efficiency and lower energy costs to consumers.
Low-Cost Hydrogen Sensor for Transportation Safety	Makel Engineering, Inc.	The micro electromechanical systems hydrogen sensor system incorporates a highly sensitive Schottky diode made of a palladium alloy on a silicon substrate for measurements in the low concentration range (50 ppm to a few percent). It can provide low-cost hydrogen leak monitoring in fuel cell vehicles, stationary fuel cells, or other areas where hydrogen leaks might occur.	The sensor is low-cost and compact, has low power consumption, can be mass-produced, and operates in suboptimal environmental conditions.
Low-Cost Manufacturing of Sheet Molding Compound Bipolar Plates for PEM Fuel Cells (SBIR Project)	Nanotek Instruments, Inc.	A new system is being developed to produce low-cost/high-performance bipolar plates for fuel cells using sheet molding compound manufacturing techniques. Use of the new roll-to-roll system for producing multiple layer bipolar plates will allow large-scale manufacturing.	The new system optimizes the composition and forming process, improving the performance of the bipolar plates while reducing the manufacturing cost.
Low Platinum Loading Fuel Cell Electrocatalysts	Brookhaven National Laboratory	The patented anode electrocatalysts have low platinum (Pt) loading that resists CO poisoning.	The electrocatalysts are cost effective to fabricate because of the extensive use of noble metals (rather than Pt) and are more durable, thereby promising an improved fuel cell lifetime.
Manufacturing of Low-Cost, Durable Membrane Electrode Assemblies	W.L. Gore and Associates, Inc.	A high-volume manufacturing process for producing low-cost, durable, high-power-density, three-layer MEAs that require minimal conditioning. The process is scalable to industry MEA volume targets of 500,000 systems per year.	MEAs produced using the new manufacturing process have withstood 9,000 hours of durability testing in an 80°C automotive duty cycle, exceeding DOE's 2015 target by 5,000 hours. The MEAs also have improved power density and conditioning times of less than 4 hours. The use of high-volume manufacturing reduces fuel cell costs.
Materials and Modules for Low-Cost, High-Performance Fuel Cell Humidifiers	W.L. Gore and Associates, Inc.	A system that uses the product water from a hydrogen fuel cell's reaction to humidify the incoming reactant gases on the cell's anode and cathode sides. The system contains an inexpensive and durable composite membrane consisting of an ionomer layer sandwiched between micro porous polymer layers. The membrane is capable of high water transport rates and prevents gas crossover from occurring.	The system improves the performance and longevity of fuel cell electrolyte membranes by controlling reactant gas humidity, which is essential for maintaining proper membrane hydration.
Nitrided Metallic Bipolar Plates for PEM Fuel Cells	Oak Ridge National Laboratory	The technique deposits a thin Cr-nitride coating on stainless steel bipolar plates to form an electrically conductive, defect-free, corrosion-resistant surface layer, even on complex surface geometries.	This technique allows for low-cost, high-volume production techniques that will reduce the net cost of fuel cells and improve their longevity and durability.

Table 3.7. Emerging Products Summary – Fuel Cells (Cont'd)

Technology	Organization	Description	Benefits
Platinum and Fluoropolymer Recovery from PEM Fuel Cells	Ion Power, Inc.	The process dissolves the used PEMs into a slurry, which is then processed to separate the Pt and Nafion® for re-use.	The process eliminates hydrofluoric acid emissions typical of other recycling methods in use today. It reduces PEM fuel cell replacement costs by recovering valuable materials from used cells.
Platinum-Group-Metal Recycling Technology	BASF Catalysts LLC	The technology recovers >98% of the platinum from various MEAs, independent of MEA aging history, membrane construction, or electrocatalyst composition.	The technique eliminates the need for hydrofluoric acid remediation, and batching multiple fuel cell types eliminates manual separation labor in the recycling process.
Platinum Monolayer Electrocatalysts on Stable Low-Cost Supports	Brookhaven National Laboratory	The high-surface-area electrocatalysts have a platinum (Pt) monolayer that is deposited on top of transition metal nanostructures. These catalysts, which are used in the fuel cell's oxygen reduction reaction, have a much higher activity per mass of Pt than pure Pt nanoparticles.	The new catalysts achieve high activity for the oxygen reduction reaction, resist Pt dissolution under cycling conditions, and reduce costs by reducing Pt loading.
PowerEdge™ Fuel Cell System (ARRA Project)	Nuvera Fuel Cells, Inc.	A fuel-cell-based power source for electric forklift fleets that increases fleet productivity and improves forklift performance compared with conventional lead-acid batteries.	The system can be refueled with hydrogen in less than 2 minutes (compared with 10 minutes or more for a battery change), allowing operators to spend more time moving product out on the floor. Constant voltage is provided throughout the entire shift, eliminating the performance degradation experienced with batteries.
Resin-Impregnated, Expanded-Graphite GRAFCELL® Bipolar Plates	GrafTech International Ltd.	The bipolar plate uses expanded graphite in conjunction with an advanced high-temperature resin system that is designed for high-volume production.	The system results in improved gas impermeability, low contact resistance, high thermal/electrical conductivity, and improved mechanical strength. The plates continuously operate at temperatures up to 120°C.
Sensors for Automotive Fuel Cell Systems	NexTech Materials, Ltd.	The H_2S sensor operates by a reversible change in resistance caused by adsorption and desorption of H_2S in a film of H_2S-sensitive material. It can detect H_2S from 25 ppb to 10 ppm, with response times of less than one minute.	The sensor will detect H_2S in the hydrogen stream, alerting operators so they can protect the cell stack from damage. This will increase membrane life, allow fuel cells to remain online longer, and extend the life of guard beds used to remove sulfur from hydrocarbon fuels before they are processed into hydrogen.
Solid Acid Fuel Cell Stack for Auxiliary Power Unit Applications	SAFCell, Inc.	The solid acid fuel cell stack generates electricity using hydrogen from a variety of commercial fuel reformate sources, including diesel fuels commonly used in the trucking industry. The technology offers near silent operation, quick start-up time, and the ability to handle start-stop cycling.	The technology can operate reliably on a variety of gas and liquid fuel reformate and reduces emissions by providing a more fuel-efficient alternative to auxiliary power generated from combustion engines. The stacks can be manufactured by low-cost, high-volume methods because of the solid nature of the electrolyte and the use of metal and polymer components.

Table 3.7. Emerging Products Summary – Fuel Cells (Cont'd)

Technology	Organization	Description	Benefits
Solid Oxide Fuel Cell Auxiliary Power Unit	Delphi Corporation	The SOFC power unit will provide up to 3 kW of auxiliary electrical power for a variety of mobile applications operating with a wide range of commercially available fuels such as natural gas, diesel, and propane. Received ARRA funding to test the power unit.	The power unit operates at a higher efficiency than internal combustion engines because of the electrochemical conversion of fuel and reduces the noise and pollutants associated with these engines.
Ultra-Low Platinum Alloy Cathode Catalysts for PEM Fuel Cells	University of South Carolina	A new catalyst synthesis process reduces the precious metal content in the cathode of PEM fuel cells while maintaining or exceeding current fuel cell durability and performance specifications.	The new catalyst process reduces fuel system costs by reducing precious metal content and is scalable from the laboratory to high-volume production.
Ultrasonics and Advanced Diagnostics for High-Temperature PEM MEA Manufacture	Rensselaer Polytechnic Institute	To aid in cost-effective, high-volume manufacturing of PEM fuel cell MEAs, advanced diagnostic methods and ultrasonic bonding processes are being developed.	The new methods and processes will reduce manufacturing costs by reducing cycle time and energy consumption and improving product yield.

Table 3.8. Emerging Products Summary – Production/Delivery

Technology	Organization	Description	Benefits
Active Magnetic Regenerative Liquefier	Emerald Energy NW, LLC	A new, high-efficiency hydrogen liquefier that uses active magnetic regenerative liquefaction (AMRL) to produce ~25 kg of liquid hydrogen per day with a thermodynamic cycle efficiency (figure of merit) of ~0.5.	The technology improves the efficiency and reduces the cost of hydrogen liquefaction.
Centrifugal Hydrogen Pipeline Gas Compressor	Concepts NREC	A centrifugal compressor system for pipeline transport of hydrogen gas achieves higher compression efficiency than conventional reciprocating compression equipment and delivers hydrogen at a rate of 240,000 kg/day at a discharge pressure of 1285 psig.	The compressor system can be used to support existing hydrogen pipeline infrastructure in the industrial sector and for future pipeline transport of high-pressure hydrogen gas from production sites to vehicle fueling stations at reduced capital costs.
Ceramic Membrane Reactor Systems for Converting Natural Gas to Hydrogen and Synthesis Gas (ITM Syngas)	Air Products and Chemicals, Inc.	The ion transport membrane (ITM) system uses ceramic membranes to generate syngas and hydrogen in a more compact, lower-cost, and higher-efficiency process than competing technologies. ITM syngas membranes combine air separation and methane partial oxidation into a single unit operation.	The system has very high flux and selectivity that help reduce both capital and operating costs. The ITM syngas process is also readily configured for carbon capture from the high-pressure syngas product.
Composite Pipeline Technology for Hydrogen Delivery	Oak Ridge National Laboratory	Extensive testing of fiber-reinforced polymer pipelines are underway to determine their use for safe delivery of hydrogen over long distances.	Composite pipelines can reduce the cost of installation and increase the corrosion resistance of the pipes
High-Performance, Low-Cost Hydrogen Generation from Renewable Energy	Proton Energy Systems, Inc.	New fuel cell materials, components, and manufacturing methods to reduce the cost and improve electrical efficiency for fuel cells integrated with renewable energy sources.	The new system is compatible with high volume manufacturing by consolidating fuel components and simplifying assembly.
Highly Efficient Solid-State Electrochemical Hydrogen Compressor	FuelCell Energy, Inc.	The new compressor is more efficient than existing mechanical compressors, contains no moving parts, and has a modular architecture which allows the capacity to be increased by simply adding more fuel cells.	The compressor can produce up to 4 lbs of hydrogen per day at pressures up to 12,000 psi at a hydrogen recovery efficiency of 95%.
HRS-100™ Hydrogen Recycling System (SBIR Project)	H2Pump, LLC	An electrochemical hydrogen recovery system that separates hydrogen from a mixed gas stream (e.g., furnace exhaust), purifies it, and pumps it back into the feed stream of an industrial process. The system can recycle up to 100 kg-H_2/day (1,600scfh) and recovers up to 90% of the hydrogen present in the exhaust stream.	The system reduces hydrogen feedstock costs for industrial processes by recovering previously wasted hydrogen at a lower cost than would be required for a new supply.
Hydrogen by Wire — Home Fueling System (SBIR Project)	Proton Energy Systems, Inc.	A new PEM electrolysis system produces 2 Kg/day of hydrogen at 350 bar for refueling hydrogen-powered vehicles or for stationary/portable power devices.	The new on-site system enables widespread adoption of hydrogen-powered transportation without a well-developed hydrogen supply infrastructure.
Hydrogen Gas Sensing System	Intelligent Optical Systems, Inc.	The quick-response sensor system accurately detects hydrogen leaks in a broad range of operating environments including fuel cell vehicle garages, production facilities, and refueling stations. The sensor detects hydrogen at concentrations from 100 ppm to 10% hydrogen-in-air with a response time of less than 5 seconds.	The system operates over a wide range of conditions, including temperatures of 10-55°C and 0-90% relative humidity. The system identifies the points at which hydrogen is leaking thus alerting users before safety is compromised.

Table 3.8. Emerging Products Summary – Production/Delivery (Cont'd)

Technology	Organization	Description	Benefits
Hydrogen Production for Refineries (SBIR Project)	TDA Research, Inc.	The hydrogen generation process uses a fluidized bed reactor to produce hydrogen from heavy feedstocks at refineries.	The process saves energy and costs by operating at lower temperatures compared with conventional methods (methane steam reforming or petcoke gasifiers).
Hydrogen Production via a Commercially Ready Inorganic Membrane Reactor	Media and Process Technology, Inc.	A chemically stable carbon molecular sieve separates hydrogen from caustic streams that contain CO, CO_2, H_2S, and heavy hydrocarbons at stream temperatures above 250°C and pressures up to 1,500 psi.	The membrane offers a low-cost, mechanically durable option for hydrogen separation under harsh conditions and functions as a membrane reactor for water gas shift reactions.
Integrated Ceramic Membrane System for Hydrogen Production	Praxair, Inc.	The hydrogen transport membrane features uniform small pores on the surface that enable a thin membrane layer to span the pores while larger pores in the bulk of the substrate provide strength to the membrane and do not restrict hydrogen flow.	The membranes help increase hydrogen yield, purity, and system energy efficiency and reduce capital costs. They are especially applicable to small, on-site hydrogen generators, such those located at fueling stations.
Integrated Short Contact Time Hydrogen Generator	GE Global Research Center	The technology integrates short contact time catalytic partial oxidation, steam reforming, and water gas shift catalysis into a single process (staged catalytic partial oxidation) in a compact reactor that can produce 60 kg of hydrogen per day.	The technology has relatively low operation temperatures that allow lower-cost stainless steel to be used, is relatively compact, is amenable to mass production, and provides efficiency gains and lower capital costs by staging and integrating three catalysts.
Leak Detection and Hydrogen Sensor Development	Los Alamos National Laboratory	A robust zirconia-based, electrochemical sensor for vehicular and stationary applications. The low-cost sensor measures hydrogen in air from 0.04-4% with an accuracy of ± 1%	The safety sensor is low-cost and durable with desirable response time, stability, and resistance to aging and degradation from thermal cycling.
Low-Cost, Large-Scale PEM Electrolysis for Renewable Energy Storage (SBIR Project)	Proton Energy Systems, Inc.	A new electrolysis system using improved catalyst and membrane materials to reduce efficiency losses arising from oxygen evolution over-potential and membrane ionic resistance.	The new catalysts and membranes reduce MEA cost by using less expensive materials while improving long-term stability and scale up.
Materials Solutions for Hydrogen Delivery in Pipelines	Secat, Inc.	Methods are being developed to identify steel compositions and associated welding filler wires and processes that would enable safe transmission of hydrogen at high pressures (800-3000 psi).	The methods would reduce pipeline infrastructure costs by identifying suitable existing pipelines thus avoiding replacement costs while ensuring safety.
Maximizing Light Utilization Efficiency and Hydrogen Production in Microalgal Cultures	UC Berkeley	The technique involves genetically engineering the length of the chlorophyll "antenna" of a strain of algae to prevent over-absorption at the surface, allowing sunlight to penetrate deeper into the culture, thereby decreasing the heat dissipation and increasing the light utilization efficiency of hydrogen production from 3% to 15%.	The technology generates carbon-neutral hydrogen from algae and sunlight without requiring fossil fuels.
MEMS Hydrogen Sensor for Leak Detection	Oak Ridge National Laboratory	Microelectromechanical system (MEMS) hydrogen sensor uses a nanostructured palladium/argon alloy to improve sensitivity and response. The sensor can be used for hazardous condition detection in hydrogen fuel-powered applications.	The sensor has sufficient response, sensitivity, and accuracy for safety applications at low-cost.

Table 3.8. Emerging Products Summary – Production/Delivery (Cont'd)

Technology	Organization	Description	Benefits
Nanotube Array Photocatalysts (SBIR Project)	Synkera Technologies, Inc.	The photoelectrochemical hydrogen production system uses high-density arrays of nanotubes with unique coaxial architecture to enhance light harvesting through a large absorption cross-section and a high surface area to promote catalytic chemistry.	The photocatalysts increases efficiency through broadband light absorption and a vertically graded bandgap. The system is scalable to large size and high volumes and lowers costs compared with traditional technologies.
Novel Catalytic Fuel Reforming	InnovaTek, Inc.	The hydrogen generator reforms multiple fuel types (natural gas, gasoline, and diesel) to produce pure hydrogen by integrating microreactor and microchannel heat exchanger technology with advanced sulfur-tolerant catalysts and membranes.	The generator system can produce 30 to 150 grams of hydrogen per hour that can be used to fuel a 1- to 5-kW polymer electrolyte membrane fuel cell or other auxiliary power unit.
Oil Free Hydrogen Compressor (SBIR Project)	Mohawk Innovative Technology, Inc.	The oil-free, high-speed centrifugal compressor uses advanced compliant surface foil gas bearings and seals, engineered coatings in conjunction with advanced high-speed drives, and centrifugal compressors.	The technology reduces capital, maintenance, and operating costs of compressors; improves compressor reliability and efficiency; and eliminates the potential for hydrogen contamination for sensitive hydrogen-consuming devices such as fuel cells.
Photoelectrochemical Hydrogen Production	MVSystems, Inc.	Five material classes have been studied, with a focus on understanding and improving photoelectrochemical (PEC) behavior and identifying relevant aspects of structural, optoelectronic, and electrochemical properties of PEC target films.	Advanced PEC hydrogen production systems allow pollution-free, sustainable, and renewable hydrogen synthesis.
Renewable Electrolysis Integrated System Development and Testing	National Renewable Energy Laboratory	The approach reduces the impact of the inherent variability of renewable energy production by storing excess energy in the form of hydrogen. Varying renewable sources are being matched to the DC requirements of multiple alkaline and PEM electrolyzer stacks.	Coupling hydrogen production to renewable energy production allows for greater renewable energy infrastructure penetration and pollution-free production of energy.
Reversible Liquid Carriers	Air Products and Chemicals, Inc.	This technology deploys a fully reversible liquid carrier that can be readily hydrogenated, transported to a distribution center, and then catalytically dehydrogenated to provide hydrogen gas to an end use such as fuel cells.	The technology increases catalyst efficiency and allows thermodynamically favorable liquid carriers to be deployed.
Unitized Design for Home Refueling Appliance for Hydrogen Generation to 5,000 psi	Giner, Inc.	The technology is a 5,000 psi PEM-based water electrolyzer system that produces hydrogen for residential refueling of hydrogen vehicles.	The refueling system reduces overall cost by eliminating the need for hydrogen storage and compression at the user end site.

Table 3.9. Emerging Products Summary – Storage

Technology	Organization	Description	Benefits
Electrochemical Reversible Formation of Alane	Savannah River National Laboratory	The process uses direct hydrogeneration and electrochemical synthesis to produce alane, a low-cost rechargeable hydrogen storage material for portable or stationary fuel cell applications.	The process increases alane production by using more efficient, less costly electrochemical reactions and avoids hazardous material handling problems by surface passivation.
High-Strength, Low-Cost Microballoons for Hydrogen Storage	Powdermet, Inc.	The microballoons are fabricated from light-weight carbon and have high-strength, defect-free coatings capable of a theoretical hydrogen storage capacity of >12 wt%, a burst strength >15,000 psig, and exceptional crush strength. The microballoons act as a scaffold for an impermeable barrier made of high-strength material.	The microballoons produce harmless waste products after hydrogen is released, may prove to be easily transportable, and flow like water to conform to any shape container.
Hydrogen Storage in Cryo-Compressed Vessels	Lawrence Livermore National Laboratory	The cryo-compressed hydrogen storage tank maintains high energy density without evaporative losses, requires fewer carbon fiber construction materials, and can store either compressed or liquid hydrogen.	The storage tank has a 500-mile range, can be dormant for extended periods without losing fuel from the tank, and has demonstrated an improved thermal endurance compared with low-pressure vessels.
Low-Cost, High-Performance Metal Hydride Hydrogen Storage System for Forklift Applications	Hawaii Hydrogen Carriers, LLC	A metal hydride solid-state-based hydrogen fuel system to power PEM fuel cell forklifts has the advantage of reduced charging/ fueling time, consistent power delivery, longer lift span, added ballast, and the ability to be used with renewable energy source.	The new system offers safer operation, increased tank storage capacity, lower capital cost, reduced fleet size, and the capability to fill directly from an electrolyzer or other low-pressure source.
Low-Cost, High Strength Commercial Textile Precursor (PAN-MA)	Oak Ridge National Laboratory	This lower cost carbon fiber precursor, polyacrylonitrile with methyl acrylate (PAN-MA), will be used to improve the strength-to-weight ratio of carbon fiber composite materials for hydrogen storage tanks.	The carbon fiber can be manufactured using existing high textile production processes rather than highly specialized processes and materials thus reducing fiber costs by 25%.
Manufacturing Technologies for Low-Cost Hydrogen Storage Vessels	Quantum Fuel System Technologies Worldwide, Inc.	A new process for manufacturing composite pressure vessels used for storing compressed hydrogen. The process combines two techniques for the placement of carbon fibers (filament winding and advanced fiber placement) to reduce the cost and weight of the vessel.	The process reduces the weight and cost of composite hydrogen storage vessels without compromising the structural integrity of the vessels.
Rapid Manufacturing of Vehicle-Scale, Carbon-Composite, High-Pressure Hydrogen Storage Cylinders	Profile Composites Inc.	The fabrication technique can create high-pressure storage tanks in less than 20 minutes to allow a production rate approaching vehicle production.	The automated system will dramatically reduce production time, lower costs, improve fabrication reliability and volumes, and provide safer failure modes compared with filament winding tanks.
Safe and Effective Storage and Transmission of Hydrogen	Safe Hydrogen, LLC	The chemical hydride technology uses the existing fossil fuel infrastructure to deliver and store a pumpable and nonexplosive magnesium hydride mineral oil slurry as a future hydrogen fuel.	The slurry delivers hydrogen without requiring significant energy, displays superior storage density compared with cryogenically cooled liquid hydrogen, and can be reused by recycling the byproducts.
Ultalightweight High Pressure Hydrogen Fuel Tanks Reinforced with Carbon Nanotubes	Applied Nanotech, Inc.	The new tanks are made using carbon nanotubes to improve the mechanical properties of the carbon-fiber-reinforced polymer. The mechanical integrity and performance of the high pressure hydrogen storage tanks are maintained while using less carbon fiber materials.	Tank weight is reduced by up to 30% which reduces tank costs and in addition mechanical integrity is maintained.

Table 3.10. Fuel Cell Challenges and Related Emerging Technologies

Challenges*	Technology Title	Organization
Develop membranes that meet all targets	Dimensionally-Stable High-Performance Membrane	Giner Electrochemical Systems, LLC
	High-Temperature Membrane with Humidification-Independent Cluster Structure	FuelCell Energy, Inc.
Develop electrodes that meet all targets	Alternative and Durable High-Performance Cathode Supports for PEM Fuel Cells	Pacific Northwest National Laboratory
	Direct Methanol Fuel Cell (DMFC) Anode Catalysts	National Renewable Energy Laboratory
	Durable Catalysts for Fuel Cell Protection During Transient Conditions	3M Company
	Extended, Continuous Pt Nanostructures in Thick, Dispersed Electrodes	National Renewable Energy Laboratory
	High-Performance, Low-Pt Cathodes Containing New Catalysts and Layer Structure	Cabot Superior MicroPowders
	Low Platinum Loading Fuel Cell Electrocatalysts	Brookhaven National Laboratory
	Platinum Monolayer Electrocatalysts on Stable Low-Cost Supports	Brookhaven National Laboratory
	Ultra-Low Platinum Alloy Cathode Catalysts for PEM Fuel Cells	University of South Carolina
Develop MEAs that meet all targets	Engineered Nanostructured MEA Technology for Low-Temperature Fuel Cells	Nanosys, Inc.
	Manufacturing of Low-Cost, Durable Membrane Electrode Assemblies	W.L. Gore and Associates, Inc.
	Platinum and Fluoropolymer Recovery from PEM Fuel Cells	Ion Power, Inc.
	Platinum-Group-Metal Recycling Technology	BASF Catalysts LLC
Develop low-cost, durable bipolar plates that meet all targets	Nitrided Metallic Bipolar Plates for PEM Fuel Cells	Oak Ridge National Laboratory
	Resin-Impregnated, Expanded-Graphite GRAFCELL® Bipolar Plates	GrafTech International Ltd.
Develop efficient, cost-effective thermal/water management systems	CIRRUS: Cell Ice Regulation and Removal Upon Start-up	Nuvera Fuel Cells, Inc.
	Materials and Modules for Low-Cost, High-Performance Fuel Cell Humidifiers	W.L. Gore and Associates, Inc.
Develop effective, reliable physical and chemical sensors that meet all targets	Low-Cost Hydrogen Sensor for Transportation Safety	Makel Engineering, Inc.
	Sensors for Automotive Fuel Cell Systems	NexTech Materials, Ltd.
Develop cost-effective, efficient, reliable and durable fuel cells for stationary applications that meet all targets	Low-Cost 3-10 kW Tubular SOFC Power System	Acumentrics Corporation
Develop cost-effective, reliable, durable fuel cells for portable power applications (e.g., cell phones, computers, etc.) that meet all targets	Direct Methanol Fuel Cell for Handheld Electronics Applications	MTI Micro Fuel Cells, Inc.
	Fuel-Cell-Based Mobile Lighting	Sandia National Laboratories

Table 3.10. Fuel Cell Challenges and Related Emerging Technologies (Cont'd)

Challenges*	Technology Title	Organization
Develop auxiliary power unit (APU) system for heavy truck applications to reduce idling of the main engine that meet all targets	Solid Acid Fuel Cell Stack for Auxiliary Power Unit Applications	SAFCell, Inc.
	Solid Oxide Fuel Cell Auxiliary Power Unit	Delphi Corporation
Develop system to allow PEM Fuel Cells to operate in off-road applications	PowerEdge™ Fuel Cell System	Nuvera Fuel Cells, Inc.
Stationary fuel cell demonstrations	GenSys® Blue: High-Temperature CHP Fuel Cell System	Plug Power Inc.
	High-Efficiency Polymer Electrolyte Membrane Fuel Cell Combined Heat and Power System	Intelligent Energy Inc.
Develop manufacturing processes for high-volume production of high-quality, uniform bipolar plates (Manufacturing PEM Fuel Cells Challenge)	Low-Cost Manufacturing of Sheet Molding Compound Bipolar Plates for PEM Fuel Cells	Nanotek Instruments, Inc.
Reduce cost of PEM materials through improved manufacturing operations (Manufacturing PEM Fuel Cells Challenge)	Fuel Cell Membrane Measurement System for Manufacturing	Scribner Associates, Inc.
	Ultrasonics and Advanced Diagnostics for High-Temperature PEM MEA Manufacture	Rensselaer Polytechnic Institute
Develop sensors to monitor performance of fuel cell and fuel cell leakage (Manufacturing PEM Fuel Cells Challenge)	Direct-Write Inkjet Printing for Fabricating Hydrogen Sensors	InnoSense, LLC

* Note: The challenges are described in the FCT Program Multi-Year Plan for fuel cells at http://www1.eere.energy.gov/hydrogenandfuelcells/mypp/pdfs/fuel_cells.pdf and manufacturing at http://www1.eere.energy.gov/hydrogenandfuelcells/mypp/pdfs/manufacturing.pdf.

Table 3.11. Production and Delivery Challenges and Related Emerging Technologies

Challenges*	Technology Title	Organization
Cost reduction of distributed hydrogen production from natural gas and bio-derived liquids	Ceramic Membrane Reactor Systems for Converting Natural Gas to Hydrogen and Synthesis Gas (ITM Syngas)	Air Products and Chemicals, Inc.
	High-Performance, Low-Cost Hydrogen Generation from Renewable Energy	Proton Energy Systems, Inc.
	Hydrogen by Wire — Home Fueling System	Proton Energy Systems, Inc.
	Hydrogen Production for Refineries	TDA Research, Inc.
	Integrated Short Contact Time Hydrogen Generator	GE Global Research Center
	Low-Cost, Large-Scale PEM Electrolysis for Renewable Energy Storage	Proton Energy Systems, Inc.
	Novel Catalytic Fuel Reforming	InnovaTek, Inc.
Hydrogen production from water via electrolysis	Renewable Electrolysis Integrated System Development and Testing	National Renewable Energy Laboratory
	Unitized Design for Home Refueling Appliance for Hydrogen Generation to 5,000 psi	Giner, Inc.
Photoelectrochemical hydrogen production from water (direct water splitting)	Nanotube Array Photocatalysts	Synkera Technologies, Inc.
	Photoelectrochemical Hydrogen Production	MVSystems, Inc.
Biological production of hydrogen	Maximizing Light Utilization Efficiency and Hydrogen Production in Microalgal Cultures	UC Berkeley
Separation and purification systems	HRS-100™ Hydrogen Recycling System	H2Pump, LLC
	Hydrogen Gas Sensing System	Intelligent Optical Systems, Inc.
	Hydrogen Production via a Commercially Ready Inorganic Membrane Reactor	Media and Process Technology, Inc.
	Integrated Ceramic Membrane System for Hydrogen Production	Praxair, Inc.
	Leak Detection and Hydrogen Sensor Development	Los Alamos National Laboratory
	MEMS Hydrogen Sensor for Leak Detection	Oak Ridge National Laboratory
Reduce capital costs and ensure safety, reliability, and durability of pipelines.	Composite Pipeline Technology for Hydrogen Delivery	Oak Ridge National Laboratory
	Materials Solutions for Hydrogen Delivery in Pipelines	Secat, Inc.
Develop carriers that can enable low cost hydrogen delivery	Reversible Liquid Carriers	Air Products and Chemicals, Inc.
Increase the reliability, reduce the cost, and improve the energy efficiency of gaseous hydrogen compression	Centrifugal Hydrogen Pipeline Gas Compressor	Concepts NREC
	Highly Efficient Solid-State Electrochemical Hydrogen Compressor	FuelCell Energy, Inc.
	Oil Free Hydrogen Compressor	Mohawk Innovative Technology, Inc.
Reduce the cost and improve the energy efficiency of hydrogen liquefaction	Active Magnetic Regenerative Liquefier	Emerald Energy NW, LLC

* Note: The challenges are described in the FCT Program Multi-Year Plan for production at http://www1.eere.energy.gov/hydrogenandfuelcells/mypp/pdfs/production.pdf and delivery at http://www1.eere.energy.gov/hydrogenandfuelcells/mypp/pdfs/delivery.pdf.

Table 3.12. Storage Approaches and Related Emerging Technologies

Challenges*	Technology Title	Organization
Compressed, cryo-compressed and conformal hydrogen tanks	Hydrogen Storage in Cryo-Compressed Vessels	Lawrence Livermore National Laboratory
	Low-Cost, High Strength Commercial Textile Precursor (PAN-MA)	Oak Ridge National Laboratory
	Manufacturing Technologies for Low-Cost Hydrogen Storage Vessels	Quantum Fuel System Technologies Worldwide, Inc.
	Rapid Manufacturing of Vehicle-Scale, Carbon-Composite, High-Pressure Hydrogen Storage Cylinders	Profile Composites Inc.
	Ultalightweight High Pressure Hydrogen Fuel Tanks Reinforced with Carbon Nanotubes	Applied Nanotech, Inc.
Advanced metal hydrides	Electrochemical Reversible Formation of Alane	Savannah River National Laboratory
	Low-Cost, High-Performance Metal Hydride Hydrogen Storage System for Forklift Applications	Hawaii Hydrogen Carriers, LLC
Chemical hydrogen storage	Safe and Effective Storage and Transmission of Hydrogen	Safe Hydrogen, LLC
Additional new materials and concepts	High-Strength, Low-Cost Microballoons for Hydrogen Storage	Powdermet, Inc.

* Note: The approaches are described in the FCT Program Multi-Year Plan for storage at http://www1.eere.energy.gov/hydrogenandfuelcells/mypp/pdfs/storage.pdf

Appendix A:
Technology Tracking List

Fuel Cell Technologies

Technology Title	Company
A Silicon-Based Solid Oxide Fuel Cell for Portable Consumer Electronics: nectar™	Lilliputian Systems, Inc.
Alternative and Durable High Performance Cathode Supports for PEM Fuel Cells	PNNL
Bio-Fueled Solid Oxide Fuel Cells	TDA Research
CIRRUS: Cell Ice Regulation and Removal Upon Start-up	Nuvera Fuel Cells, Inc.
Cathode Catalysts and Supports for PEM Fuel Cells	3M Company
Compact, Multi-Fuel Solid Oxide Fuel Cell (SOFC) System	Technology Management, Inc.
Complex Coolant for Polymer Electrolyte Membrane (PEM) Fuel Cells	Dynalene, Inc.
Conductive Compound for Molding Fuel Cell Bipolar Plates	Bulk Molding Compounds, Inc.
Corrosion Test Cell for PEM Bipolar Plate Materials	Fuel Cell Technologies, Inc.
Cost-Effective, High-Efficiency, Advanced Reforming Module (CHARM)	Nuvera Fuel Cells, Inc.
Dimensionally-Stable High-Performance Membrane	Giner Electrochemical Systems, LLC
Direct Methanol Fuel Cell (DMFC) Anode Catalysts	NREL
Direct Methanol Fuel Cell for Handheld Electronics Applications	MTI Micro Fuel Cells, Inc.
Direct-Write Inkjet Printing for Fabricating Hydrogen Sensors	InnoSense, LLC
Durable Catalysts for Fuel Cell Protection During Transient Conditions	3M Company
Engineered Nanostructured MEA Technology for Low-Temperature Fuel Cells	Nanosys, Inc.
Extended, Continuous Pt Nanostructures in Thick, Dispersed Electrodes	NREL
FARADAYIC ElectroEtching of Stainless Steel Bipolar Plates	Faraday Technology, Inc.
Fuel Cell Membrane Measurement System for Manufacturing	Scribner Associates, Inc.
Fuel-Cell-Based Mobile Lighting	SNL
GCtool: Fuel Cell Systems Analysis Software Model	ANL
GenDrive™ Fuel Cell Power System	Plug Power Inc.
GenSys® Blue: High-Temperature CHP Fuel Cell System	Plug Power Inc.
High-Efficiency PEM Fuel Cell Combined Heat and Power System	Intelligent Energy Inc.
High-Performance, Low-Pt Cathodes Containing New Catalysts and Layer Structure	Cabot Superior MicroPowders
High Speed, Low Cost Fabrication of Gas Diffusion Electrodes for Membrane Electrode Assemblies	BASF Fuel Cell, Inc.
High-Temperature Membrane with Humidification-Independent Cluster Structure	FuelCell Energy, Inc.
Improved Catalyst Coated Membrane (CCM) Manufacturing	IRD Fuel Cells LLC
Improved Fuel Cell Cathode Catalysts Using Combinatorial Methods	NuVant Systems Inc.
Integrated Manufacturing for Advanced Membrane Electrode Assemblies	BASF Fuel Cell, Inc.
Lifetime Improvements for PEM Fuel Cells	DuPont Fuel Cells
Low-Cost 3-10 kW Tubular SOFC Power System	Acumentrics Corporation
Low-Cost Hydrogen Sensor for Transportation Safety	Makel Engineering, Inc.
Low-Cost Manufacturing of Sheet Molding Compound Bipolar Plates for PEM Fuel Cells	Nanotek Instruments, Inc.
Low-Cost PEM Fuel Cell Metal Bipolar Plates	TreadStone Technologies, Inc.
Low Platinum Loading Fuel Cell Electrocatalysts	BNL
Manufacture of Durable Seals for PEM Fuel Cells	Freudenberg-NOK General Partnership
Manufacturing of Low-Cost, Durable MEAs	W.L. Gore and Associates, Inc.
Materials and Modules for Low-Cost, High-Performance Fuel Cell Humidifiers	W.L. Gore and Associates, Inc.
Membranes and MEAs for Dry, Hot Operating Conditions	3M Company
Nitrided Metallic Bipolar Plates for PEM Fuel Cells	ORNL
Novel Manufacturing Process for PEM Fuel Cell Stacks	Protonex Technology Corporation
Platinum and Fluoropolymer Recovery from PEM Fuel Cells	Ion Power, Inc.

Technologies highlighted in red are commercial and blue are emerging.

Fuel Cell Technologies (Cont'd)

Platinum-Group-Metal Recycling Technology	BASF Catalysts LLC
Platinum Monolayer Electrocatalysts on Stable Low-Cost Supports	BNL
Portable Reformed Methanol Fuel Cells	UltraCell Corporation
PowerEdge™ Fuel Cell System	Nuvera Fuel Cells, Inc.
PureMotion® Model 120 Fuel Cell Power Plant	UTC Power
Reduction in Fabrication Costs of Gas Diffusion Layers	Ballard Material Products, Inc.
Resin-Impregnated, Expanded-Graphite GRAFCELL® Bipolar Plates	GrafTech International Ltd
Scale-Up of Carbon-Carbon Composite Bipolar Plates	Porvair Advanced Materials, Inc.
Sensors for Automotive Fuel Cell Systems	NexTech Materials, Ltd.
Solid Acid Fuel Cell Stack for Auxiliary Power Unit Applications	SAFCell, Inc.
Solid Oxide Fuel Cell Auxiliary Power Unit	Delphi Corporation
Ultra-Low Platinum Alloy Cathode Catalysts for PEM Fuel Cells	University of South Carolina
Ultrasonics and Advanced Diagnostics for High-Temperature PEM MEA Manufacture	Rensselaer Polytechnic Institute

Technologies highlighted in red are commercial and blue are emerging.

Production/Delivery Technologies

Technology Title	Company
Active Magnetic Regenerative Liquefier	Emerald Energy NW, LLC
Centrifugal Hydrogen Pipeline Gas Compressor	Concepts NREC
Ceramic Membrane Reactor Systems for Converting Natural Gas to Hydrogen and Synthesis Gas (ITM Syngas)	Air Products and Chemicals, Inc.
Composite Pipeline Technology for Hydrogen Delivery	ORNL
FuelGen® Hydrogen Fueling Systems	Proton Energy Systems, Inc.
H2 ProGen: A Total Supply Solution for Hydrogen Vehicles	GreenField Compression
High-Performance, Low-Cost Hydrogen Generation from Renewable Energy	Proton Energy Systems, Inc.
High Performance Palladium-Based Membrane	Pall Corporation
Highly Efficient Solid-State Electrochemical Hydrogen Compressor	FuelCell Energy, Inc.
HRS-100™ Hydrogen Recycling System	H2Pump, LLC
Hydrogen By Wire — Home Fueling System	Proton Energy Systems, Inc.
Hydrogen Distributed Production System	Air Liquide Process and Construction, Inc.
Hydrogen Gas Sensing System	Intelligent Optical Systems, Inc.
Hydrogen Generation from Electrolysis	Proton Energy Systems, Inc.
Hydrogen Production for Refineries	TDA Research
Hydrogen Production via a Commercially Ready Inorganic Membrane Reactor	Media and Process Technology, Inc.
Hydrogen Safety Sensor for Advanced Energy Applications	NexTech Materials, Ltd.
Integrated Ceramic Membrane System for Hydrogen Production	Praxair, Inc.
Integrated Short Contact Time Hydrogen Generator	GE Global Research Center
Leak Detection and Hydrogen Sensor Development	LANL
Low-Cost, Large-Scale PEM Electrolysis for Renewable Energy Storage	Proton Energy Systems, Inc.
Materials Solutions for Hydrogen Delivery in Pipelines	Secat, Inc.
Maximizing Light Utilization Efficiency and Hydrogen Production in Microalgal Cultures	U. of California-Berkeley
ME100 Methanol Reforming Hydrogen Generator	REB Research & Consulting
Membrane Structures for Hydrogen Separation	Genesis Fueltech, Inc.
MEMS Hydrogen Sensor for Leak Detection	ORNL
Nanoscale Water Gas Shift Catalysts	NexTech Materials, Ltd.
Nanotube Array Photocatalysts	Synkera Technologies, Inc.
Novel Catalytic Fuel Reforming	InnovaTek, Inc.
Oil Free Hydrogen Compressor	Mohawk Innovative Technology, Inc.
PEM Electrolyzer Incorporating Low-Cost Membrane	Giner Electrochemical Systems, LLC
Photoelectrochemical Hydrogen Production	MVSystems, Inc.
Renewable Electrolysis Integrated System Development and Testing	NREL
Reversible Liquid Carriers	Air Products and Chemicals, Inc.
Stackable Structural Reactor (SSR®) for Low-Cost Hydrogen Production	Catacel Corporation
TITAN™: High-Pressure Hydrogen Storage Tank for Gaseous Truck Delivery	Lincoln Composites, Inc.
Unitized Design for Home Refueling Appliance for Hydrogen Generation to 5,000 psi	Giner Electrochemical Systems, LLC

Technologies highlighted in red are commercial and blue are emerging.

Storage Technologies

Technology Title	Company
Electrochemical Reversible Formation of Alane	SRNL
High-Strength, Low-Cost Microballoons for Hydrogen Storage	Powdermet, Inc.
Hydrogen Composite Tanks	Quantum Technologies, Inc.
Hydrogen Storage in Cryo-Compressed Vessels	LLNL
Low-Cost, High-Performance Metal Hydride Hydrogen Storage System for Forklift Applications	Hawaii Hydrogen Carriers LLC
Low-Cost, High Strength Commercial Textile Precursor (PAN-MA)	ORNL
Manufacturing Technologies for Low-Cost Hydrogen Storage Vessels	Quantum Fuel System Technologies Worldwide, Inc.
Rapid Manufacturing of Vehicle-Scale, Carbon-Composite, High-Pressure Hydrogen Storage Cylinders	Profile Composites Inc.
Safe and Effective Storage and Transmission of Hydrogen	Safe Hydrogen, LLC
Sodium Silicide (NaSi) Hydrogen Generation System	SiGNa Chemistry, Inc.
Ultralightweight High Pressure Hydrogen Fuel Tanks Reinforced with Carbon Nanotubes	Applied Nanotech, Inc.

Technologies highlighted in red are commercial and blue are emerging.

Appendix B:
Patent Status Lists

Fuel Cell Patents Status

Patent Number	Award Date	Organization	Title	Description	Status
8,481,227	07/09/13	3M Company	Proton conducting materials	Fuel cell membrane materials with an increased number of strong acid groups created in some embodiments by reaction of these acid-containing molecules with acid-containing organic molecules, metal oxide or phosphate particles, metal salts, heteropolyacids, and the like.	Still being used in ongoing research efforts. Part of a commercial fuel cell technology project.
8,465,858	06/18/13	University of South Carolina	Development of a novel method for preparation of PEMFC electrodes	A method for preparation of membrane electrode assemblies that is based on pulse electrodeposition.	Research complete - licensed/ seeking to license. Part of an emerging fuel cell technology project.
8,420,271	04/16/13	General Motors Corporation	Method to improve reliability of a fuel cell system using low performance cell detection at low power operation	A system and method for detecting a low performing cell in a fuel cell stack using measured cell voltages. The method includes determining that the fuel cell stack is running, the stack coolant temperature is above a certain temperature and the stack current density is within a relatively low power range.	Licensed to Honda.
8,415,070	04/09/13	E.I. du Pont de Nemours and Company	Partially Fluorinated Cyclic Ionic Polymers and Membranes	Ionic polymers are made from selected partially fluorinated dienes, in which the repeat units are cycloaliphatic. The polymers are formed into membranes.	Still being used in ongoing research efforts.
8,394,352	03/12/13	University of South Carolina	Porous metal oxide particles and their methods of synthesis	Methods for the formation of metal oxide nanoparticles that can be used in solid oxide fuel cells.	Research complete - licensed/ seeking to license.
8,394,298	03/12/13	LANL	Non-aqueous liquid compositions comprising ion exchange polymers	Compositions useful for formation of uniformly-dispersed electrodes, which in turn are useful as a component of membrane-electrode assemblies for, e.g., fuel cells, sensors and capacitors.	Still being used in ongoing research efforts.
8,329,006	12/11/12	Faraday Technology, Inc.	Electroplating cell with hydrodynamics facilitating more uniform deposition across a workpiece during plating	An apparatus for establishing more uniform deposition across one or more faces of a workpiece in an electroplating process. The apparatus employs eductors in conjunction with a flow dampener member and other measures to provide a more uniform current distribution and a more uniform metal deposit distribution as reflected in a coefficient of variability that is lower than conventional processes.	Being used in ongoing research. Part of a commercial fuel cell technology project.
8,326,477	12/04/12	General Motors Corporation	Heel and toe driving on fuel cell vehicle	A system and method for providing nearly instantaneous power in a fuel cell vehicle.	Licensed to Honda.

Fuel Cell Patents Status

Patent Number	Award Date	Organization	Title	Description	Status
8,323,809	12/04/12	3M Company	Fuel cell electrolyte membrane with basic polymer	An electrolyte membrane comprising an acid and a basic polymer, where the acid is a low-volatile acid that is fluorinated and is either oligomeric or non-polymeric, and where the basic polymer is protonated by the acid and is stable to hydrolysis.	Still being used in ongoing research efforts. Part of a commercial fuel cell technology project.
8,308,989	11/13/12	BNL	Electrocatalyst for oxygen reduction with reduced platinum oxidation and dissolution rates	Methods for preventing the oxidation of the platinum electrocatalyst in the cathodes of fuel cells by use of platinum-metal oxide composite particles.	Still being used in research and seeking to license. Part of an emerging fuel cell technology project.
8,304,122	11/06/12	Protonex Technology Corporation	Solid oxide fuel cell systems with hot zones having improved reactant distribution	A solid oxide fuel cell system having a hot zone with a center cathode air feed tube for improved reactant distribution, a catalytic partial oxidation reactor attached at the anode feed end of the hot zone with a tail gas combustor at the opposing end for more uniform heat distribution, and a counter-flow heat exchanger for efficient heat retention.	Being used in ongoing research.
8,278,011	10/02/12	Nanosys, Inc.	Nanostructured catalyst supports	Silicon carbide nanostructures that can be used as catalyst supports in membrane electrode assemblies and in fuel cells.	Being used in ongoing research. Part of an emerging fuel cell technology project.
8,236,207	08/07/12	LANL	Non-aqueous liquid compositions comprising ion exchange polymers reference to related application	Compositions useful for formation of uniformly-dispersed electrodes, which in turn are useful as a component of membrane-electrode assemblies for, e.g., fuel cells, sensors and capacitors.	Still being used in ongoing research efforts.
8,227,147	07/24/12	LANL	Advanced membrane electrode assemblies for fuel cells	Method for producing polymer electrolyte membranes with improved performance and durability for fuel cell use.	Still being used in ongoing research efforts.
8,227,140	07/24/12	3M Company	Proton conducting materials	Fuel cell membrane materials with an increased number of strong acid groups created in some embodiments by reaction of these acid-containing molecules with acid-containing organic molecules, metal oxide or phosphate particles, metal salts, heteropolyacids, and the like.	Still being used in ongoing research efforts. Part of a commercial fuel cell technology project.
8,206,682	06/26/12	BASF Corporation	Method for recovering catalytic elements from fuel cell membrane electrode assemblies	A method for recovering catalytic elements from a fuel cell membrane electrode assemblies. Recovery of the membrane electrode assembly materials is achieved by converting the membranes into particulate, forming a slurry and then dissolving catalytic elements into a soluble catalytic element salt.	Research complete - company holding IP. Part of an emerging fuel cell technology project.

Fuel Cell Patents Status

Patent Number	Award Date	Organization	Title	Description	Status
8,197,955	06/12/12	General Electric Company	Electrolyte membrane, methods of manufacture thereof and articles comprising the same	Method to form an electrolyte membrane comprising of polyhydroxy, aromatic polyhalide and alkali metal hydroxide compounds. The process forms a porous substrate; and a crosslinked proton conductor deposited onto the porous substrate.	Still being used in ongoing research.
8,178,463	05/15/12	ANL	Highly durable nanoscale electrocatalyst based on core shell particles	A multimetallic nanoscale catalyst having a core portion enveloped by a shell portion and exhibiting high catalytic activity and improved catalytic durability	Still being used in ongoing research efforts.
8,153,324	04/10/12	Nanotek Instruments, Inc.	Controlled-release vapor fuel cell	A controlled-release fuel cell that is particularly useful for powering small vehicles and portable electronic devices.	Being used in ongoing research.
8,137,858	03/20/12	ANL	Method of fabricating electrode catalyst layers with directionally oriented carbon support for proton exchange membrane fuel cell	A new method of preparing a membrane electrode assembly (MEA) for a PEMFC that reduces precious metal usage, eliminates the need for GDE and simplifies the design and fabrication of bipolar plates.	Still being used in ongoing research efforts.
8,129,306	03/06/12	ANL	Non-platinum bimetallic polymer electrolyte fuel cell catalysts	A polymetallic nanoparticle alloy having enhanced catalytic properties including at least one noble metal and at least one base metal, where the noble metal is preferentially dispersed near the surface of the nanoparticle and the base metal modifies the electronic properties of the surface disposed noble metal.	Research complete; seeking to license.
8,124,261	02/28/12	BASF Corporation	Process for recycling components of a PEM fuel cell membrane electrode assembly	Process for recycling components of a PEM fuel cell membrane electrode assembly. The membrane electrode assembly (MEA) of a PEM fuel cell can be recycled by dissolving the MEA with a lower alkyl alcohol solvent which separates the membrane from the anode and cathode layers of the assembly. The solution contains both the polymer membrane and noble metal catalysts which can be heated to form particulates which can then be separated by filtration.	Research complete - company holding IP. Part of an emerging fuel cell technology project.
8,114,547	02/14/12	Ford Motor Company	Fuel cell stack flow diversion	A control valve to affect the flow of compressed gas in a fuel cell system.	Being used in ongoing research.
8,101,317	01/24/12	3M Company	Durable fuel cell having polymer electrolyte membrane comprising manganese oxide	Fuel cell membrane electrode assemblies and fuel cell polymer electrolyte membranes are provided comprising manganese oxides which demonstrate increased durability.	Still being used in ongoing research efforts.

Fuel Cell Patents Status

Patent Number	Award Date	Organization	Title	Description	Status
8,092,954	01/10/12	3M Company	Method of making a fuel cell polymer electrolyte membrane comprising manganese oxide	Fuel cell membrane electrode assemblies and fuel cell polymer electrolyte membranes are provided comprising manganese oxides which demonstrate increased durability. Methods of making the same are provided.	Still being used in ongoing research efforts.
8,088,526	01/03/12	General Motors Corporation	Anode reactive bleed and injector shift control strategy	A system and method for correcting a large fuel cell voltage spread for a split sub-stack fuel cell system.	Licensed to Honda.
8,062,552	11/22/11	BNL	Electrocatalyst for oxygen reduction with reduced platinum oxidation and dissolution rates	Method for using platinum-metal oxide composite particles as electrocatalysts in oxygen-reducing cathodes in fuel cells. The method prevents oxidation of platinum electrocatalyst at the cathodes.	Still being used in research and seeking to license. Part of an emerging fuel cell technology project.
8,058,383	11/15/11	E.I. du Pont de Nemours and Company	Arylene-fluorinated-sulfonimide ionomers and membranes for fuel cells	Method for preparation of aromatic sulfonimide polymers for membranes in electrochemical cells. The resulting polymers are useful as cation-exchange resins which can be used for producing proton-exchange membranes for fuel cells and can be used in any application wherein cation-exchange capacity is desired. The resins may also be used as electrolytes, electrode binders, in lithium batteries in lithium salt form, and in any application requiring charge-transfer phenomena, such as components of light-emitting displays. The polymers described herein can be either homopolymers or copolymers.	Research complete - company holding IP.
8,057,949	11/15/11	Ford Motor Company	Fuel cell stack flow diversion	A control valve to affect the flow of compressed gas in a fuel cell system.	Being used in ongoing research.
8,048,548	01/11/11	BNL	Electrocatalyst for alcohol oxidation at fuel cell anodes	An electrocatalyst is used in an anode for oxidizing alcohol in a fuel cell. The electrocatalyst consists of a noble metal particle with surface clusters of SnO_2 and Rh. The noble metal particles include platinum, palladium, ruthenium, iridium, gold, and combinations thereof. In some embodiments the electrocatalyst particle cores are nanoparticles.	Still being used in research and seeking to license. Part of an emerging fuel cell technology project.

Fuel Cell Patents Status

Patent Number	Award Date	Organization	Title	Description	Status
8,039,160	10/18/11	Arkema Inc.	Multi-layer polyelectrolyte membrane	Method to produce multi-layer polyelectrolyte membranes containing polymeric resins, specifically fluoropolymer and non-perfluorinated polymeric resins containing ionic and/or ionizable groups (also referred to as a "polyelectrolytes"). These are useful in a variety of products such as fuel cells.	Still being used in ongoing research efforts.
8,028,842	10/04/11	Virginia Polytechnic Institute	Chlorine resistant desalination membranes based on directly sulfonated poly(arylene ether sulfone) copolymers	A method of making a hydrophilic-hydrophobic random copolymer membrane that can be used in fuel cells.	Research complete; seeking to license.
8,011,598	09/06/11	Delphi Technologies, Inc.	SOFC power system with A/C system and heat pump for stationary and transportation applications	A combined heat and power system wherein the compressor motor of a heat pump is powered by a portion of the electricity generated by a solid oxide fuel cell (SOFC), and wherein the thermal output of the heat pump is increased by abstraction of heat from the SOFC exhaust.	Still being used in ongoing research efforts. Part of an emerging fuel cell technology project.
7,981,319	07/19/11	LANL	Non-aqueous liquid compositions comprising ion exchange polymers	Compositions useful for formation of uniformly-dispersed electrodes, which in turn are useful as a component of membrane-electrode assemblies for, e.g., fuel cells, sensors and capacitors.	Still being used in ongoing research efforts.
7,955,759	06/07/11	ORNL	Metallization of bacterial cellulose for electrical and electronic device manufacture	Method for deposition of metals in bacterial cellulose and the utilization of the metallized bacterial cellulose in the construction of fuel cells and other electronic devices.	Still being used in ongoing research efforts.
7,943,266	05/17/11	General Electric Company	SOFC seal and cell thermal management	A solid oxide fuel cell module in which the cell and its peripheral gas-flow-directing components (e.g., manifold and seals) are cooled to reduce stress-inducing thermal gradients and prevent cell cracking.	Being used in continuing research at the company.
7,927,748	04/19/11	ANL	Catalytic membranes for fuel cells	A fuel cell of the present invention comprises a cathode and an anode, one or both of the anode and the cathode including a catalyst comprising a bundle of longitudinally aligned graphitic carbon nanotubes including a catalytically active transition metal incorporated longitudinally and atomically distributed throughout the graphitic carbon walls of said nanotubes.	Still being used in ongoing research efforts.

Fuel Cell Patents Status

Patent Number	Award Date	Organization	Title	Description	Status
7,910,653	03/22/11	E.I. du Pont de Nemours and Company	Process for the preparation of arylene fluorinated sulfonimide polymers and membranes	Polymer electrolyte membrane fuel cells (PEMFC) are expected to provide higher efficiencies, fewer environmental pollutants, and reduced operating and maintenance costs than traditional power sources. An important component of a PEMFC is a polymer electrolyte membrane (PEM). The range of potential candidates for use as membrane materials in PEMFCs is limited by a number of requirements, including chemical, thermal, and mechanical stability, high ionic conductivity, and low reactant permeability. Developments have been made in the use of sulfonic acid functionalized polymers, including membranes such as Nafion.RTM. perfluorosulfonic acid membranes.	No longer being used.
7,906,251	03/15/11	3M Company	Oxygen-reducing catalyst layer	Process for thin film deposition of oxygen-reducing catalysts on a substrate using vapor deposition and thermal treatment. The catalytic material film includes a transition metal that is substantially free of platinum.	Still being used in ongoing research.
7,902,299	03/08/11	LBNL	Single ion conductor cross-linked polymeric networks	The invention relates to the synthesis, characterization, and electrochemical response of a new type of single-ion comb-branch polymer electrolyte that can be used as a proton exchange membrane in fuel cells.	Being used in research at LBNL and seeking to license.
7,901,940	03/08/11	BASF Corporation	Method for measuring recovery of catalytic elements from fuel cells	A method for measuring the concentration of a catalytic element in a fuel cell powder. The method includes depositing a powder mixture consisting of the fuel cell powder and an internal standard material on a porous substrate, ablating a sample of the powder mixture using a laser, and vaporizing the sample using an inductively coupled plasma.	No longer being used.
7,887,927	02/15/11	Nanotek Instruments, Inc.	Highly conductive, multi-layer composite precursor composition to fuel cell flow field plate or bipolar plate	A roll-to-roll method of producing a flexible graphite-based, highly electrically conductive sheet molding compound (SMC) and SMC-based flow field or bipolar plates for use in a proton exchange membrane fuel cell.	Part of an emerging fuel cell technology project.
7,871,738	01/18/11	ANL	Nanosegregated surfaces as catalysts for fuel cells	A method of preparing a nanosegregated Pt alloy having enhanced catalytic properties. The method includes providing a sample of Pt and one or more of a transition metal in a substantially inert environment, and annealing the sample in such an environment for a period of time and at a temperature profile to form a nanosegregated Pt alloy having a Pt-skin on a surface.	Still being used in ongoing research efforts.

Fuel Cell Patents Status

Patent Number	Award Date	Organization	Title	Description	Status
7,868,086	01/11/11	E.I. du Pont de Nemours and Company	Arylene fluorinated sulfonimide polymers and membranes	Aromatic sulfonimide polymers that are useful in making proton exchange membranes for fuel cells.	Being used in continuing research at the company.
7,867,669	01/11/11	Giner Electrochemical Systems, LLC	Solid polymer electrolyte composite membrane comprising laser micromachined porous support	A solid polymer electrolyte composite membrane and methods of manufacturing the same.	Part of an emerging fuel cell technology project.
7,855,021	12/21/10	BNL	Electrocatalysts having platinum monolayers on palladium, palladium alloy, and gold alloy core-shell nanoparticles, and uses thereof	The invention relates to platinum-coated particles useful as fuel cell electrocatalysts. The particles are composed of a noble metal or metal alloy core at least partially encapsulated by an atomically thin surface layer of platinum atoms. The invention particularly relates to such particles having a palladium, palladium alloy, gold alloy, or rhenium alloy core encapsulated by an atomic monolayer of platinum.	Part of an emerging fuel cell technology project.
7,851,399	12/14/10	LANL	Method of making chalcogen catalysts for polymer electrolyte fuel cells	A method of making a catalyst material for use in fuel cell cathodes. The catalyst material includes a support comprising at least one transition metal and at least one chalcogen disposed on a surface of the transition metal.	Being used in continuing research at LANL.
7,838,612	11/23/10	E.I. du Pont de Nemours and Company	Arylene fluorinated sulfonimide compositions	Aromatic sulfonimide compositions that can be used to prepare polymers useful as membranes in electrochemical cells.	Still being used in ongoing research efforts.
7,838,138	11/23/10	3M Company	Fuel cell electrolyte membrane with basic polymer	A fuel cell electrolyte membrane that includes an acid and a basic polymer. The acid is a low-volatility acid that is fluorinated and is either oligomeric or non-polymeric. The basic polymer is protonated by the acid and is stable to hydrolysis. As a result, the electrolyte membrane may be used at high operating temperatures while preserving proton conductivity.	Part of a commercial fuel cell technology project.
7,829,603	11/09/10	E.I. du Pont de Nemours and Company	Stable trifluorostyrene containing compounds grafted to base polymers, and their use as polymer electrolyte membranes	Ion exchange polymers that are useful in preparing catalyst coated membranes and membrane electrode assemblies used in fuel cells.	No longer being used.

Fuel Cell Patents Status

Patent Number	Award Date	Organization	Title	Description	Status
7,829,194	11/09/10	ORNL	Iron-based alloy and nitridation treatment for PEM fuel cell bipolar plates	A corrosion resistant electrically conductive component that can be used as a bipolar plate in a PEM fuel cell. The plates are composed of an alloy substrate (Fe base metal with 10-30 wt. % Cr and 0.5-7 wt. % V) and a continuous surface layer of chromium nitride and vanadium nitride.	Part of an emerging fuel cell technology project.
7,824,651	11/02/10	Nanotek Instruments, Inc.	Method of producing exfoliated graphite, flexible graphite, and nano-scaled graphene platelets	A method of exfoliating a layered material (e.g., graphite and graphite oxide) to produce nano-scaled platelets having a thickness smaller than 100 nm and typically smaller than 10 nm. The invention can be used in the manufacturing of fuel cell bipolar plates.	Part of an emerging fuel cell technology project.
7,815,986	10/19/10	Arkema Inc.	Blend of ionic (co)polymer resins and matrix (co) polymers	A novel polymeric resin blend useful for forming durable and chemical-resistant films for fuel cell membranes.	No longer being used.
7,807,063	10/05/10	Giner Electrochemical Systems, LLC	Solid polymer electrolyte composite membrane comprising plasma etched porous support	A solid polymer electrolyte composite membrane and methods of manufacturing the same.	Part of an emerging fuel cell technology project.
7,803,891	09/28/10	Arkema Inc.	Blend of ionic (co)polymer resins and matrix (co)polymers	A novel polymeric resin blend useful for forming durable and chemical-resistant films for fuel cell membranes.	No longer being used.
7,803,493	09/28/10	General Electric Company	Fuel cell system with separating structure bonded to electrolyte	The invention relates to a fuel cell assembly that is sealed in an efficient way to keep the fuel and oxidant paths separated at high operating temperatures.	Being used in continuing research at the company.
7,803,477	09/28/10	ORNL	Metallization of bacterial cellulose for electrical and electronic device manufacture	A method for the deposition of metals in bacterial cellulose and for the employment of the metallized bacterial cellulose in the construction of fuel cells and other electronic devices.	Being used in continuing research at ORNL.
7,794,170	09/14/10	PNNL	Joint with application in electrochemical devices	A hermetic seal forming flexible joint for use in electrochemical devices, such as solid oxide fuel cells (SOFCs), oxygen separators, and hydrogen separators, at operating temperatures of greater than 600°C and other extreme operating conditions. The joint is comprised of metal and ceramic pats and a flexible gasket. The flexible gasket is metal, but is thinner and more flexible than the metal part.	Research Complete; Seeking to License

Fuel Cell Patents Status

Patent Number	Award Date	Organization	Title	Description	Status
7,790,837	09/07/10	Virginia Polytechnic Institute	Ion-conducting sulfonated polymeric materials	Sulfonated polymers that can be formed into membranes that may be used in proton exchange membrane fuel cells.	Licensed to Battelle Memorial Institute.
7,790,314	09/07/10	Virginia Polytechnic Institute	Sulfonated polymer composition for forming fuel cell electrodes	Materials for a fuel cell membrane electrode assembly that are formed from sulfonated polymers.	Licensed to Battelle Memorial Institute.
7,785,454	08/31/10	BASF Corporation	Gas diffusion electrodes, membrane-electrode assemblies and method for the production thereof	The invention relates to the production of an improved gas diffusion electrode for fuel cells. The electrode consists of an electrically conductive web, a non-catalyzed gas diffusion layer, and a noble metal coating.	Part of a commercial fuel cell technology project.
7,781,529	08/24/10	Arkema Inc.	Blend of ionic (co)polymer resins and matrix (co) polymers	A novel polymeric resin blend useful for forming durable and chemical-resistant films for fuel cell membranes.	No longer being used.
7,781,364	08/24/10	LANL	Chalcogen catalysts for polymer electrolyte fuel cell	A cathode catalyst comprising a metal support that includes at least one transition metal and at least one chalcogen, both in elemental form. The catalyst is intended for use in polymer electrolyte membrane fuel cells and direct methanol fuel cells.	Being used in continuing research at LANL.
7,767,616	08/03/10	ANL	Aligned carbon nanotube with electro-catalytic activity for oxygen reduction reaction	A catalyst for an electro-chemical oxygen reduction reaction (ORR) of a bundle of longitudinally aligned carbon nanotubes having a catalytically active transition metal incorporated longitudinally in said nanotubes.	No longer being used in research/ no longer being pursued.
7,767,610	08/03/10	SNL	Metal nanoparticles as a conductive catalyst	A metal nanocluster composite material for use as a conductive catalyst in fuel cell electrodes. The material has noble metal nanoclusters on a carbon substrate formed within a porous zeolitic material.	Being used in continuing research at SNL.
7,763,217	07/27/10	PNNL	Rapid start fuel reforming systems and techniques	An on-board fuel processor includes a microchannel steam reforming reactor and a water vaporizer heated in series with a combustion gas. A rapid cold start can be achieved in under 30 seconds with a manageable amount of electric power consumption, making the device advantageous for use in automotive fuel cell applications.	Research complete; seeking to license.

Fuel Cell Patents Status

Patent Number	Award Date	Organization	Title	Description	Status
7,758,921	07/20/10	ANL	Method of fabricating electrode catalyst layers with directionally oriented carbon support for proton exchange membrane fuel cell	A method of making a membrane electrode assembly (MEA) having an anode and a cathode and a proton conductive membrane there between. A bundle of longitudinally aligned carbon nanotubes with a catalytically active transition metal incorporated in the nanotubes forms at least one portion of the MEA and is in contact with the membrane.	No longer being used in research/ no longer being pursued.
7,758,783	07/20/10	Nanotek Instruments, Inc.	Continious production of exfoliated graphite composite compositions and flow field plates	A process for continuously producing a composite composition that can be used to make fuel cell bipolar plates or flow field plates. The flow field plates have an exceptionally high electrical conductivity in the plate thickness direction.	Part of an emerging fuel cell technology project.
7,737,190	06/15/10	E.I. du Pont de Nemours and Company	Process to prepare stable trifluorostyrene containing compounds grafted to base polymers using a solvent/ water mixture	A process for preparing a fluorinated ion exchange polymer that involves grafting at least one monomer derived from trifluorostyrene onto at least one base polymer in an organic solvent/water mixture. These ion exchange polymers are useful in preparing catalyst coated membranes and membrane electrode assemblies used in fuel cells.	No longer being used.
7,732,084	06/08/10	General Electric Company	Solid oxide fuel cell with internal reforming, catalyzed interconnect for use therewith, and methods	A catalyzed interconnect for placement between an anode and a current collector in a fuel cell. This interconnect improves the efficiency of internal reforming of hydrocarbon fuels in solid oxide fuel cells.	Being used in continuing research at the company.
7,709,135	05/04/10	BASF Corporation	Efficient process for precious metal recovery from cell membrane electrode assemblies	A method is provided for recovering a catalytic element from a fuel cell membrane electrode assembly. The method includes grinding the membrane electrode assembly into a powder, extracting the catalytic element by forming a slurry comprising the powder and an acid leachate adapted to dissolve the catalytic element into a soluble salt, and separating the slurry into a depleted powder and a supernatant containing the catalytic element salt.	Part of an emerging fuel cell technology project.
7,704,919	04/27/10	BNL	Elecrocatalysts having gold monolayers on platinum nanoparticle cores, and uses thereof	Gold-coated particles useful as fuel cell electrocatalyts. The particles are composed of a platinum or platinum alloy core at least partially encapsulated by an outer shell of gold or gold alloy.	Being used in continuing research at BNL and seeking to license.

Fuel Cell Patents Status

Patent Number	Award Date	Organization	Title	Description	Status
7,704,918	04/27/10	BNL	Synthesis of metal-metal oxide catalysts and electrocatalysts using a metal cation adsorption/ reduction and adatom replacement by more noble ones	Platinum-metal oxide composite particles and their use as electrocatalysts in oxygen-reducing cathodes and fuel cells. The invention also relates to methods of making the metal-metal oxide composites.	Being used in continuing research at BNL and seeking to license.
7,699,916	04/20/10	ANL	Corrosion-resistant, electrically-conductive plate for use in a fuel cell stack	A corrosion resistant, electrically-conductive, durable plate at least partially coated with an anchor coating and a corrosion resistant coating. Preferably, the plate is used as a bipolar plate in a proton exchange membrane (PEMFC) fuel cell stack.	Being used in continuing research efforts at ANL.
7,691,780	04/06/10	BNL	Platinum- and platinum alloy-coated palladium and palladium alloy particles and uses thereof	The invention relates to particle and nanoparticle composites useful as oxygen-reduction electrocatalysts. The particle composites are composed of a palladium or palladium-alloy particle or nanoparticle substrate coated with an atomic submonolayer, monolayer, bilayer, or trilayer of zerovalent platinum atoms.	Part of an emerging fuel cell technology project. Non-exclusive license to N.E. Chemcat Corporation.
7,691,770	04/06/10	General Electric Company	Electrode structure and methods of making same	The invention relates to a new electrode structure that improves the performance of solid oxide fuel cells.	Being used in continuing research at the company.
7,659,026	02/09/10	E.I. du Pont de Nemours and Company	Fluorinated Sulfonamide Compounds and Polymer Electrolyte Membranes Prepared Therefrom For Use In Electrochemical Cells	A fluorinated sulfonamide small molecule with an aromatic heterocyclic group, carbon atoms substituted by fluorinated sulfonamide groups and linear or branched perfluoroalkylene groups, optionally containing oxygen, chlorine, bromine, or iodine atoms. These polymers and small molecules are useful in making polymer electrode membranes, membrane electrode assemblies, and electrochemical cells, such as fuel cells.	No longer being used.
7,652,479	01/26/10	Scribner Associates, Inc.	Electrolyte measurement device and measurement procedure	A novel electrode design and measurement system that allows rapid assessment of the through-thickness resistance of bare, non-catalyzed thin electrolytes such as those used in PEM fuel cells.	Part of an emerging fuel cell technology project.

Fuel Cell Patents Status

Patent Number	Award Date	Organization	Title	Description	Status
7,648,784	01/19/10	Delphi Technologies, Inc.	Method and apparatus for controlling a fuel cell system having a variable number of parallel-connected modules	A fuel cell APU system comprising a plurality of fuel cell modules connected in parallel. Each module includes a local controller connected to a master controller that coordinates the modules to achieve a desired power output at any given time. Each module is operated within an output range to maximize efficiency of the system.	Still being used in ongoing research efforts. Part of an emerging fuel cell technology project.
7,635,534	12/22/09	BASF Corporation	Simplified process for leaching precious metals from fuel cell membrane electrode assemblies	An improved process for recovering precious metal catalysts from recycled fuel cell membrane electrode assemblies.	Part of an emerging fuel cell technology project.
7,633,267	12/15/09	Farasis Energy, Inc.	Apparatus for combinatorial screening of electrochemical materials	A high throughput combinatorial screening method and apparatus for the evaluation of electrochemical materials using a single voltage source.	No longer being used.
7,632,601	12/15/09	BNL	Palladium-cobalt particles as oxygen-reduction electrocatalysts	An electrocatalyst is provided for oxygen-reducing cathodes and fuel cells containing palladium-cobalt particles.	Part of an emerging fuel cell technology project.
7,632,595	12/15/09	General Electric Company	Compliant fuel cell system	A fuel cell assembly comprising at least one metallic component, at least one ceramic component, and a structure disposed between the metallic component and the ceramic component. The assembly is designed to withstand strain during thermal cycles.	Being used in continuing research at the company.
7,632,593	12/15/09	ANL	Bipolar plate supported solid oxide fuel cell with a sealed anode compartment	A bipolar plate supported solid oxide fuel cell with a sealed anode compartment. An improved method of sealing is provided by extending the metal seal around the entire perimeter of the cell between an electrolyte and the bipolar plate to form the anode compartment.	No longer being used in research/ no longer being pursued.
7,629,426	12/08/09	Arkema Inc.	Blend of ionic (co)polymer resins and matrix (co) polymers	A novel polymeric resin blend useful for forming durable and chemical-resistant films for fuel cell membranes.	No longer being used.
7,629,285	12/08/09	University of South Carolina	Carbon-based composite electrocatalysts for low temperature fuel cells	A process for synthesis of a low-cost, easily manufactured carbon-based composite catalyst for use in proton exchange membrane (PEM) fuel cells is provided.	Research complete - licensed/ seeking to license.
7,618,915	11/17/09	University of South Carolina	Composite catalysts supported on modified carbon substrates and methods of making the same	A method of producing a low-cost, easily manufactured carbon-based composite catalyst for use in proton exchange membrane (PEM) fuel cells is disclosed.	Research complete - licensed/ seeking to license.

Fuel Cell Patents Status

Patent Number	Award Date	Organization	Title	Description	Status
7,601,216	10/13/09	BASF Corporation	Gas diffusion electrodes, membrane-electrode assemblies and method for the production thereof	The invention relates to the production of an improved gas diffusion electrode for fuel cells. A method for forming a patterned noble metal coating on a gas diffusion medium is provided.	Part of a commercial fuel cell technology project.
7,589,047	09/15/09	LANL	Composite materials and method of making	A method of depositing noble metals on a metal hexaboride support. The method permits the deposition of metallic films of controlled thickness and particle size at room temperature without using separate reducing agents. Composite materials comprising noble metal films deposited on such metal hexaborides may be used as catalysts and electrodes in fuel cells.	Being used in continuing research at LANL.
7,588,857	09/15/09	LANL	Chalcogen catalysts for polymer electolyte fuel cell	A methanol-tolerant cathode catalyst and a membrane electrode assembly for fuel cells that includes such a cathode catalyst. The cathode catalyst includes a support having at least one transition metal in elemental form and a chalcogen disposed on the support. Methods of making the cathode catalyst and membrane electrode assembly are also described.	Research complete; seeking to license.
7,588,849	09/15/09	Delphi Technologies, Inc.	Solid-oxide fuel cell system having tempering of fuel cell stacks by exhaust gas	A fuel cell system which enhances stack performance via heat exchange with exhaust gas and use of a tempering jacket space surrounding the stack.	Part of an emerging fuel cell technology project.
7,575,824	08/18/09	LANL	Method of improving fuel cell performance by removing at least one metal oxide contaminant from a fuel cell electrode	A method of removing contaminants from a fuel cell electrode. The method includes providing a getter electrode and a fuel cell catalyst electrode having at least one contaminant to a bath and applying a voltage sufficient to drive the contaminant from the fuel cell catalyst electrode to the getter electrode.	Being used in continuing research at LANL and seeking to license.
7,572,534	08/11/09	3M Company	Fuel cell membrane electrode assembly	A highly durable fuel cell membrane electrode assembly and methods of manufacturing are provided.	Part of a commercial fuel cell technology project.
7,563,532	07/21/09	E.I. du Pont de Nemours and Company	Trifluorostyrene containing compounds, and their use in polymer electrolyte membranes	A method for preparing a fluorinated ion exchange polymer by grafting a monomer onto a base polymer. These ion exchange polymers are useful in preparing catalyst coated membranes and membrane electrode assemblies for fuel cells.	No longer being used.

Fuel Cell Patents Status

Patent Number	Award Date	Organization	Title	Description	Status
7,562,588	07/21/09	Delphi Technologies, Inc.	Method and apparatus for controlling mass flow rate of recycled anode tail gas in solid oxide fuel cell system	A system for controlling the mass flow rate of anode tail gas being recycled in a solid oxide fuel cell system.	Still being used in ongoing research efforts.
7,550,223	06/23/09	LANL	Method of making metal-polymer composite catalysts	A metal-polymer-carbon composite catalyst for use as a cathode electrocatalyst in fuel cells. The catalyst includes a heteroatomic polymer, a transition metal linked to the heteroatomic polymer by one of nitrogen, sulfur, and phosphorus, and a recast ionomer dispersed throughout the heteroatomic polymer-carbon composite.	Being used in continuing research at LANL.
7,544,764	06/09/09	Virginia Polytechnic Institute	Sulfonated polymer composition for forming fuel cell electrodes	Materials for a fuel cell membrane electrode assembly that are formed from sulfonated polymers.	Licensed to Battelle Memorial Institute.
7,518,886	04/14/09	Virginia Polytechnic Institute	Multiphase soft switched DC/DC converter and active control technique for fuel cell ripple current elimination	A fuel cell having an n-phase transformer isolated phase shift DC/DC converter, a three-phase transformer isolated phase shift DC/DC converter, and/or an active current ripple control.	Research complete; seeking to license.
7,517,604	04/14/09	3M Company	Fuel cell electrolyte membrane with acidic polymer	A fuel cell electrolyte membrane that can be used at high operating temperatures while preserving proton conductivity.	Part of a commercial fuel cell technology project.
7,507,495	03/24/09	BNL	Hydrogen absorption induced metal deposition on palladium and palladium-alloy particles	Methods for producing metal-coated palladium or palladium-alloy particles, and for producing catalysts using the particles.	Being used in continuing research at BNL and seeking to license. Non-exclusive license to N.E. Chemcat Corporation.
7,473,714	01/06/09	Virginia Polytechnic Institute	Materials for use as proton conducting membranes for fuel cells	A family of polymers having pendent sulfonate moieties connected to polymeric main chain phenyl groups. These polymers can be used in proton exchange membranes for fuel cells.	Licensed to Battelle Memorial Institute.
7,456,314	11/25/08	E.I. du Pont de Nemours and Company	Partially fluorinated ionic compounds	Cation-exchange resins that are useful in making proton-exchange membranes for electrochemical cells such as fuel cells.	Still being used in ongoing research efforts.
7,449,111	11/11/08	Arkema Inc.	Resins containing ionic or ionizable groups with small domain sizes and improved conductivity	A polymer that contains at least one acrylic resin or vinyl resin having at least one ionic or ionizable group. The polymer has improved conductivity when formed into a film and can be used in fuel cell membranes.	No longer being used.

Fuel Cell Patents Status

Patent Number	Award Date	Organization	Title	Description	Status
7,419,546	09/02/08	BASF Corporation	Gas diffusion electrodes, membrane-electrode assemblies and method for the production thereof	The invention relates to the production of an improved gas diffusion electrode for fuel cells. A method for forming a noble metal coating on a gas diffusion medium is provided.	Part of a commercial fuel cell technology project.
7,396,880	07/08/08	Arkema Inc.	Blend of ionic (co)polymer resins and matrix (co) polymers	A novel polymeric resin blend useful for forming durable and chemical-resistant films for fuel cell membranes.	No longer being used.
7,373,819	05/20/08	Honeywell International Inc.	Stress sensitive humidity sensor based on a MEMS structure	A humidity sensing apparatus and method include a substrate and a MEMS structure. The MEMS structure comprises a humidity-sensitive material in association with a movable member. Changes in humidity causes movement in the MEMS structure providing an indication of humidity based on a stress within the MEMS structure.	No longer being used.
7,365,121	04/29/08	Virginia Polytechnic Institute	Highly conductive thermoplastic composites for rapid production of fuel cell bipolar plates	A low-cost method of fabricating bipolar plates for use in fuel cells that uses a wet lay process for combining graphite particles, thermoplastic fibers, and reinforcing fibers to produce a plurality of formable sheets.	Research complete; seeking to license.
7,361,729	04/22/08	Virginia Polytechnic Institute	Ion-conducting sulfonated polymeric materials	Sulfonated polymers that can be formed into membranes that may be used in proton exchange membrane fuel cells.	Licensed to Battelle Memorial Institute.
7,323,159	01/29/08	ANL	Method for fast start of a fuel processor	An improved fuel processor for fuel cells is provided whereby the startup time of the processor is less than 60 seconds and can be as low as 30 seconds, if not less.	Not licensed and not being used in research at ANL.
7,270,906	09/18/07	Delphi Technologies, Inc.	Solid-oxide fuel cell module for a fuel cell stack	A novel fuel cell module having four sheet metal parts stamped from flat stock. The parts do not require any forming operations such as folding or dishing, and each part may have a different thickness to suit its function.	Part of an emerging fuel cell technology project.
7,264,778	09/04/07	SNL	Carbon monoxide sensor and method of use	Carbon monoxide sensors suitable for use in hydrogen feed streams and methods of use. The sensors are palladium metal/insulator/semiconductor sensors. The methods and sensors are particularly suitable for use in proton exchange membrane fuel cells.	Not licensed and not being used in research at SNL.

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Patent Number	Award Date	Organization	Title	Description	Status
7,255,798	08/14/07	Ion Power, Inc.	Recycling of used perfluorosulfonic acid membranes	A method for recovering and recycling catalyst-coated fuel cell membranes includes dissolving the used membranes in water and solvent, heating the dissolved membranes under pressure, and separating the components.	Used in Ion Power's emerging technology.
7,247,403	07/24/07	ORNL	Surface modified stainless steels for PEM fuel cell bipolar plates	A nitridation treated stainless steel article (such as a bipolar plate for a proton exchange membrane fuel cell) having lower interfacial contact electrical resistance and better corrosion resistance than an untreated stainless steel article.	Part of an emerging fuel cell technology project.
7,214,442	05/08/07	LANL	High specific power, direct methanol fuel cell stack	A fuel cell stack including at least one direct methanol fuel cell. A cathode manifold is used to convey ambient air to each fuel cell, and an anode manifold is used to convey liquid methanol fuel to each fuel cell.	Being used in continuing research at LANL.
7,211,346	05/01/07	ORNL	Corrosion-resistant metallic bipolar plate	An electrically conductive component such as a bipolar plate for a PEM fuel cell. The component has a substantially external, continuous layer of chromium nitride.	Part of an emerging fuel cell technology project.
7,195,835	03/27/07	ANL	Proton conducting membrane for fuel cells	An ion conducting membrane comprising dendrimeric polymers covalently linked into a network structure.	No licensee and no further development of this technology at ANL.
7,138,199	11/21/06	Dynalene, Inc.	Fuel cell and fuel cell coolant compositions	Directed to coolant compositions, particularly coolant compositions useful in fuel cells, and to fuel cells containing such coolant compositions.	Part of a commercial fuel cell technology project.
7,135,537	11/14/06	E.I. du Pont de Nemours and Company	Sulfonimide-containing poly(arylene ether)s and poly(arylene ether sulfone) s, methods for producing the same, and their uses	Directed to sulfonimide-containing polymers, for use in conductive membranes and fuel cells.	No longer being used.
7,101,643	09/05/06	LBNL	Polymeric electrolytes based on hydrosilyation reactions	New polymer electrolytes that are prepared by in situ cross-linking of allyl functional polymers based on a hydrosilation reaction using a multifunctional silane cross-linker and an organoplatinum catalyst. The electrolyte membranes are insoluable in organic solvents and have high mechanical strength.	Being used in research at LBNL and seeking to license.
7,101,635	09/05/06	LANL	Methanol-tolerant cathode catalyst composite for direct methanol fuel cells	A direct methanol fuel cell having a methanol fuel supply, oxidant supply, and its membrane electrode assembly.	Not licensed and not being used at LANL for research.

Fuel Cell Patents Status

Patent Number	Award Date	Organization	Title	Description	Status
7,101,527	09/05/06	Iowa State University	Mixed anion materials and compounds for novel proton conducting membranes	The present invention provides new amorphous or partially crystalline mixed anion chalcogenide compounds for use in proton exchange membranes which are able to operate over a wide variety of temperature ranges, including in the intermediate temperature range of about 100 ° C. to 300° C., and new uses for crystalline mixed anion chalcogenide compounds in such proton exchange membranes.	Being used in research at Iowa State University and seeking to license.
7,052,793	05/30/06	Foster-Miller, Inc.	Composite solid polymer electrolyte membranes	The invention relates to composite solid polymer electrolyte membranes (SPEMs), which include a porous polymer substrate interpenetrated with an ion-conducting material. These SPEMs are useful in electrochemical applications, including fuel cells and electrodialysis.	Being used in continuing research at the company.
7,022,810	04/04/06	SNL	Proton exchange membrane materials for the advancement of direct methanol fuel-cell technology	A new class of hybrid organic-inorganic materials, and methods of synthesis, which can be used as a proton exchange membrane in a direct methanol fuel cell.	Not licensed and not being used in research at SNL.
7,018,604	03/28/06	Iowa State University	Compounds for novel proton conducting membranes and methods of making same	A new set of compounds for use in polymer electrolyte membranes which are able to operate in a wide variety of temperature ranges, including in the intermediate temperature range of about 100°C to 700°C.	Being used in research at Iowa State University and seeking to license.
7,014,931	03/21/06	LANL	Methanol-tolerant cathode catalyst composite for direct methanol fuel cells	A direct methanol fuel cell having a methanol fuel supply, oxidant supply, and its membrane electrode assembly.	Not licensed and not being used at LANL for research.
6,995,114	02/07/06	Symyx Technologies, Inc.	Platinum-ruthenium-palladium fuel cell electrocatalyst	A catalyst for use in electrochemical reactor devices, the catalyst containing platinum, ruthenium, and palladium.	Not licensed and no research being done with this patent.
6,994,829	02/07/06	PNNL	Fluid processing device and method	A fluid processing unit having first and second interleaved flow paths in a cross flow configuration. The device can be used for vaporization of water, gasoline, and other fluids, and is useful for automotive fuel cell applications requiring rapid startup.	Research complete; seeking to license.
6,986,963	01/17/06	ORNL	Metallization of bacterial cellulose for electrical and electronic device manufacture	Metallized bacterial cellulose used in constructing fuel cells and other electronic devices.	No commercialization and no further development being pursued using this patent.

Fuel Cell Patents Status

Patent Number	Award Date	Organization	Title	Description	Status
6,986,961	01/17/06	LANL	Fuel cell stack with passive air supply	A fuel cell stack comprised of a plurality of polymer electrolyte fuel cells.	Not licensed and not being used at LANL for research.
6,977,122	12/20/05	ANL	Proton conducting membrane for fuel cells	An ion conducting membrane comprising dendrimeric polymers covalently linked into a network structure.	No licensee and no further development of this technology at ANL.
6,962,760	11/08/05	LANL	Methods of conditioning direct methanol fuel cells	Methods for conditioning the membrane electrode assembly of a direct methanol fuel cell.	Not licensed and not being used at LANL for research.
6,960,235	11/01/05	LLNL	Chemical microreactor and method thereof	A chemical microreactor suitable for generation of hydrogen fuel from liquid sources such as ammonia, methanol, and butane through steam reforming processes when mixed with an appropriate amount of water contains capillary microchannels with integrated resistive heaters to facilitate the occurrence of catalytic steam reforming reactions.	Licensed to Bren-Tronics, Inc.; part of a commercial fuel cell technology project.
6,956,083	10/18/05	LBNL	Single ion conductor cross-linked polymeric networks	The invention relates to the synthesis, characterization, and electrochemical response of a new type of single-ion comb-branch polymer electrolyte that can be used as a proton exchange membrane in fuel cells.	Being used in research at LBNL and seeking to license.
6,926,986	08/09/05	Energy Conversion Devices, Inc.	Fuel cell with encapsulated electrodes	A fuel cell utilizing parallel flow of a hydrogen stream, an oxygen stream, and an electrolyte solution with respect to the electrodes, while maintaining mechanical support within the fuel cell. The fuel cell utilizes encapsulated electrodes to maintain a high air flow rate and low pressure throughout the fuel cell.	No longer being used.
6,921,605	07/26/05	Symyx Technologies, Inc.	Platinum-ruthenium-nickel fuel cell electrocatalyst	A catalyst suitable for use in a fuel cell, especially as an anode catalyst, that contains platinum, ruthenium, and nickel.	Not licensed and no research being done with this patent.
6,921,595	07/26/05	Nuvera Fuel Cells, Inc.	Joint-cycle high-efficiency fuel cell system with power generating turbine	Process for increasing the efficiency of a system comprising a fuel reformer coupled to a fuel cell. Pressurized air and heat generated by the fuel cell are used to make a pressurized air/steam mixture. The air/steam mixture is then fed as an oxidant into a fuel burner; producing a steam-containing exhaust having an expansion potential from the fuel burner; driving an expander using the expansion potential of the steam-containing exhaust; and recovering mechanical energy from the expander in excess of the energy used in compressing the pressurized air.	No longer being used in research/ no longer being pursued.

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Patent Number	Award Date	Organization	Title	Description	Status
6,916,564	07/12/05	Nuvera Fuel Cells, Inc.	High-efficiency fuel cell power system with power generating expander	A hydrogen fuel cell power system with improved efficiency comprising of a fuel cell, hydrogen gas source, compressor for creating a pressurized air stream, and a liquid supply which is heated by waste heat form the power system to produce a pressurized air and steam mixture. The pressurized air/steam mixture, which is preferably used as the oxidant in the fuel cell, is combusted with fuel in a burner to produce a high-temperature steam-laden exhaust stream. The high-temperature steam-laden exhaust stream drives an expander to produce a power output, and a power take-off from the expander uses the expander power to, for instance, drive an electrical generator, or drive other system components.	No longer being used in research/ no longer being pursued.
6,864,004	03/08/05	LANL	Direct methanol fuel cell stack	A stack of direct methanol fuel cells exhibiting a circular footprint.	Not licensed and not being used at LANL for research.
6,861,169	03/01/05	Nuvera Fuel Cells, Inc.	Cogeneration of power and heat by an integrated fuel cell power system	Methods and apparatus for the cogeneration of power and heat from a fuel cell stack and an associated fuel processor assembly (i.e., a fuel reforming system) to provide both electricity and heating for a particular site, such as a building or a group of buildings.	No longer being used in research/ no longer being pursued.
6,847,188	01/25/05	General Motors Corporation	Fuel cell stack monitoring and system control	A control method for monitoring a fuel cell stack in a fuel cell system in which the actual voltage and actual current from the fuel cell stack are monitored.	Being used in continuing research at the company.
6,828,057	12/07/04	Energy Conversion Devices, Inc.	Fuel cell with framed electrodes	A fuel cell utilizing parallel flow of a hydrogen stream, an oxygen stream, and an electrolyte solution with respect to the electrodes, while maintaining mechanical support within the fuel cell. The fuel cell utilizes framed electrodes to maintain a high air flow rate and low pressure throughout the fuel cell.	Being used in ongoing research as part of Tactical Fuel Cells at Energy Technologies, Inc.
6,818,341	11/16/04	LANL	Fuel cell anode configuration for CO tolerance	A polymer electrolyte fuel cell (PEFC) is designed to operate on a reformate fuel stream containing oxygen and diluted hydrogen fuel with CO impurities.	Being used in research at LANL but no licensees.
6,808,838	10/26/04	LANL	Direct methanol fuel cell and system	A fuel cell having an anode and a cathode and a polymer electrolyte membrane located between anode and cathode gas diffusion backings uses a methanol vapor fuel supply.	Not licensed and not being used at LANL for research.

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Patent Number	Award Date	Organization	Title	Description	Status
6,790,548	09/14/04	General Motors Corporation	Staged venting of fuel cell system during rapid shutdown	A venting methodology and system for rapid shutdown of a fuel cell apparatus used in a vehicle propulsion system.	Being used in continuing research at the company.
6,723,678	04/20/04	Symyx Technologies, Inc.	Platinum-ruthenium-nickel alloy for use as a fuel cell catalyst	An improved noble metal alloy composition for a fuel cell catalyst, the alloy containing platinum, ruthenium, and nickel. The alloy shows methanol oxidation activity.	Not licensed and no research being done with this patent.
6,696,382	02/24/04	LANL	Catalyst inks and method of application for direct methanol fuel cells	Inks are formulated for forming anode and cathode catalyst layers and applied to anode and cathode sides of a membrane for a direct methanol fuel cell.	Not licensed and not being used at LANL for research.
6,692,851	02/17/04	General Motors Corporation	Fuel cell stack monitoring and system control	A control method for monitoring the voltage and current from a fuel cell stack.	Being used in continuing research at the company.
6,686,084	02/03/04	Hybrid Power Generation Systems, LLC	Gas block mechanism for water removal in fuel cells	An apparatus and method for removing water from the cathode side of a fuel cell.	No longer being used.
6,682,837	01/27/04	Symyx Technologies, Inc.	Method for producing electricity using a platinum-ruthenium-palladium catalyst in a fuel cell	A method for producing electricity using a fuel cell that utilizes a ternary alloy composition as a fuel cell catalyst, the ternary alloy composition containing platinum, ruthenium, and palladium.	Not licensed and no research being done with this patent.
6,670,305	12/30/03	ANL	Free-standing monolithic catalyst with micro-scale channel dimensions	A monolithic catalyst with micro-scale flow channels and methods of making such a monolithic catalyst.	No longer being used in research/ no longer being pursued.
6,670,301	12/30/03	BNL	Carbon monoxide tolerant electrocatalyst with low platinum loading and a process for its preparation	An electrocatalyst is provided for use in a fuel cell that has low platinum loading and a high tolerance to carbon monoxide poisoning.	Part of an emerging fuel cell technology project.
6,653,005	11/25/03	University of Central Florida	Portable hydrogen generator-fuel cell apparatus	A compact hydrogen generator is coupled to or integrated with a fuel cell for portable power applications.	Being used in research at University of Central Florida but no licensees.
6,635,369	10/21/03	LANL	Method for improving fuel cell performance	A method is provided for operating a fuel cell at high voltage for sustained periods of time.	Being used in research at LANL but no licensees.
6,617,065	09/09/03	Teledyne Energy Systems, Inc.	Method and apparatus for maintaining neutral water balance in a fuel cell system	A method for maintaining a neutral water balance in a fuel cell system, wherein water from the exhaust of a fuel cell stack is recycled for use in the system's humidifiers and other components. The water balance is maintained by adjusting the fuel cell stack operating temperature based on the water level in the system's water reservoir.	No longer being used.

Fuel Cell Patents Status

Patent Number	Award Date	Organization	Title	Description	Status
6,607,854	08/19/03	Honeywell International Inc.	Three-wheel air turbocompressor for PEM fuel cell systems	A fuel cell system that utilizes a pair of parallel turbines engaged to a compressor for increased system efficiency.	No longer being used.
6,602,624	08/05/03	General Motors Corporation	Control apparatus and method for efficiently heating a fuel processor in a fuel cell system	An apparatus and method for efficiently controlling the amount of heat generated by a fuel processor in a fuel cell system. A temperature error between actual and desired fuel processor temperatures is determined; this error is converted to a combustor fuel injector command signal or a heat dump valve position command signal depending upon the type of error.	Being used in continuing research at the company.
6,596,422	07/22/03	LANL	Air breathing direct methanol fuel cell	A method for activating a membrane electrode assembly for a direct methanol fuel cell is disclosed. The method comprises operating the fuel cell with humidified hydrogen as the fuel followed by running the fuel cell with methanol as the fuel.	Not licensed and not being used at LANL for research.
6,576,359	06/10/03	General Motors Corporation	Controlled air injection for a fuel cell system	A method and apparatus for injecting oxygen into a fuel cell reformate stream to reduce the level of carbon monoxide while preserving the level of hydrogen in a fuel cell system.	Being used in continuing research at the company.
6,551,736	04/22/03	Teledyne Energy Systems, Inc.	Fuel cell collector plates with improved mass transfer channels	Fuel cell collector plates with new channel constructions for improving the transportation of gases to the cell's gas diffusion layers.	Research complete; seeking to license.
6,528,198	03/04/03	Plug Power, Inc.	Fuel cell membrane hydration and fluid metering	A hydration system includes fuel cell fluid flow plate(s) and injection port(s).	No longer being used.
6,517,965	02/11/03	Symyx Technologies, Inc.	Platinum-ruthenium-nickel alloy for use as a fuel cell catalyst	An improved noble metal alloy composition for a fuel cell catalyst, the alloy containing platinum, ruthenium, and nickel. The alloy shows methanol oxidation activity.	Not licensed and no research being done with this patent.
6,498,121	12/24/02	Symyx Technologies, Inc.	Platinum-ruthenium-palladium alloys for use as a fuel cell catalyst	A noble metal alloy composition for a fuel cell catalyst, a ternary alloy composition containing platinum, ruthenium and palladium. The alloy shows increased activity compared with well-known catalysts.	Not licensed and no research being done with this patent.
6,497,970	12/24/02	General Motors Corporation	Controlled air injection for a fuel cell system	A method and apparatus for injecting oxygen into a fuel cell reformate stream to reduce the level of carbon monoxide while preserving the level of hydrogen in a fuel cell system.	Being used in continuing research at the company.

Fuel Cell Patents Status

Patent Number	Award Date	Organization	Title	Description	Status
6,492,052	12/10/02	LANL	Air breathing direct methanol fuel cell	An air breathing direct methanol fuel cell is provided with a membrane electrode assembly, a conductive anode assembly that is permeable to air and directly open to atmospheric air, and a conductive cathode assembly that is permeable to methanol and directly contacting a liquid methanol source.	Not licensed and not being used at LANL for research.
6,490,812	12/10/02	PNNL	Active microchannel fluid processing unit and method of making	An active microchannel fluid processing unit.	Exclusive license to Velocys, Inc.
6,458,479	10/01/02	LANL	Air breathing direct methanol fuel cell	An air breathing direct methanol fuel cell is provided with a membrane electrode assembly, a conductive anode assembly that is permeable to air and directly open to atmospheric air, and a conductive cathode assembly that is permeable to methanol and directly contacting a liquid methanol source.	Not licensed and not being used at LANL for research.
6,455,180	09/24/02	General Motors Corporation	Flexible method for monitoring fuel cell voltage	A method for monitoring the voltage of different groups of cells (a.k.a., "clusters") within a fuel cell stack, wherein the number of cells in a cluster can be varied. The method improves fuel cell stack diagnostic monitoring by enabling identification of individual cells within the stack that are contributing to a voltage drop across the entire stack.	Being used in continuing research at the company.
6,454,922	09/24/02	LANL	Corrosion test cell for bipolar plates	A corrosion test cell for evaluating corrosion resistance in fuel cell bipolar plates.	Exclusive license to Fuel Cell Technologies, Inc. - Commercial
6,451,471	09/17/02	Teledyne Energy Systems, Inc.	Conductivity fuel cell collector plate and method of fabrication	An improved method of manufacturing PEM fuel cell collector plates that increases the electrical conductivity and mechanical strength of the plates.	Research complete; seeking to license.
6,451,465	09/17/02	General Motors Corporation	Method for operating a combustor in a fuel cell system	A method of operating a combustor to heat a fuel processor in a fuel cell system, in which the fuel processor includes a reactor which generates a hydrogen containing stream.	No longer being pursued, abandoned.
6,436,561	08/20/02	General Motors Corporation	Methanol tailgas combustor control method	A method for controlling the power, temperature, and fuel source of a combustor used to supply heat to a fuel reformer used for generating hydrogen from liquid fuels (e.g., methanol) in on-board automotive applications.	Being used in continuing research at the company.

Fuel Cell Patents Status

Patent Number	Award Date	Organization	Title	Description	Status
6,416,893	07/09/02	General Motors Corporation	Method and apparatus for controlling combustor temperature during transient load changes	A method and apparatus for controlling the temperature of a combustor in an automotive fuel cell system. The method includes a fast acting air bypass valve connected in parallel with an air inlet to the combustor.	Being used in continuing research at the company.
6,413,662	07/02/02	General Motors Corporation	Fuel cell system shutdown with anode pressure control	A venting methodology and pressure sensing and vent valving arrangement for monitoring anode bypass valve operating during the normal shutdown of a fuel cell apparatus of the type used in vehicle propulsion systems.	Being used in continuing research at the company.
6,413,661	07/02/02	General Motors Corporation	Method for operating a combustor in a fuel cell system	A method of operating a combustor to heat a fuel processor to a desired temperature in a fuel cell system, wherein the fuel processor generates hydrogen from a hydrocarbon for reaction within a fuel cell to generate electricity.	No longer being pursued, abandoned.
6,395,414	05/28/02	General Motors Corporation	Staged venting of fuel cell system during rapid shutdown	A venting methodology and system for rapid shutdown of a fuel cell apparatus of the type used in a vehicle propulsion system.	Being used in continuing research at the company.
6,376,112	04/23/02	General Motors Corporation	Controlled shutdown of a fuel cell	A method is provided for the shutdown of a fuel cell system to relieve system overpressure while maintaining air compressor operation, and corresponding vent valving and control arrangement. The method and venting arrangement can be employed in a fuel cell system used for vehicle propulsion.	Being used in continuing research at the company.
6,372,376	04/16/02	General Motors Corporation	Corrosion resistant PEM fuel cell	A PEM fuel cell having electrical contact elements comprising a corrosion-susceptible substrate metal coated with an electrically conductive, corrosion-resistant polymer.	Being used in continuing research at the company.
6,306,531	10/23/01	General Motors Corporation	Combustor air flow control method for fuel cell apparatus	A method for controlling the heat output of a combustor used to provide heat to a fuel reformer in a fuel cell apparatus.	Being used in continuing research at the company.
6,296,964	10/02/01	LANL	Enhanced methanol utilization in direct methanol fuel cell	The fuel utilization of a direct methanol fuel cell is enhanced for improved cell efficiency.	Not licensed and not being used at LANL for research.
6,277,513	08/21/01	General Motors Corporation	Layered electrode for electrochemical cells	A fuel cell electrode structure consisting of a current collector sheet and first and second layers of electrode material. The electrode design improves catalyst utilization and water management.	Being used in continuing research at the company.

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Patent Number	Award Date	Organization	Title	Description	Status
6,268,074	07/31/01	General Motors Corporation	Water injected fuel cell system compressor	A fuel cell system that uses a dry compressor for pressurizing air supplied to the cathode side of the fuel cell. An injector sprays a controlled amount of water onto the compressor's rotor(s) to improve the energy efficiency of the compressor.	Being used in continuing research at the company.
6,265,222	07/24/01	Advanced Technology Materials, Inc.	Micro-machined thin film hydrogen gas sensor and method of making and using the sensor	A hydrogen sensor including a thin film sensor element formed, e.g., by metalorganic chemical vapor deposition or physical vapor deposition, on a microhotplate structure.	Patent sold to Honeywell but no further R&D being done with the patent at this time.
6,265,092	07/24/01	General Motors Corporation	Method of controlling injection of oxygen into hydrogen-rich fuel cell feed stream	A method of operating a H_2 - O_2 fuel cell fueled by hydrogen-rich fuel stream containing CO. The CO content is reduced to acceptable levels by injecting oxygen into the fuel gas stream.	Being used in continuing research at the company.
6,255,012	07/03/01	LANL	Pleated metal bipolar assembly	Bipolar plates for electrochemical cells are formed from conductive foils that are supported by a polymer support plate. The polymer support plate can be readily configured with flow fields during a manufacturing process, such as injection molding, without the need for machining. Likewise, the conductive foils can be stamped or corrugated to matching configurations without any need for machining. The resulting structure is inexpensive to form and is compact and lightweight.	Being used in continuing research at LANL.
6,248,469	06/19/01	Foster-Miller, Inc.	Composite solid polymer electrolyte membranes	The invention relates to composite solid polymer electrolyte membranes (SPEMs), which include a porous polymer substrate interpenetrated with an ion-conducting material. These SPEMs are useful in electrochemical applications, including fuel cells and electrodialysis.	Being used in continuing research at the company.
6,248,467	06/19/01	LANL	Composite bipolar plate for electrochemical cells	A bipolar separator plate for fuel cells consists of a molded mixture of a vinyl ester resin and graphite powder.	Exclusive license to BMCI - Commercial
6,232,005	05/15/01	General Motors Corporation	Fuel cell system combustor	A fuel cell system including a fuel reformer heated by a catalytic combustor fired by anode and cathode effluents.	No longer being pursued, abandoned.

Fuel Cell Patents Status

Patent Number	Award Date	Organization	Title	Description	Status
6,207,312	03/27/01	Energy Partners, LC	Self-humidifying fuel cell	A self-humidifying polymer electrolyte membrane (PEM) fuel cell assembly that has an ion-exchange membrane interposed between hydrogen and oxygen diffusion layers to form a membrane electrode assembly (MEA).	No longer being used.
6,207,310	03/27/01	LANL	Fuel cell with metal screen flow-field	A polymer electrolyte membrane fuel cell is provided with electrodes supplied with a reactant on each side of a catalyzed membrane assembly.	Not licensed and not being used at LANL for research.
6,200,536	03/13/01	PNNL	Active microchannel heat exchanger	An active microchannel heat exchanger with an active heat source and with microchannel architecture. The invention is particularly useful as a liquid fuel vaporizer and/or a steam generator for fuel cell power systems.	Exclusive license to Velocys, Inc.
6,192,596	02/27/01	PNNL	Active microchannel fluid processing unit and method of making	An active microchannel fluid processing unit.	Exclusive license to Velocys, Inc., and in pilot testing now.
6,183,894	02/06/01	BNL	Electrocatalyst for alcohol oxidation in fuel cells	Binary and ternary electrocatalysts are provided for oxidizing alcohol in a fuel cell.	Not licensed or commercialized. Research is on-going.
6,180,275	01/30/01	Energy Partners, LC	Fuel cell collector plate and method of fabrication	An improved molding composition is provided for compression molding or injection molding a current collector plate for a polymer electrolyte membrane fuel cell.	No longer being used in research.
6,171,720	01/09/01	ORNL	Bipolar plate/diffuser for a proton exchange membrane fuel cell	A combination bipolar plate/diffuser fuel cell component that includes an electrically conducting solid material having a porous region and a hermetic region.	Being used in commercially available bipolar plates sold by Porvair Advanced Materials, Inc.
6,159,626	12/12/00	General Motors Corporation	Fuel cell system logic for differentiating between rapid and normal shutdown commands	A method of controlling the operation of a fuel cell system wherein each shutdown command for the system is subjected to decision logic which determines whether the command should be a normal shutdown command or rapid shutdown command.	Being used in continuing research at the company.
6,159,533	12/12/00	Southwest Research Institute	Method of depositing a catalyst on a fuel cell electrode	Fuel cell electrodes comprising a minimal load of catalyst having maximum catalytic activity and a method of forming such fuel cell electrodes.	No licensee and no research being done with this technology.
6,129,973	10/10/00	PNNL	Microchannel laminated mass exchanger and method of making	A microchannel mass exchanger having a first plurality of inner thin sheets and a second plurality of outer thin sheets is described. The device enables solute molecules in a solvent to pass from the solvent to a mass transfer medium in an efficient manner.	Exclusive license to Velocys, Inc.

Fuel Cell Patents Status

Patent Number	Award Date	Organization	Title	Description	Status
6,126,723	10/03/00	PNNL	Microcomponent assembly for efficient contacting of fluid	Method and apparatus for a microcomponent assembly that achieves state-of-the-art chemical separation via absorption and/or adsorption mechanisms. The device can be utilized as a fuel processing system in fuel-cell-powered automobiles for removal of catalyst poisons (e.g., H_2S and CO) from the fuel stream.	Exclusive license to Velocys, Inc.
6,117,577	09/12/00	LANL	Ambient pressure fuel cell system	An ambient pressure fuel cell system is provided with a fuel cell stack formed from a plurality of fuel cells having membrane/electrode assemblies.	Non-exclusive license to IdaTech - Not being used.
6,103,409	08/15/00	General Motors Corporation	Fuel cell flooding detection and correction	A method and apparatus for monitoring PEM fuel cells to detect and correct flooding.	Being used in continuing research at the company.
6,099,984	08/08/00	General Motors Corporation	Mirrored serpentine flow channels for fuel cell	A PEM fuel cell having serpentine flow field channels, wherein the input/inlet legs of each channel border the input/inlet legs of the next adjacent channels in the same flow field.	Being used in continuing research at the company.
6,077,620	06/20/00	General Motors Corporation	Fuel cell system with combustor-heated reformer	A fuel cell system including a fuel reformer heated by a catalytic combustor fired by anode effluent and/or fuel from a liquid fuel supply providing fuel for the fuel cell.	No longer being pursued, abandoned.
6,074,692	06/13/00	General Motors Corporation	Method of making MEA for PEM/SPE fuel cell	A method of making a membrane-electrode-assembly (MEA) for a PEM/SPE fuel cell by applying a slurry of electrode-forming material directly onto a membrane-electrolyte film.	Being used in continuing research at the company.
6,066,408	05/23/00	Plug Power, LLC	Fuel cell cooler-humidifier plate	A cooler-humidifier plate for use in a proton exchange membrane fuel cell stack assembly. The cooler-humidifier plate combines functions of cooling and humidification within the fuel cell stack assembly, thereby providing a more compact structure, simpler manifolding, and reduced reject heat from the fuel cell.	No longer being used.
6,063,516	05/16/00	General Motors Corporation	Method of monitoring CO concentrations in hydrogen feed to a PEM fuel cell	The CO concentration in the H_2 feed stream to a PEM fuel cell stack is monitored by measuring current and/or voltage behavior patterns from a PEM-probe communicating with the reformate feed stream.	Being used in continuing research at the company.
6,017,648	01/25/00	Plug Power, LLC	Insertable fluid flow passage bridgepiece and method	A fluid flow passage bridgepiece for insertion into an open-face fluid flow channel of a fluid flow plate.	No longer being used.
6,007,933	12/28/99	Plug Power, LLC	Fuel cell assembly unit for promoting fluid service and electrical conductivity	Fluid service and/or electrical conductivity for a fuel cell assembly.	Still being used in research.

Fuel Cell Patents Status

Patent Number	Award Date	Organization	Title	Description	Status
6,001,499	12/14/99	General Motors Corporation	Fuel cell CO sensor	The CO concentration in the H_2 feed stream to a PEM fuel cell stack is monitored by measuring current and/or voltage behavior patterns from a PEM-probe communicating with the reformate feed stream.	Being used in continuing research at the company.
5,998,054	12/07/99	Plug Power, LLC	Fuel cell membrane hydration and fluid metering	A hydration system including fuel cell fluid flow plate(s) and injection port(s). Each plate has flow channel(s) with respective inlet(s) for receiving portion(s) of a reactant fluid for a fuel cell. Each injection port injects a portion of liquid water directly into its respective flow channel to mix its portion of liquid water with a portion of the stream.	No longer being used.
5,952,119	09/14/99	LANL	Fuel cell membrane humidification	A method for supplying liquid water to the polymer electrolyte membrane of a fuel cell using distribution channels over the gas diffusion backing. This simple membrane humidification system uniformly distributes water to the membrane surface thus improving the performance of the fuel cell.	Non-exclusive license to IdaTech - Not being used.
5,945,229	08/31/99	General Motors Corporation	Pattern recognition monitoring of PEM fuel cell	The CO-concentration in the H_2 feed stream to a PEM fuel cell stack is monitored by measuring current and voltage behavior patterns from an auxiliary cell attached to the end of the stack.	Being used in continuing research at the company.
5,932,185	08/03/99	LLNL	Method for making thin carbon foam electrodes	A method for fabricating thin, flat carbon electrodes by infiltrating highly porous carbon papers, membranes, felts, metal fibers/powders, or fabrics with an appropriate carbon foam precursor material.	No licenses and no research being done with this patent.
5,916,710	06/29/99	LBNL	Sodium cobalt bronze batteries and a method for making same	A solid state secondary battery utilizing a low cost, environmentally sound, sodium cobalt bronze electrode.	No longer being used.
5,798,187	08/25/98	LANL	Fuel cell with metal screen flow-field	A polymer electrolyte membrane fuel cell is provided with electrodes supplied with a reactant on each side of a catalyzed membrane assembly.	Not licensed and not being used at LANL for research.
5,783,152	07/21/98	SRNL	Thin-film fiber optic hydrogen and temperature sensor system	A sensor probe device for monitoring of hydrogen gas concentrations and temperatures.	No longer being used in research; returned to DOE.

Fuel Cell Patents Status

Patent Number	Award Date	Organization	Title	Description	Status
5,776,624	07/07/98	General Motors Corporation	Brazed bipolar plates for PEM fuel cells	A liquid-cooled, bipolar plate separating adjacent cells of a PEM fuel cell comprising corrosion-resistant metal sheets brazed together so as to provide a passage between the sheets through which a dielectric coolant flows.	Being used in continuing research at the company.
5,763,113	06/09/98	General Motors Corporation	PEM fuel cell monitoring system	A method and apparatus for monitoring the performance of PEM fuel cells. Outputs from a cell/stack voltage monitor and a cathode exhaust gas hydrogen sensor are corrected for stack operating conditions, and then compared to predetermined levels of acceptability.	Being used in continuing research at the company.
5,743,646	04/28/98	General Motors Corporation	Temperature sensor with improved thermal barrier and gas seal between the probe and housing	An improved temperature sensor that can be used to measure gas temperature in automotive exhaust systems or in fuel cell subsystems used to generate electric power.	Being used in continuing research at the company.
5,707,755	01/13/98	General Motors Corporation	PEM/SPE fuel cell	A PEM/SPE fuel cell including a membrane-electrode assembly (MEA) having a plurality of oriented filament embedded the face thereof for supporting the MEA and conducting current therefrom to contiguous electrode plates.	Being used in continuing research at the company.
5,654,109	08/05/97	General Motors Corporation	Composite fuel cell membranes	A bilayer or trilayer composite ion exchange membrane suitable for use in a fuel cell. The composite membrane has a high equivalent weight thick layer in order to provide sufficient strength and low equivalent weight surface layers for improved electrical performance.	Being used in continuing research at the company.
5,641,586	06/24/97	LANL	Fuel cell with interdigitated porous flow-field	A polymer electrolyte membrane fuel cell is formed with an improved system for distributing gaseous reactants to the membrane surface.	Not licensed and not being used at LANL for research.
5,636,437	06/10/97	LLNL	Fabricating solid carbon porous electrodes from powders	Fabrication of conductive solid porous carbon electrodes for use in batteries, double layer capacitors, fuel cells, capacitive deionization, and waste treatment.	No licenses and no research being done with this patent.
5,624,769	04/29/97	General Motors Corporation	Corrosion resistant PEM fuel cell	A PEM fuel cell having electrical contact elements (e.g., bipolar plates) that consist of a titanium-nitride-coated, lightweight metal core, with a passivating, protective metal layer between the core and the titanium nitride.	Being used in continuing research at the company.
5,601,938	02/11/97	LLNL	Carbon aerogel electrodes for direct energy conversion	A direct energy conversion device, such as a fuel cell, using carbon aerogel electrodes, wherein the carbon aerogel is loaded with a noble catalyst, such as platinum or rhodium and soaked with phosphoric acid.	No licenses and no research being done with this patent.

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Patent Number	Award Date	Organization	Title	Description	Status
5,558,961	09/24/96	LBNL	Secondary cell with orthorhombic alkali metal/ manganese oxide phase active cathode material	An alkali metal manganese oxide secondary cell that can provide a high rate of discharge, good cycling capabilities, good stability of the cathode material, high specific energy (energy per unit of weight) and high energy density (energy per unit volume).	No longer being used.
5,443,601	08/22/95	LBNL	Method for intercalating alkali metal ions into carbon electrodes	A low cost, relatively flexible, carbon electrode for use in a secondary battery. Methods for producing the electrode are also provided, including intercalating alkali metal salts such as sodium and lithium into carbon.	No longer being used.
5,316,871	05/31/94	General Motors Corporation	Method of making membrane-electrode assemblies for electrochemical cells and assemblies made thereby	A method of making a combination, unitary, membrane and electrode assembly having a solid polymer electrolyte membrane, and first and second electrodes at least partially embedded in opposed surfaces of the membrane.	Being used in continuing research at the company.
5,248,566	09/28/93	ANL	Fuel cell system for transportation applications	A propulsion system for a vehicle having pairs of front and rear wheels and a fuel tank.	Not licensed but being used in research at ANL.
4,657,829	04/14/87	United Technologies Corporation	Fuel cell power supply with oxidant and fuel gas switching	Relating to a fuel cell vehicular power plant, fuel for the fuel stack is supplied by a hydrocarbon (methanol) catalytic cracking reactor and CO shift reactor.	Patent has expired and not used by UTC in commercial products.
4,650,727	03/17/87	LANL	Fuel processor for fuel cell power system	A catalytic organic fuel processing apparatus, which can be used in a fuel cell power system, contains within a housing ca catalyst chamber, a variable speed fan, and a combustion chamber.	Not licensed and not being used for research at LANL.

Production/Delivery Patents Status

Patent Number	Award Date	Organization	Title	Description	Status
8,492,595	07/23/13	Virent Energy Systems, Inc.	Methods and systems for generating polyols	Methods for generating propylene glycol, ethylene glycol and other polyols, diols, ketones, aldehydes, carboxylic acids and alcohols using hydrogen produced from biomass.	Being used in continuing research at the company; non-exclusive license to Equilon Enterprises, LLC (d.b.a. Shell Oil Products U.S.).
8,455,382	06/04/13	Air Products & Chemicals, Inc.	Fabrication of catalyzed ion transport membrane systems	A process for fabricating a catalyzed ion transport membrane having essentially constant oxygen stoichiometry and no anion mobility.	Still being used in ongoing research efforts.
8,410,183	04/02/13	Virent Energy Systems, Inc.	Method for producing bio-fuel that integrates heat from carbon-carbon bond-forming reactions to drive biomass gasification reactions	A low-temperature catalytic process for converting biomass (preferably glycerol recovered from the fabrication of bio-diesel) to synthesis gas (i.e., H_2/CO gas mixture) in an endothermic gasification reaction.	Being used in continuing research at the company; non-exclusive license to Equilon Enterprises, LLC (d.b.a. Shell Oil Products U.S.).
8,397,508	03/19/13	University of Colorado	Metal ferrite spinel energy storage device and methods for making and using same	Metal ferrite spinel coatings are provided on substrates, preferably by using an atomic layer deposition process. The coatings are able to store energy such as solar energy, and to release that stored energy, via a redox reaction. The coating is first thermally or chemically reduced. The reduced coating is then oxidized in a second step to release energy and/or hydrogen, carbon monoxide or other reduced species.	Licensed to ALD NanoSolutions, Inc.
8,349,151	1/8/13	Giner Electrochemical Systems, LLC	Universal cell frame for high-pressure water electrolyzer and electrolyzer including the same	A universal cell frame generic for use as an anode frame and as a cathode frame in a water electrolyzer.	Being used in ongoing research. Part of an emerging hydrogen production technology project.
8,349,035	01/08/13	ANL	Autothermal and partial oxidation reformer-based fuel processor, method for improving catalyst function in autothermal and partial oxidation reformer-based processors	Segmented catalyst systems for reforming fuels for use in fuel cells.	Still being used in ongoing research efforts.

Production/Delivery Patents Status

Patent Number	Award Date	Organization	Title	Description	Status
8,323,614	12/04/12	University of South Carolina	Hydrolysis reactor for hydrogen production	A novel reactor configuration and method for delivering a hydride to a reaction zone in a manner that enables rapid reaction with water to produce hydrogen.	Research complete - licensed/seeking to license.
8,262,755	09/11/12	Air Products & Chemicals, Inc.	Staged membrane oxidation reactor system	An ion transport membrane oxidation system comprising two or more membrane oxidation stages, each stage comprising a reactant zone, an oxidant zone, one or more ion transport membranes separating the reactant zone from the oxidant zone, a reactant gas inlet region, a reactant gas outlet region, an oxidant gas inlet region, and an oxidant gas outlet region.	Still being used in ongoing research efforts.
8,231,857	07/31/12	Virent Energy Systems, Inc.	Catalysts and methods for reforming oxygenated compounds	Catalysts and methods that can reform aqueous solutions of oxygenated compounds such as ethylene glycol, glycerol, sugar alcohols, and sugars to generate products such as hydrogen and alkanes.	Being used in continuing research at the company; non-exclusive license to Equilon Enterprises, LLC (d.b.a. Shell Oil Products U.S.).
8,231,697	07/31/12	PNNL	Rapid start fuel reforming systems and techniques	An on-board fuel processor includes a microchannel steam reforming reactor and a water vaporizer heated in series with a combustion gas.	Research complete; seeking to license.
8,226,750	07/24/12	Genesis Fueltech, Inc.	Hydrogen purifier module with membrane support	Hydrogen purifier utilizing a hydrogen-permeable membrane to purify hydrogen from mixed gases containing hydrogen. A purifier module with improved mechanical support for the permeable membrane is described, enabling forward or reverse differential pressurization of the membrane.	Research complete -seeking to license.
8,210,360	07/03/12	Synkera Technologies, Inc.	Composite membranes and methods for making same	Composite membranes that are adapted for separation, purification, filtration, analysis, reaction and sensing. The composite membranes can include a porous support structure having elongate pore channels extending through the support structure.	Being used in ongoing research.
8,198,486	06/12/12	Virent Energy Systems, Inc.	Methods and systems for generating polyols	Methods for generating propylene glycol, ethylene glycol and other polyols, diols, ketones, aldehydes, carboxylic acids and alcohols using hydrogen produced from biomass.	Being used in continuing research at the company; non-exclusive license to Equilon Enterprises, LLC (d.b.a. Shell Oil Products U.S.).

Production/Delivery Patents Status

Patent Number	Award Date	Organization	Title	Description	Status
8,187,731	05/29/12	University of Colorado	Metal ferrite spinel energy storage devices and methods for making and using same	Metal ferrite spinel coatings are provided on substrates, preferably by using an atomic layer deposition process. The coatings are able to store energy such as solar energy, and to release that stored energy, via a redox reaction. The coating is first thermally or chemically reduced. The reduced coating is then oxidized in a second step to release energy and/or hydrogen, carbon monoxide or other reduced species.	Licensed to ALD NanoSolutions, Inc.
8,172,913	05/08/12	Intelligent Energy, Inc.	Array of planar membrane modules for producing hydrogen	Membrane reactor containing planar membrane modules with top and bottom thin foil membranes supported by both an intermediary porous support plate and a central base which has both solid extended members and hollow regions or a hollow region whereby the two sides of the base are in fluid communication. The membrane reactor operates at elevated temperatures for generating hydrogen from hydrogen rich feed fuels.	Still being used in ongoing research.
8,153,698	04/10/12	Virent Energy Systems, Inc.	Method for producing bio-fuel that integrates heat from carbon-carbon bond-forming reactions to drive biomass gasification reactions	A low-temperature catalytic process for converting biomass (preferably glycerol recovered from the fabrication of bio-diesel) to synthesis gas (i.e., H_2/CO gas mixture) in an endothermic gasification reaction.	Being used in continuing research at the company; non-exclusive license to Equilon Enterprises, LLC (d.b.a. Shell Oil Products U.S.).
8,148,583	04/03/12	Air Products & Chemicals, Inc.	Feed gas contaminant removal in ion transport membrane systems	An oxygen ion transport membrane process wherein a heated oxygen-containing gas having one or more contaminants is contacted with a reactive solid material to remove the one or more contaminants.	Still being used in ongoing research efforts.
8,110,022	02/07/12	Genesis Fueltech, Inc.	Hydrogen purifier module and method for forming the same	A hydrogen purifier utilizing a hydrogen permeable membrane, and a gas-tight seal, where the seal is uses a low temperature melting point metal, which forms a seal when heated above the melting point which is greater than the purifier operating temperature. The purifier is constructed such that a degree of isolation exists between the metal that melts to form the seal and the active area of the purifier membrane, so that the active area of the purifier membrane is not corrupted.	Research complete -seeking to license.

Production/Delivery Patents Status

Patent Number	Award Date	Organization	Title	Description	Status
8,088,261	01/03/12	Gas Technology Institute	CuCl thermochemical cycle for hydrogen production	This invention relates to a method and apparatus for electrochemically producing high porosity, high activity copper powders for high-temperature thermochemical water splitting.	Still being used in ongoing research.
8,070,860	12/06/11	United Technologies Corporation	Pd membrane having improved H_2-permeance, and method of making	Improved palladium membranes for the separation of hydrogen from a gas stream.	Being used in ongoing research.
8,002,854	08/23/11	University of Central Florida	Thermocatalytic process for CO_2-free production of hydrogen and carbon from hydrocarbons	Process and apparatus for sustainable CO_2-free production of hydrogen and carbon by thermocatalytic decomposition (dissociation, pyrolysis, cracking) of hydrocarbon fuels over carbon-based catalysts in the absence of air and/or water. The apparatus and thermocatalytic process improve the activity and stability of carbon catalysts during the thermocatalytic process and produce both high purity hydrogen (at least, 99.0 volume %) and carbon, from any hydrocarbon fuel, including sulfurous fuels. The process and apparatus can be conveniently integrated with any type of fuel cell to generate electricity.	Research complete; seeking to license.
7,989,664	08/02/11	Virent Energy Systems, Inc.	Methods and systems for generating polyols	Methods for generating propylene glycol, ethylene glycol and other polyols, diols, ketones, aldehydes, carboxylic acids and alcohols using hydrogen produced from biomass.	Being used in continuing research at the company; non-exclusive license to Equilon Enterprises, LLC (d.b.a. Shell Oil Products U.S.).
7,988,925	08/02/11	ANL	Fuel processing device	An improved fuel processor for fuel cells is provided whereby the startup time of the processor is less than sixty seconds and can be as low as 30 seconds, if not less. A rapid startup time is achieved by either igniting or allowing a small mixture of air and fuel to react over and warm up the catalyst of an autothermal reformer (ATR).	Still being used in ongoing research efforts.

Production/Delivery Patents Status

Patent Number	Award Date	Organization	Title	Description	Status
7,981,261	07/19/11	ANL	Integrated device and substrate for separating charged carriers and reducing photocorrosion and method for the photoelectrochemical production of electricity and photocatalytic production of hydrogen	A system for separating oppositely-charged charge carriers that can be used for producing electricity or hydrogen gas.	Still being used in ongoing research efforts.
7,951,283	05/31/11	INL	High temperature electrolysis for syngas production	A method for producing at least one syngas component that involves directly exposing water and carbon dioxide to heat generated by a nuclear power source.	No longer being used in research/no longer being pursued.
7,947,116	05/24/11	Eltron Research & Development, Inc.	Hydrogen separation process	Method for separating a hydrogen-rich product stream from a feed stream comprised of hydrogen and at least one carbon-containing gas, at an inlet pressure greater than atmospheric pressure and a temperature greater than 200^{o}C, to a hydrogen separation membrane system that is selectively permeable to hydrogen, and producing a hydrogen-rich permeate product stream on the permeate side of the membrane and a carbon dioxide-rich product raffinate stream on the raffinate side of the membrane.	Still being used in ongoing research.
7,939,026	05/10/11	INL	Apparatus for chemical synthesis	A method and apparatus for forming a chemical hydride which includes a pseudo-plasma-electrolysis reactor which is operable to receive a solution capable of forming a chemical hydride and includes a cathode and a movable anode. The anode is moved into and out of fluidic, ohmic electrical contact with the solution capable of forming a chemical hydride and when energized produces an oxygen plasma which facilitates the formation of a chemical hydride in the solution.	No longer being used in research/no longer being pursued.
7,932,437	04/26/11	ORNL	Designer proton-channel transgenic algae for photobiological hydrogen production	A designer proton-channel transgenic alga for photobiological hydrogen production that is specifically designed for production of molecular hydrogen through photosynthetic water splitting.	Assigned to inventor - no longer being pursued.
7,926,793	04/19/11	PNNL	Mixing in wicking structures and the use of enhanced mixing within wicks in microchannel devices	Advanced wicking structures and methods utilizing these structures are described. Particularly improved results in fluid contacting processes can be achieved by enhanced mixing within a wicking layer within a microchannel.	Being used in continuing research at PNNL and seeking to license.

Production/Delivery Patents Status

Patent Number	Award Date	Organization	Title	Description	Status
7,914,683	03/29/11	University of Central Florida	Particles of spilled oil-absorbing carbon in contact with water	Hydrogen generator coupled to or integrated with a fuel cell for portable power applications. Hydrogen is produced via thermocatalytic decomposition (cracking, pyrolysis) of hydrocarbon fuels in oxidant-free environment. The apparatus can utilize a variety of hydrocarbon fuels, including natural gas, propane, gasoline, kerosene, diesel fuel, crude oil (including sulfurous fuels). The hydrogen-rich gas produced is free of carbon oxides or other reactive impurities, so it could be directly fed to any type of a fuel cell.	Research complete; seeking to license.
7,910,373	03/22/11	NREL	H_2O doped WO_3, ultra-fast, high-sensitivity hydrogen sensors	An improved sensor for optically detecting hydrogen gas at low concentrations. The sensor consists of a substrate, a water-doped WO_3 layer coated on the substrate, and a palladium layer coated on the water-doped WO_3 layer.	Research complete; seeking to license.
7,906,079	03/15/11	Catacel Corporation	Stackable structural reactor	A reactor including a monolith having a plurality of fins in an annular arrangement for receiving fluid flow through the reactor. The monolith is disposed within a generally cylindrical outer tube, and around a corrugated inner tube. The reactor includes a device for urging the monolith radially outward, so as to maintain contact between the monolith and the outer tube.	Part of a commercial hydrogen production technology project.
7,897,122	03/01/11	Media & Process Technology	Hybrid adsorptive membrane reactor	A hybrid adsorbent-membrane reactor in which the chemical reaction, membrane separation, and product adsorption are coupled. In the reaction chamber one or more reactants and a catalyst react in a water-gas-shift (WGS) reaction producing at least one desired product and at least one by-product. A membrane selectively permits the desired product and the by-product to pass from the chamber to an adsorbent for the by-product; and an outlet for the desired product.	Still being used in ongoing research. Part of an emerging hydrogen production technology project.
7,879,750	02/01/11	General Electric Company	Anodes for alkaline electrolysis	A method of making an anode for alkaline electrolysis cells used for the production of hydrogen.	Research complete; seeking to license.

Production/Delivery Patents Status

Patent Number	Award Date	Organization	Title	Description	Status
7,872,054	01/18/11	Virent Energy Systems, Inc.	Method for producing bio-fuel that integrates heat from carbon-carbon bond-forming reactions to drive biomass gasification reactions	A low-temperature catalytic process for converting biomass (preferably glycerol recovered from the fabrication of bio-diesel) to synthesis gas (i.e., H_2/CO gas mixture) in an endothermic gasification reaction.	Being used in continuing research at the company; non-exclusive license to Equilon Enterprises, LLC (d.b.a. Shell Oil Products U.S.).
7,850,838	12/14/10	Proton Energy Systems, Inc.	Cold weather hydrogen generation system and method of operation	An enclosed system that produces hydrogen gas from the electrolysis of water. Operation in cold climates is enabled by one or more heat generation devices that prevent the system's components from freezing.	Being used by Proton Energy Systems in a commercial product, FuelGen® Hydrogen Fueling Systems.
7,842,276	11/30/10	University of Central Florida	Catalysts for the evolution of hydrogen from borohydride solution	Organic pigments which can catalyze the decomposition reaction of hydrogen-rich, stabilized, borohydride solutions to generate hydrogen gas. These are useful for on-board hydrogen-consuming devices such as motor vehicles or other combustion engines. The organic pigments can be used in hydrogen generating systems and for controlling the generation of hydrogen gas from metal hydride solutions.	Research complete; seeking to license.
7,818,993	10/26/10	ANL	High-performance flexible hydrogen sensors	Single-walled carbon nanotubes (SWNTs) are decorated with metal nanoparticles to form high-performance flexible hydrogen sensors.	Still being used in ongoing research efforts.
7,771,519	08/10/10	Air Products & Chemicals, Inc.	Liners for ion transport membrane systems	An ion transport membrane system consisting of a pressure vessel, a series of planar ion transport membrane modules in the interior of the pressure vessel, a gas manifold that is in flow communication with each membrane module, and a liner within the inlet/outlet conduits to the pressure vessel and on the interior surface of the gas manifold.	Part of an emerging hydrogen production technology project.
7,767,867	08/03/10	Virent Energy Systems, Inc.	Methods and systems for generating polyols	Methods for generating propylene glycol, ethylene glycol and other polyols, diols, ketones, aldehydes, carboxylic acids and alcohols using hydrogen produced from biomass.	Being used in continuing research at the company; non-exclusive license to Equilon Enterprises, LLC (d.b.a. Shell Oil Products U.S.).

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Patent Number	Award Date	Organization	Title	Description	Status
7,745,696	06/29/10	University of California - Berkeley	Suppression of TLA1 gene expression for improved solar conversion efficiency and photosynthetic productivity in plants and algae	Methods and compositions to minimize the chlorophyll antenna size of photosynthesis by decreasing TLA1 gene expression, thereby improving solar conversion efficiencies and photosynthetic productivity in plants, e.g., green microalgae, under bright sunlight conditions.	Non-exclusive license to Benson Hill Biosystems. Part of an emerging hydrogen production technology project.
7,744,733	06/29/10	Proton Energy Systems, Inc.	Gas venting system	A system for venting a moist gas stream resulting from operation of electrochemical cells within an enclosure, and for preventing the water vapor in the moist gas stream from freezing within the enclosure.	Being used by Proton Energy Systems in a commercial product, FuelGen® Hydrogen Fueling Systems.
7,736,609	06/15/10	Ergenics Corporation	Hydrogen purification system	The invention provides a system to purify hydrogen involving the use of a hydride compressor and catalytic converters combined with a process controller.	Research complete; seeking to license.
7,732,174	06/08/10	NREL	Multi-stage microbial system for continuous hydrogen production	The invention relates to a continuous H_2 production system in which photosynthetic O_2 evolution and H_2 photoproduction are separated physically in two separate bioreactors.	Being used in continuing research efforts at NREL and seeking to license.
7,722,853	05/25/10	University of Central Florida	Catalysts for the evolution of hydrogen from borohydride solution	Organic pigments which can catalyze the decomposition reaction of hydrogen-rich, stabilized, borohydride solutions to generate hydrogen gas. These are useful for on-board hydrogen-consuming devices such as motor vehicles or other combustion engines. The organic pigments can be used in hydrogen generating systems and for controlling the generation of hydrogen gas from metal hydride solutions.	Research complete; seeking to license.
7,722,757	05/25/10	ANL	Process for the production of hydrogen from water	A method and device for the production of hydrogen from water and electricity using an active metal alloy. The active metal alloy reacts with water producing hydrogen and a metal hydroxide.	No longer being used in research/no longer being pursued. DOE now owns patent.
7,703,472	04/27/10	Air Products & Chemicals, Inc.	Module isolation devices	Gas flow isolation devices for Ion Transport Membrane (ITM) modules designed for producing purified oxygen from an oxygen-containing gas (e.g., air) or for producing synthesis gas. The devices isolate the flow of gas from one module into one or more other modules that are joined together through one or more common headers.	Part of an emerging hydrogen production technology project.

Production/Delivery Patents Status

Patent Number	Award Date	Organization	Title	Description	Status
7,695,580	04/13/10	Air Products & Chemicals, Inc.	Method of forming a ceramic to ceramic joint	A method of forming a joint at an interface between two sintered bodies comprising metallic oxides of specific crystal structure. The method can be used to form gas-tight joints between ceramic components in an oxygen separation device.	Part of an emerging hydrogen production technology project.
7,691,775	04/06/10	University of Michigan	Reducible oxide based catalysts	The invention relates to an improved catalyst for the water gas shift reaction, which is used in the production of hydrogen. The catalyst includes a reducible oxide support and at least one noble metal fixed on the reducible oxide support.	Research complete; seeking to license.
7,682,580	03/23/10	Catacel Corporation	Catalytic reactor having radial leaves	All-metal structure, cylindrical reactor for surface catalytic reactions and/or heat exchange and avoids the low conductivity problems associated with the use of packed bed ceramic materials in the manufacture and operation of catalytic reactors. Also, the thermal mismatch between the metal and ceramic portions of prior art reactors eventually leads to pulverization of the ceramic material, thus limiting the useful life of the reactor. This design has leaves that are not spiral, but radially extend outward from the interior of the reactor to its exterior to provide improved heat transfer between the exterior and the interior of the reactor.	No licenses issued & no internal research being done with this patent
7,678,251	03/16/10	Proton Energy Systems, Inc.	System and method for detecting gas	A method for detecting the presence of a specific gas in a mixture of gases resulting from operation of an electrochemical cell.	Being used by Proton Energy Systems in a commercial product, FuelGen® Hydrogen Fueling Systems.
7,666,534	02/23/10	ANL	Electro-catalytic oxidation device for removing carbon from a fuel reformate	An electro-catalytic oxidation device (ECOD) for the removal of contaminates, preferably carbonaceous materials, from an influent comprising an ECOD anode, an ECOD cathode, and an ECOD electrolyte.	Being used in continuing research efforts at ANL.
7,658,788	02/09/10	Air Products & Chemicals, Inc.	Ion transport membrane module and vessel system with directed internal gas flow	An ion transport membrane reactor system which can be used to oxidize a reactant gas feed stream containing hydrocarbons, such as methane, and thereby produce a product gas stream containing hydrogen and carbon oxides.	Part of an emerging hydrogen production technology project.

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Patent Number	Award Date	Organization	Title	Description	Status
7,651,669	01/26/10	PNNL	Microsystem process networks	Various aspects and applications of microsystem process networks which can be improved by employing ortho-cascading mass, heat, or other unit process operations are described. One such application is the production of hydrogen via steam reformation of hydrocarbons.	No longer being pursued at PNNL; owned by the U.S. Department of Energy.
7,642,405	01/05/10	ORNL	Switchable photosystem-II designer algae for photobiological hydrogen production	A switchable photosystem-II (PSII) designer algae for photobiological hydrogen production. The designer transgenic algae includes at least two transgenes for enhanced photobiological H_2 production wherein a first transgene serves as a genetic switch that can control PSII oxygen evolution and a second transgene encodes for creation of free proton channels in the algal photosynthetic membrane.	No longer being used.
7,604,771	10/20/09	ANL	Thermal method for fabricating a hydrogen separation membrane on a porus substrate	A thermal method of making a hydrogen permeable composition for use in hydrogen separation membranes.	Being used in continuing research efforts at ANL.
7,591,864	09/22/09	University of Central Florida	Catalysts for the evolution of hydrogen from borohydride solution	Organic pigments which can catalyze the decomposition reaction of hydrogen-rich, stabilized, borohydride solutions to generate hydrogen gas. These are useful for on-board hydrogen-consuming devices such as motor vehicles or other combustion engines. The organic pigments can be used in hydrogen generating systems and for controlling the generation of hydrogen gas from metal hydride solutions.	Research complete; seeking to license.
7,588,626	09/15/09	Boston University	Composite mixed oxide ionic and electronic conductors for hydrogen separation	A mixed ionic and electrically conducting membrane that includes a two-phase solid state ceramic composite, wherein the first phase is an oxygen ion conductor and the second phase is an n-type electrically conductive oxide. The membrane can be used to separate hydrogen from a mixture of gases and purify it for use in fuel cells.	Research complete; seeking to license.
7,581,765	09/01/09	Air Products & Chemicals, Inc.	Seal assembly for materials with different coefficients of thermal expansion	An improved seal assembly for couplings and joints between materials with different coefficients of thermal expansion (e.g., metals and ceramics) used in high-temperature gas processing devices.	Part of an emerging hydrogen production technology project.

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Patent Number	Award Date	Organization	Title	Description	Status
7,575,614	08/18/09	Nuvera Fuel Cells, Inc.	Startup burner	Startup burner design to make fuel reformers with sufficient energy density suitable for automotive use. The design however, compact does not necessarily provide rapid startup. One of the limiting factors in starting up a cold reformer is heating the catalyst contained therein to a desired light off temperature. The burner produces a hot gas emission suitable for heating a catalyst (e.g., a catalyst used in an autothermal reforming (ATR)) to a desired temperature (e.g., the light-off temperature of the catalyst). Preferably the catalyst achieves the desired temperature in about three minutes or less, or more generally in about one-quarter or less of the time required to heat the catalyst without the burner.	No longer being used in research/no longer being pursued.
7,569,293	08/04/09	Nuvera Fuel Cells, Inc.	Methods and systems for efficient operation of integrated fuel cell-fuel reformer systems	Methods and related systems for determining an efficient operating state for an integrated fuel cell/fuel reformer power system. The method optimizes the efficiency of operation of a power system comprising a fuel processor and a fuel cell operating in an integrated way. The operating properties of the system components are used to for controlling and optimizing system efficiency at any desired power output level.	No longer being used in research/no longer being pursued.
7,565,743	07/28/09	Catacel Corporation	Method for insertion and removal of a catalytic reactor cartridge	Cartridge that can be used for catalytic or non-catalytic combustion and/or as a heat exchanger which can be stacked with similar cartridges in a long tube or pipe. The cartridge also requires a method of moving a cartridge into or out of a pipe, and a tool for accomplishing such a transfer.	No licenses issued & no internal research being done with this patent.
7,563,292	07/21/09	ANL	Fuel processor and method for generating hydrogen for fuel cells	A method of producing a H_2 rich gas stream includes supplying an O_2 rich gas, steam, and fuel to an inner reforming zone of a fuel processor that includes a partial oxidation catalyst and a steam reforming catalyst or a combined partial oxidation and stream reforming catalyst.	Being used in continuing research efforts at ANL.
7,559,978	07/14/09	General Electric Company	Gas-liquid separator and method of operation	A system for gas-liquid separation in electrolysis equipment used for hydrogen production.	Research complete; seeking to license.

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Patent Number	Award Date	Organization	Title	Description	Status
7,556,675	07/07/09	Air Products & Chemicals, Inc.	Feed gas contaminant control in ion transport membrane systems	Methods for constructing ion transport membrane (ITM) reactor systems so that the system's metal components do not react with high-temperature mixtures of steam, methane, and/or synthesis gas, thereby preventing the production of ITM-poisoning contaminant vapors.	Part of an emerging hydrogen production technology project.
7,540,475	06/02/09	PNNL	Mixing in wicking structures and the use of enhanced mixing within wicks in microchannel devices	Advanced wicking structures and methods utilizing these structures are described. Particularly improved results in fluid contacting processes can be achieved by enhanced mixing within a wicking layer within a microchannel.	Being used in continuing research at PNNL and seeking to license.
7,520,917	04/21/09	PNNL	Devices with extended area structures for mass transfer processing of fluids	The invention relates to microchannel devices used for performing fluid processing and heat exchange.	Being used in continuing research at PNNL.
7,513,932	04/07/09	Air Products & Chemicals, Inc.	Planar ceramic membrane assembly and oxidation reactor system	A planar ceramic membrane assembly comprising a dense layer of mixed-conducting multi-component metal oxide material, wherein the dense layer has a first side and a second side, a porous layer of mixed-conducting multi-component metal oxide material in contact with the first side of the dense layer, and a ceramic channeled support layer in contact with the second side of the dense layer.	Part of an emerging hydrogen production technology project.
7,507,690	03/24/09	ANL	Autothermal reforming catalyst having perovskite structure	A novel fuel reforming catalyst with a perovskite structure that can be used to produce hydrogen for use in fuel cells.	Being used in continuing research efforts at ANL.
7,507,384	03/24/09	Nuvera Fuel Cells, Inc.	Preferential oxidation reactor temperature regulation	Hydrocarbon fuel reforming system for reforming a gaseous or liquid hydrocarbon fuel to produce a hydrogen-rich product stream for use in, among other things, fuel cells. A method and apparatus for selective or preferential oxidation of carbon monoxide, and particularly in the control of reactor temperature during this process is provided.	No longer being used in research/no longer being pursued.
7,501,102	03/10/09	Catacel Corporation	Reactor having improved heat transfer	A reactor or heat exchanger with an annular monolith with multiple leaves inside a cylindrical outer tube, and around a corrugated inner tube. The reactor includes a device for urging the monolith radially outward, so as to maintain contact between the monolith and the outer tube. The reactor compensates for metal creep, and virtually insures continued contact between the monolith and the outer tube for heat transfer.	No licenses issued & no internal research being done with this patent.

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Patent Number	Award Date	Organization	Title	Description	Status
7,501,101	03/10/09	PNNL	Microchannel apparatus comprising plural microchannels and methods of conducting unit operations	A microchannel apparatus comprising a header and plural flow microchannels is described in which orifices connect the header and the flow microchannels. Methods of conducting unit operations in the apparatus are also described.	Exclusive license to Velocys, Inc.
7,485,161	02/03/09	Air Products & Chemicals, Inc.	Dehydrogenation of liquid fuel in microchannel catalytic reactor	An improved process for the storage and delivery of hydrogen by the reversible hydrogenation/ dehydrogenation of an organic compound in a microchannel reactor.	Part of an emerging hydrogen production technology project.
7,472,936	01/06/09	Catacel Corporation	Tool for insertion and removal of a catalytic reactor cartridge	A reactor cartridge includes a plurality of spaced-apart monoliths, formed along a tube or other mandrel. Each monolith is formed of a pair of flat and corrugated metal strips, spirally wound around the tube. These strips could be made of solid or screen material. The corrugations are skewed, such that the monolith imparts a swirl to gases flowing through it to promote mixing of gases and better heat transfer from the exterior to the interior of the cartridge. An insertion and removal tool simplifies the procedure for stacking such cartridges in a long pipe, or for removing cartridges from the pipe. The all-metal construction facilitates heat transfer through the entire reactor, and avoids the problems associated with packed ceramic beds.	No licenses Issued & no internal research being done with this patent
7,468,092	12/23/08	Air Products & Chemicals, Inc.	Operation of mixed conducting metal oxide membrane systems under transient conditions	A method of operating an oxygen-permeable mixed conducting membrane having an oxidant feed side, an oxidant feed surface, a permeate side, and a permeate surface. The method consists of controlling the differential strain between the permeate surface and the oxidant feed surface by varying the oxygen partial pressure on either or both sides of the membrane.	Part of an emerging hydrogen production technology project.
7,434,547	10/14/08	Nuvera Fuel Cells, Inc.	Fuel fired hydrogen generator	A system that combines an IC engine with a fuel processor for hydrocarbon fuels and generates and stores hydrogen with high efficiency and low operation cost.	Still being used in ongoing research.
7,429,372	09/30/08	Air Products & Chemicals, Inc.	Hydrogen storage by reversible hydrogenation of pi-conjugated substrates	A novel process for the storage and release of hydrogen by means of a substantially reversible catalytic hydrogenation of extended pi-conjugated substrates.	Part of an emerging hydrogen production technology project.

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Patent Number	Award Date	Organization	Title	Description	Status
7,425,231	09/16/08	Air Products & Chemicals, Inc.	Feed gas contaminant removal in ion transport membrane systems	A method for purification of a gas stream containing contaminants such as volatile metal oxy-hydroxides, volatile metal oxides, and volatile silicon hydroxide. The method consists of contacting the feed gas stream with a reactive solid material in a guard bed to form a solid reaction product, after which the purified gas stream is withdrawn from the guard bed.	Part of an emerging hydrogen production technology project.
7,419,635	09/02/08	NREL	Pd/V_2O_5 device for colorimetric H_2 detection	A sensor structure for chemochromic optical detection of hydrogen gas over a wide response range.	Research complete; seeking to license.
7,367,996	05/06/08	Nuvera Fuel Cells, Inc.	Heat transfer optimization in multi shelled reformers	A hydrocarbon fuel reformers for reforming a gaseous or liquid hydrocarbon fuel into a hydrogen-enriched product stream or reformate for use in hydrogen fuel cells. The reformer consists of coaxially arranged zones, through which reactants and processed streams are cooperatively flowed to accomplish necessary reactions, preheating and thermal efficiency.	Still being used in ongoing research.
7,354,465	04/08/08	Nuvera Fuel Cells, Inc.	Device for cooling and humidifying reformate	A device for cooling and humidifying a reformate stream from a reforming reactor as well as related methods, modules and systems includes a heat exchanger and a sprayer. The heat exchanger is adapted to allow a flow of a first fluid (e.g. water) inside the conduit and to establish a heat exchange relationship between the first fluid and a second fluid (e.g. reformate from a reforming reactor) flowing outside the conduit. The sprayer is coupled to the outlet of the heat exchanger for spraying the first fluid exiting the heat exchanger into the second fluid.	No longer being used in research/no longer being pursued.
7,351,395	04/01/08	Air Products & Chemicals, Inc.	Hydrogen storage by reversible hydrogenation of pi-conjugated substrates	A novel process for the storage and release of hydrogen by means of a substantially reversible catalytic hydrogenation of extended pi-conjugated substrates.	Part of an emerging hydrogen production technology project.
7,344,576	03/18/08	PNNL	Conditions for fluid separations in microchannels, capillary-driven fluid separations, and laminated devices capable of separating fluids	Methods of separating fluids using capillary forces and/or improved conditions. The improved methods may include control of the ratio of gas and liquid Reynolds numbers relative to the Suratman number. Also disclosed are wick-containing, laminated devices that are capable of separating fluids.	Exclusive license to Velocys, Inc.
7,340,938	03/11/08	University of Colorado	MIS-based sensors with hydrogen selectivity	Hydrogen-selective metal-insulator-semiconductor sensors which include a layer of hydrogen-selective material.	Licensed to the Electric Power Research Institute.

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Patent Number	Award Date	Organization	Title	Description	Status
7,335,247	02/26/08	Air Products & Chemicals, Inc.	Ion transport membrane module and vessel system	An ion transport membrane reactor system which can be used to oxidize a reactant gas feed stream containing hydrocarbons, such as methane, and thereby produce a product gas stream containing hydrogen and carbon oxides.	Part of an emerging hydrogen production technology project.
7,311,755	12/25/07	Air Products & Chemicals, Inc.	Control of differential strain during heating and cooling of mixed conducting metal oxide membranes	A method of operating an oxygen-permeable mixed conducting membrane having an oxidant feed side and a permeate side. The method consists of controlling the differential strain between the oxidant feed side and the permeate side by varying the oxygen partial pressure on either or both sides of the membrane.	Part of an emerging hydrogen production technology project.
7,297,324	11/20/07	PNNL	Microchannel reactors with temperature control	Microchannel devices and methods of use are disclosed wherein a reaction microchamber is in thermal contact with a heat exchange channel. A catalyst can be provided in the microchamber in sheet form such that reactants flow by the catalyst sheet.	Exclusive license to Velocys, Inc.
7,279,027	10/09/07	Air Products & Chemicals, Inc.	Planar ceramic membrane assembly and oxidation reactor system	Planar ceramic membrane assembly comprising a dense layer of mixed-conducting multi-component metal oxide material, wherein the dense layer has a first side and a second side, a porous layer of mixed-conducting multi-component metal oxide material in contact with the first side of the dense layer, and a ceramic channeled support layer in contact with the second side of the dense layer.	Part of an emerging hydrogen production technology project.
7,276,306	10/02/07	LLNL	System for the co-production of electricity and hydrogen	System for the co-generation of hydrogen gas and electricity, wherein the proportion of hydrogen to electricity can be adjusted from 0% to 100%.	No license issued and no research being done with this patent.
7,272,941	09/25/07	PNNL	Methods for fluid separations, and devices capable of separating fluids	A wick-containing apparatus and methods of separating fluids using wicks.	Being used in continuing research at PNNL.
7,270,905	09/18/07	PNNL	Microsystem process networks	Various aspects and applications of microsystem process networks which can be improved by employing ortho-cascading mass, heat, or other unit process operations are described. One such application is the production of hydrogen via steam reformation of hydrocarbons.	Research complete; seeking to license.

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Patent Number	Award Date	Organization	Title	Description	Status
7,233,034	06/19/07	NREL	Hydrogen permeable protective coating for a catalytic surface	A protective coating for a surface comprising a layer permeable to hydrogen, said coating being deposited on a catalyst layer wherein the catalytic activity of the catalyst layer is preserved.	Exclusive license to Nuclear Filter Technology. Still working with NREL via CRADA on further development.
7,229,785	06/12/07	NREL	Fluorescence technique for on-line monitoring of state of hydrogen-producing microorganisms	An in situ method for external on-line monitoring of the physiological state of an algal culture inside a closed photobioreactor system to ascertain the culture's production of hydrogen.	Not licensed but still being used in research at NREL.
7,179,323	02/20/07	Air Products & Chemicals, Inc.	Ion transport membrane module and vessel system	An ion transport membrane reactor system which can be used to oxidize a reactant gas feed stream containing hydrocarbons, such as methane, and thereby produce a product gas stream containing hydrogen and carbon oxides.	Part of an emerging hydrogen production technology project.
7,176,005	02/13/07	University of California - Berkeley	Modulation of sulfate permease for photosynthetic hydrogen production	Sustained hydrogen production is obtained by the culturing of a genetically-modified algae, where the ability of the chloroplasts to intake sulfate is reduced or eliminated compared with wild-type algae.	Part of an emerging hydrogen production technology project.
7,157,167	01/02/07	University of Central Florida Research Foundation	Thermocatalytic process for CO_2-free production of hydrogen and carbon from hydrocarbons	A novel process and apparatus for sustainable CO_2-free production of hydrogen and carbon by thermocatalytic decomposition (dissociation, pyrolysis, cracking) of hydrocarbon fuels over carbon-based catalysts in the absence of air and/or water.	Exclusive license to Contained Energy, Inc. Continued development with the goal of a commercial product in 3-5 years.
7,148,389	12/12/06	University of Michigan	Selective sorbents for purification of hydrocartons	A method for removing thiophene and thiophene compounds from liquid fuel using an adsorbent which preferentially adsorbs thiophene and thiophene compounds. The adsorption takes place at a selected temperature and pressure, thereby producing a non-adsorbed component and a thiophene/thiophene compound-rich adsorbed component. A further method includes selective removal of aromatic compounds from a mixture of aromatic and aliphatic compounds.	Research complete; seeking to license.
7,125,540	10/24/06	PNNL	Microsystem process networks	Various aspects and applications of microsystem process networks which can be improved by employing ortho-cascading mass, heat, or other unit process operations are described. One such application is the production of hydrogen via steam reformation of hydrocarbons.	Exclusive license to Velocys, Inc.

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Patent Number	Award Date	Organization	Title	Description	Status
7,122,873	10/17/06	U. of Hawaii	Hybrid solid state/ electrochemical photoelectrode for hydrogen production	A semiconductor device for producing a gas from a material comprising the gas using light as the sole power source.	Part of an emerging hydrogen production technology project.
7,101,530	09/05/06	Air Products & Chemicals, Inc.	Hydrogen storage by reversible hydrogenation of pi-conjugated substrates	A novel process for the storage and release of hydrogen by means of a substantially reversible catalytic hydrogenation of extended pi-conjugated substrates.	Part of an emerging hydrogen production technology project.
7,094,333	08/22/06	University of Michigan	Selective sorbents for purification of hydrocartons	A method for removing thiophene and thiophene compounds from liquid fuel using an adsorbent which preferentially adsorbs thiophene and thiophene compounds. The adsorption takes place at a selected temperature and pressure, thereby producing a non-adsorbed component and a thiophene/thiophene compound-rich adsorbed component. A further method includes selective removal of aromatic compounds from a mixture of aromatic and aliphatic compounds.	Research complete; seeking to license.
7,094,301	08/22/06	Air Products & Chemicals, Inc.	Method of forming a joint	A method of forming a joint at an interface between two sintered bodies comprising multicomponent metallic oxides of specific crystal structure. Typical sintered bodies are an ion transport membrane (an electrolyte), ceramic tubes, and additional supporting equipment such as seals and conduits.	Part of an emerging hydrogen production technology project.
7,087,211	08/08/06	ANL	Hydrogen production by high temperature water splitting using electron conducting membranes	A device and method for separating water into hydrogen and oxygen.	No longer being used in research/no longer being pursued.
7,067,453	06/27/06	InnovaTek, Inc.	Hydrocarbon fuel reforming catalyst and use thereof	The subject invention is a catalyst consisting of an oxide or mixed oxide support and bimetallic catalytically active compounds.	Part of an emerging hydrogen production technology project.
7,066,973	06/27/06	Nuvera Fuel Cells, Inc.	Integrated reformer and shift reactor	A hydrocarbon fuel reformer for producing diatomic hydrogen gas.	Being used in the New Millenium Project.

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Patent Number	Award Date	Organization	Title	Description	Status
7,063,131	06/20/06	Nuvera Fuel Cells, Inc.	Perforated fin heat exchangers and catalytic support	Perforated fins are provided to improve the capabilities of fin and tube type heat exchangers, and to adapt them for flow outside of the tube that is essentially parallel to the axis of the tube. The fins are made of a thermally conductive material, such as metal, with perforations in the fins. The perforations allow heat exchange with the contents of a tube of a fluid flowing essentially parallel to the axis of the tube, in contrast to conventional fin-tube heat exchangers. The fins may also be bonded to a post or other securing means and inserted into the inside of a tube or other hollow body to improve efficiency of heat exchange. In addition, the fins may carry a catalyst, optionally carried on a washcoat or similar treatment to increase surface area.	No longer being used in research/no longer being pursued.
7,059,364	06/13/06	Gas Technology Institute	Control method for high-pressure hydrogen vehicle fueling station dispensers	A method for quick filling a vehicle hydrogen storage vessel with hydrogen, the key component of which is an algorithm used to control the fill process, which interacts with the hydrogen dispensing apparatus to determine the vehicle hydrogen storage vessel capacity.	Being used in a commercial product, H2 ProGen, by GreenField Compression.
7,053,256	05/30/06	University of Michigan	Selective sorbents for purification of hydrocartons	A method for removing thiophene and thiophene compounds from liquid fuel includes contacting the liquid fuel with an adsorbent which preferentially adsorbs the thiophene and thiophene compounds. The adsorption takes place at a selected temperature and pressure, thereby producing a non-adsorbed component and a thiophene/thiophene compound-rich adsorbed component. The adsorbent includes either a metal or a metal cation that is adapted to form .pi.-complexation bonds with the thiophene and/or thiophene compounds, and the preferential adsorption occurs by .pi.-complexation. A further method includes selective removal of aromatic compounds from a mixture of aromatic and aliphatic compounds.	Research complete; seeking to license.
7,051,540	05/30/06	PNNL	Methods for fluid separations, and devices capable of separating fluids	A wick-containing apparatus and methods of separating fluids using wicks.	Being used in continuing research at PNNL and seeking to license.

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Patent Number	Award Date	Organization	Title	Description	Status
7,033,570	04/25/06	University of Colorado	Solar-thermal fluid-wall reaction processing	A method for carrying out high temperature thermal dissociation reactions requiring rapid-heating and short residence times using solar energy.	Licensed to Sundrop Fuels, Inc. and still being used in research at the company.
7,029,574	04/18/06	University of Michigan	Selective sorbents for purification of hydrocartons	A method for removing thiophene and thiophene compounds from liquid fuel using an adsorbent which preferentially adsorbs thiophene and thiophene compounds. The adsorption takes place at a selected temperature and pressure, thereby producing a non-adsorbed component and a thiophene/thiophene compound-rich adsorbed component. A further method includes selective removal of aromatic compounds from a mixture of aromatic and aliphatic compounds.	Research complete; seeking to license.
7,011,898	03/14/06	Air Products & Chemicals, Inc.	Method of joining ITM materials using a partially or fully-transient liquid phase	A method of forming a joint at an interface between two sintered bodies comprising multicomponent metallic oxides of specific crystal structure. Typical sintered bodies are an ion transport membrane (an electrolyte), ceramic tubes, and additional supporting equipment such as seals and conduits.	Part of an emerging hydrogen production technology project.
7,011,694	03/14/06	University of Kentucky	CO_2-selective membranes containing amino groups	A CO_2-selective membrane constructed in the hollow-fiber configuration using air as the sweep gas for use in water gas shift reactors to aid in the production of high-purity H_2.	Still being used in on-going research efforts.
6,989,252	01/24/06	NREL	Hydrogen production using hydrogenase-containing oxygenic photosynthetic organisms	A reversible physiological process provides for the temporal separation of oxygen evolution and hydrogen production in a microorganism.	Part of an emerging hydrogen production technology project.
6,986,797	01/17/06	Nuvera Fuel Cells, Inc.	Auxiliary reactor for a hydrocarbon reforming system	An integrated hydrocarbon fuel reforming system for reforming a gaseous or liquid hydrocarbon fuel to produce a hydrogen-rich product stream used in, among other things, hydrogen fuel cells. An improved integrated hydrocarbon reforming system is detailed, including, an autothermal reformer having distinct zones for partial oxidation reforming and steam reforming, an integrated shift bed for reducing carbon monoxide in the product stream, a preferential oxidation reactor, and an auxiliary reactor.	No longer being used in research/no longer being pursued.

Production/Delivery Patents Status

Patent Number	Award Date	Organization	Title	Description	Status
6,985,082	01/10/06	NexTech Materials, Ltd.	Carbon monoxide sensor and method of use	A sensor and method of use for detection of low levels of carbon monoxide in gas mixtures.	Not being pursued at this time. Put on the shelf.
6,967,063	11/22/05	ANL	Autothermal hydrodesulfurizing reforming method and catalyst	A method for reforming a sulfur-containing carbonaceous fuel in which the sulfur-containing carbonaceous fuel is mixed with H_2O and an oxidant, forming a fuel/H_2O/ oxidant mixture.	Licensed to a small company that wishes to remain anonymous and being used in research.
6,887,728	05/03/05	U. of Hawaii	Hybrid solid state/ electrochemical photoelectrode for hydrogen production	A semiconductor device for production of a gas from a material comprising the gas using light as the sole power source.	Part of an emerging hydrogen production technology project.
6,878,362	04/12/05	General Electric Company	Fuel processor apparatus and method based on autothermal cyclic reforming	In a fuel processor based on autothermal cyclic reforming process, a method of generating hydrogen gas includes receiving a mixture of fuel and steam in the reformer reactor operating in a reforming step to produce hydrogen-rich reformate gas.	Research not continuing in this area and nothing being done with patent.
6,875,247	04/05/05	PNNL	Conditions for fluid separations in microchannels, capillary-driven fluid separations, and laminated devices capable of separating fluids	Methods of separating fluids using capillary forces and/ or improved conditions. The improved methods may include control of the ratio of gas and liquid Reynolds numbers relative to the Suratman number. Also disclosed are wick-containing, laminated devices that are capable of separating fluids.	Exclusive license to Velocys, Inc. The patent is not planned for development for hydrogen production but for distillation purposes.
6,872,378	03/29/05	NREL	Solar thermal aerosol flow reaction process	An environmentally beneficial process using concentrated sunlight to heat radiation absorbing particles to carry out highly endothermic gas phase chemical reactions ultimately resulting in the production of hydrogen or hydrogen synthesis gases.	Licensed to Sundrop Fuels, Inc. and still being used in research at the company.
6,869,462	03/22/05	PNNL	Methods of contacting substances and microsystem contactors	The invention provides an apparatus and methods for efficiently capturing and separating fluids from gas/liquid streams. One possible application of the invention is for recycling water used in fuel cells.	Being used in continuing research at PNNL and seeking to license.

Production/Delivery Patents Status

Patent Number	Award Date	Organization	Title	Description	Status
6,783,742	08/31/04	Nuvera Fuel Cells, Inc.	Reactor for producing hydrogen from hydrocarbon fuels	A reformer for producing a hydrogen-rich gas with multiple reaction zones and a product gas collection space. The zones are sequentially adjacent and the flow path directs flow of the reactants in diverging directions. Divergent flow permits flow into and through a zone over more than just a single cross-sectional geometry of the zone or a single cross-section of the flow path. This technique can be used for at lower pressure for flowing the reaction stream so as to reduce the parasitic requirements of the reactor, and can also be used to increase throughput of the reactor.	Still being used in ongoing research.
6,726,893	04/27/04	ANL	Hydrogen production by high-temperature water splitting using electron-conducting membranes	A device and method for separating water into hydrogen and oxygen.	No longer being used in research/no longer being pursued.
6,723,566	04/20/04	NREL	Pd/Ni-WO_3 anodic double layer gasochromic device	An anodic double layer gasochromic sensor structure for optical detection of hydrogen in improved response time and with improved optical absorption real time constants.	Exclusive license to Nuclear Filter Technology. Still working with NREL via CRADA on further development.
6,716,275	04/06/04	SNL	Gas impermeable glaze for sealing a porous ceramic surface	A process for fabricating a gas impermeable seal on a porous ceramic surface using a thin, glass-based, pinhole free glaze.	Not licensed to anyone but still being used in research.
6,713,040	03/30/04	ANL	Method for generating hydrogen for fuel cells	A method of producing a H_2 rich gas stream includes supplying an O_2 rich gas, steam, and fuel to an inner reforming zone of a fuel processor that includes a partial oxidation catalyst and a steam reforming catalyst or a combined partial oxidation and stream reforming catalyst.	Being used in continuing research efforts at ANL.
6,670,058	12/20/03	University Central Florida	Thermocatalytic process for CO_2-free production of hydrogen and carbon from hydrocarbons	A novel process for sustainable CO_2-free production of hydrogen and carbon by thermocatalytic decomposition (or dissociation, pyrolysis, cracking) of hydrocarbon fuels over carbon-based catalysts in the absence of air and/or water.	Exclusive license to Contained Energy, Inc. Continued development with the goal of a commercial product in 3-5 years.

Production/Delivery Patents Status

Patent Number	Award Date	Organization	Title	Description	Status
6,666,909	12/23/03	PNNL	Microsystem capillary separations	Laminated, multiphase separators and contactors having wicking structures and gas flow channels. Some preferred embodiments are combined with microchannel heat exchange. Integrated systems containing these components are also part of the invention.	Exclusive license to Velocys, Inc. Being developed for distillation uses.
6,641,625	11/04/03	Nuvera Fuel Cells, Inc.	Integrated hydrocarbon reforming system and controls	A hydrocarbon reformer system including a first reactor configured to generate hydrogen-rich reformate.	Being used by Nuvera in research in a demo prototype for truck APUs. Five years from commercialization.
6,623,720	09/23/03	University of Michigan	Transition metal carbides, nitrides and borides, and their oxygen containing analogs useful as water gas shift catalysts	Mono- and bimetallic transition metal carbides, nitrides and borides, and their oxygen containing analogs (e.g. oxycarbides) for use as water gas shift catalysts.	No license yet but looking for a commercial partner for future research.
6,572,829	06/03/03	University Central Florida	Closed cycle photocatalytic process for decomposition of hydrogen sulfide to its constituent elements	System for separating hydrogen and sulfur from hydrogen sulfide (H_2S) gas produced from oil and gas waste streams.	Not licensed and no research being done at University of Central Florida.
6,551,561	04/22/03	University Central Florida	Apparatus for decoupled thermo-photocatalytic pollution control	A new method for design and scale-up of photocatalytic and thermocatalytic processes.	Not licensed and no research being done at University of Central Florida.
6,531,035	03/11/03	University Central Florida	Apparatus and method for low flux photocatalytic pollution control	A new method for design and scale-up of photocatalytic and thermocatalytic processes.	Not licensed and no research being done at University of Central Florida.
6,492,290	12/10/02	Air Products & Chemicals, Inc.	Mixed conducting membranes for syngas production	A new class of multicomponent metallic oxides that are particularly suited in fabricating components used in processes for producing syngas.	Part of an emerging hydrogen production technology project.
6,478,077	11/12/02	SNL	Self supporting heat transfer element	An improved internal heat exchange element arranged so as to traverse the inside diameter of a container vessel such that it makes good mechanical contact with the interior wall of that vessel.	Not licensed and no research being done at SNL.

Production/Delivery Patents Status

Patent Number	Award Date	Organization	Title	Description	Status
6,468,499	10/22/02	ANL	Method of generating hydrogen by catalytic decomposition of water	A method for producing hydrogen includes providing a feed stream comprising water; contacting at least one proton conducting membrane adapted to interact with the feed stream; splitting the water into hydrogen and oxygen at a predetermined temperature; and separating the hydrogen from the oxygen.	No longer being used in research/no longer being pursued.
6,468,480	10/22/02	Nuvera Fuel Cells, Inc.	Apparatus for converting hydrocarbon fuel into hydrogen gas and carbon dioxide	Hydrocarbon fuel reformer suitable for producing synthesis hydrogen gas from reactions with hydrocarbons fuels, oxygen, and steam.	Being used by Nuvera in research in a demo prototype for truck APUs. Five years from commercialization.
6,448,068	09/10/02	NREL	System for rapid biohydrogen phenotypic screening of microorganisms using a chemochromic sensor	A system for identifying a hydrogen gas producing organism.	Currently in licensing negotiations.
6,395,252	05/28/02	ORNL	Method for the continuous production of hydrogen	A method for the continuous production of hydrogen.	Not licensed and no research being done at ORNL.
6,391,484	05/21/02	General Motors Corporation	Fuel processor temperature monitoring and control	A method and system for maintaining temperature control in a fuel processor (reformer) used to produce hydrogen for a fuel cell.	Being used in continuing research at the company.
6,303,098	10/16/01	ANL	Steam reforming catalyst	A method of forming a hydrogen rich gas from a source of hydrocarbon fuel.	No longer being used in research.
6,302,402	10/16/01	Air Products & Chemicals, Inc.	Compliant high temperature seals for dissimilar materials	A high temperature, gas-tight seal is formed by utilizing one or more compliant metallic toroidal ring sealing elements, where the applied pressure serves to activate the seal, thus improving the quality of the seal. The compliant nature of the sealing element compensates for differences in thermal expansion between the materials to be sealed, and is particularly useful in sealing a metallic member and a ceramic tube at elevated temperatures.	Part of an emerging hydrogen production technology project.
6,277,589	08/21/01	NREL	Method and apparatus for rapid biohydrogen phenotypic screening of microorganisms using a chemochromic sensor	An assay system for identifying a hydrogen-gas-producing organism, including a sensor film having a first layer comprising a transition metal oxide or oxysalt and a second layer comprising hydrogen-dissociative catalyst metal.	Currently in licensing negotiations.

Production/Delivery Patents Status

Patent Number	Award Date	Organization	Title	Description	Status
6,254,839	07/03/01	Arthur D. Little, Inc.	Apparatus for converting hydrocarbon fuel into hydrogen gas and carbon dioxide	A hydrocarbon fuel reformer suitable for producing synthesis hydrogen gas from reactions with hydrocarbons fuels, oxygen, and steam.	Being used by Nuvera in research in a demo prototype for truck APUs. Five years from commercialization.
6,244,367	06/12/01	ANL	Methanol partial oxidation reformer	A partial oxidation reformer comprising a longitudinally extending chamber having a methanol, water, and an air inlet and an outlet.	No longer being used in research.
6,238,815	05/29/01	GM Corp.	Thermally integrated staged methanol reformer and method	A thermally integrated two-stage methanol reformer including a heat exchanger and first and second reactors colocated in a common housing in which a gaseous heat transfer medium circulates to carry heat from the heat exchanger into the reactors.	No longer being pursued, abandoned.
6,207,122	03/27/01	Arthur D. Little, Inc.	Method for converting hydrocarbon fuel into hydrogen gas and carbon dioxide	A hydrocarbon fuel reforming method suitable for producing synthesis hydrogen gas from reactions with hydrocarbons fuels, oxygen, and steam.	Being used by Nuvera in research in a demo prototype for truck APUs. Five years from commercialization.
6,162,558	12/19/00	General Motors Corporation	Method and apparatus for selective removal of carbon monoxide	A method and apparatus for reducing the carbon monoxide content of a hydrogen-rich gas.	Being used in continuing research at the company.
6,132,689	10/17/00	General Motors Corporation	Multi-stage, isothermal CO preferential oxidation reactor	A multi-stage, isothermal, carbon monoxide preferential oxidation (PrOx) reactor comprising a plurality of serially arranged, catalyzed heat exchangers, each separated from the next by a mixing chamber for homogenizing the gases exiting one heat exchanger and entering the next.	Being used in continuing research at the company.
6,126,908	10/03/00	Arthur D. Little, Inc.	Method and apparatus for converting hydrocarbon fuel into hydrogen gas and carbon dioxide	An apparatus and a method for converting hydrocarbon fuel or an alcohol into hydrogen gas and carbon dioxide.	Being used by Nuvera in research in a demo prototype for truck APUs. Five years from commercialization.
6,123,913	09/26/00	Arthur D. Little, Inc.	Method for converting hydrocarbon fuel into hydrogen gas and carbon dioxide	A method for synthesizing hydrogen gas from hydrocarbon fuel. A first mixture of steam and a first fuel are directed into a first tube to subject the first mixture to a first steam reforming reaction in the presence of a first catalyst.	Being used by Nuvera in research in a demo prototype for truck APUs. Five years from commercialization.

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Patent Number	Award Date	Organization	Title	Description	Status
6,114,400	09/05/00	Air Products & Chemicals, Inc.	Synthesis gas production by mixed conducting membranes with integrated conversion into liquid products	Natural gas or other methane-containing feed gas is converted to a C_5 -C_{19} hydrocarbon liquid in an integrated system comprising an oxygenative synthesis gas generator, a non-oxygenative synthesis gas generator, and a hydrocarbon synthesis process such as the Fischer-Tropsch process. The oxygenative synthesis gas generator is a mixed conducting membrane reactor system.	Part of an emerging hydrogen production technology project.
6,110,861	08/29/00	ANL	Partial oxidation catalyst	A two-part catalyst comprising a dehydrogenation portion and an oxide-ion conducting portion.	Research complete; seeking to license.
6,083,425	07/04/00	Arthur D. Little, Inc.	Method for converting hydrocarbon fuel into hydrogen gas and carbon dioxide	A method for converting hydrocarbon fuel into hydrogen gas and carbon dioxide within a reformer.	Being used by Nuvera in research in a demo prototype for truck APUs. Five years from commercialization.
6,051,125	04/18/00	LLNL	Natural gas-assisted steam electrolyzer	An efficient method of producing hydrogen by high temperature steam electrolysis that will lower the electricity consumption to an estimated 65 percent lower than has been achievable with previous steam electrolyzer systems.	One commercial license was issued but is terminated.
5,942,346	08/24/99	ANL	Methanol partial oxidation reformer	A partial oxidation reformer comprising a longitudinally extending chamber having a methanol, water, and an air inlet and an outlet.	No longer being used in research.
5,939,025	08/17/99	ANL	Methanol partial oxidation reformer	A partial oxidation reformer comprising a longitudinally extending chamber having a methanol, water and an air inlet and an outlet.	No longer being used in research.
5,929,286	07/27/99	ANL	Method for making hydrogen rich gas from hydrocarbon fuel	A method of forming a hydrogen rich gas from a source of hydrocarbon fuel in which the hydrocarbon fuel contacts a two-part catalyst comprising a dehydrogenation portion and an oxide-ion conducting portion.	Research complete; seeking to license.
5,895,518	04/20/99	SNL	Synthesis of alloys with controlled phase structure	A method for preparing controlled phase alloys useful for engineering and hydrogen storage applications.	Not licensed and no research being done at SNL.
5,886,614	03/23/99	General Motors Corporation	Thin film hydrogen sensor	A thin film hydrogen sensor consisting of a flat ceramic substrate, a thin film temperature-responsive resistor, and a thin film hydrogen-responsive metal resistor.	Being used in continuing research at the company.

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Patent Number	Award Date	Organization	Title	Description	Status
5,821,111	10/13/98	Bioengineering Resources, Inc.	Bioconversion of waste biomass to useful products	A process for converting waste biomass to useful products by gasifying the biomass to produce synthesis gas and converting the synthesis gas substrate to one or more useful products.	No longer being pursued for hydrogen production
5,637,415	06/10/97	General Motors Corporation	Controlled CO preferential oxidation	A method for controlling the supply of air to a preferential oxidation reactor in which the CO content of a hydrogen-rich gas stream is reduced.	Being used in continuing research at the company.
5,271,916	12/21/93	General Motors Corporation	Device for staged carbon monoxide oxidation	A method and apparatus for selectively oxidizing carbon monoxide in a hydrogen-rich feed stream.	Being used in continuing research at the company.
4,473,622	09/25/84	United Technologies Corporation	Rapid starting methanol reactor system	A methanol-to-hydrogen cracking reactor for use with a fuel cell vehicular power plant.	Patent has expired and is not being used at UTC.
4,358,429	11/09/82	ANL	Oxygen stabilized zirconium vanadium intermetallic compound	A new oxygen stabilized intermetallic compound that can repeatedly sorbing hydrogen from a mixture of gases.	No licensee and no further development of this technology at ANL.
4,142,300	03/06/79	ANL	Lanthanum nickel aluminum alloy	A ternary intermetallic compound capable of reversible sorption of hydrogen having the chemical formula $LaNi_5$-x Al_x, where x is in the range of about 0.01 to 1.5 and the method of storing hydrogen using the intermetallic compound.	No licensee and no further development of this technology at ANL.

Storage Patents Status

Patent Number	Award Date	Organization	Title	Description	Status
8,426,337	12/11/12	University of Michigan	Metal salt catalysts for enhancing hydrogen spillover	A composition for hydrogen storage including receptor with hydrogen dissociating metal and metal salt doping is configured to spill over hydrogen to the receptor, and the metal salt is configured to increase the rate of the spill over of the hydrogen to the receptor.	Research complete; seeking to license.
8,372,369	02/12/13	University of Michigan	Enhancing hydrogen spillover and storage	Methods for enhancing hydrogen spillover and storage are disclosed. One embodiment of the method includes doping a hydrogen receptor with metal particles, and exposing the hydrogen receptor to ultrasonication during doping. Another embodiment includes doping a hydrogen receptor with metal particles, and exposing the doped hydrogen receptor to a plasma treatment.	Research complete; seeking to license.
8,338,330	12/25/12	University of Michigan	Chemical bridges for enhancing hydrogen storage by spillover and methods for forming the same	A composition for hydrogen storage includes a source of hydrogen atoms, a receptor, and a chemical bridge formed between the source and the receptor. The chemical bridge is formed from a precursor material. The receptor is adapted to receive hydrogen spillover from the source.	Research complete; seeking to license.
8,329,140	12/11/12	LANL	Method and system for hydrogen evolution and storage	A method and system for storing and evolving hydrogen that uses chemical compounds that can be hydrogenated to store hydrogen and dehydrogenated to evolve hydrogen. A catalyst lowers the energy required for storing and evolving hydrogen.	Still being used in ongoing research efforts.
8,268,288	09/18/12	BNL	Regeneration of aluminum hydride	Methods and materials for the formation of hydrogen storage alanes, AlH_x, where x is greater than 0 and less than or equal to 6 at reduced H_2 pressures and temperatures.	Still being used in research and seeking to license.
8,193,113	06/05/12	General Electric Company	Hydrogen storage material and related processes	A metal hydride comprising of a complex hydride and a borohydride catalyst that can be used for hydrogen storage. The borohydride catalyst comprises a BH_4 group, and a group IV metal, a group V metal, or a combination of a group IV and a group V metal.	Research complete, seeking to license.

Storage Patents Status

Patent Number	Award Date	Organization	Title	Description	Status
8,153,554	04/10/12	University of South Carolina	Reversible hydrogen storage materials	Process for synthesis of a complex hydride material for hydrogen storage and includes mixing a borohydride with at least one additive agent and at least one catalyst and heating the mixture at a temperature of less than about 600°C. The hydride material comprises of an alkali metal or group IIA metal, aluminum and boron. The material is capable of cyclic dehydrogenation and rehydrogenation and has a hydrogen capacity of at least about 4 weight percent.	Research complete - licensed/ seeking to license.
8,153,020	04/10/12	University of South Florida	Hydrogen-storing hydride complexes	Hydrogen storage material comprising of a complex hydride using light-weight elements or compounds.	Research complete - licensed/ seeking to license.
8,147,796	04/03/12	University of Utah	Hydrogen storage in a combined M.sub.xAlH. sub.6/M'.sub.y(NH.sub.2). sub.z system and methods of making and using the same	Reversible hydrogen storage compositions, methods for reversibly storing hydrogen, and methods of making reversible hydrogen storage compositions.	Research complete; seeking to license.
8,147,788	04/03/12	SNL	Direct synthesis of magnesium borohydride	Method of directly synthesizing an alkaline earth metal borohydride compound and a method to directly produce magnesium borohydride.	Still being used in ongoing research efforts.
8,105,974	01/31/12	SRNL	Destabilized and catalyzed borohydride for reversible hydrogen storage	Hydrogen storage materials, and with improved thermodynamic properties.	No longer being used in research/ no longer being pursued.
8,101,786	01/24/12	LANL	Energy efficient synthesis of boranes	Borane material for hydrogen storage, and an energy efficient synthesis of boranes (boron compounds having at least one B--H bond).	Still being used in ongoing research efforts.
8,076,382	12/13/11	ANL	Porous polymeric materials for hydrogen storage	Porous polymers that have a higher hydrogen storage capacity at ambient temperatures than benchmark materials.	Still being used in ongoing research efforts.
8,003,073	08/23/11	Air Products & Chemicals, Inc.	Autothermal hydrogen storage and delivery systems	Process of releasing the stored hydrogen from hydrogen carrier compositions ("carrier") for use in a fuel cell or internal combustion engine. The methods and apparatus provide a thermally self-sustaining or autothermal catalytic dehydrogenation of a carrier to supply hydrogen wherein the necessary heat for this reaction is derived, at least in part, from an accompanying exothermic dehydrogenation of the carrier.	Research complete; seeking to license.

Storage Patents Status

Patent Number	Award Date	Organization	Title	Description	Status
7,963,116	06/21/11	PNNL	Bulk-scaffolded hydrogen storage and releasing materials and methods for preparing and using same	Materials and processes for storing hydrogen, and uses bulk-scaffolded materials, compounds, materials, and combinations that provide storage and release of bulk quantities of hydrogen at lower release temperatures and faster release rates for operation of hydrogen-fueled on-board and off-board devices and applications.	Still being used in ongoing research.
7,951,749	05/31/11	University of Michigan	Enhancing hydrogen spillover and storage	Methods for enhancing hydrogen spillover and storage. One method includes doping a hydrogen receptor with metal particles, and exposing the hydrogen receptor to ultrasonification as doping occurs while another method dopes a hydrogen receptor with metal particles, and exposes the doped hydrogen receptor to a plasma treatment.	Research complete.
7,927,507	04/19/11	HRL Laboratories, LLC	Hydrogen storage compositions	Materials for reversible hydrogen storage that employ an alloy exhibiting reversible formation/deformation of BH_4^- anions. The materials are prepared by combining a metal hydride with a ternary alloy consisting of magnesium, boron and another metal.	Being used in continuing research at the company.
7,897,129	03/01/11	PNNL	Process for synthesis of ammonia borane for bulk hydrogen storage	The invention describes new methods for synthesizing ammonia borane, which shows promise as a chemical hydrogen storage material for fuel-cell-powered applications.	Being used in continuing research at PNNL and seeking to license.
7,846,410	12/07/10	LANL	Regeneration of polyborazylene	The invention provides methods for regenerating ammonia borane, a hydrogen storage material, from polyborazylene.	Being used in continuing research at LANL.
7,837,852	11/23/10	LANL	Energy efficient synthesis of boranes	An energy-efficient method for synthesizing boranes that are used for storing hydrogen. The boranes are prepared at close to ambient temperature without the need for thermal quenching and rapid separation, and without the energy cost of generating active metal hydrides.	Being used in continuing research at LANL.
7,790,133	09/07/10	UOP, LLC	Multi-component hydrogen storage material	A reversible hydrogen storage material that shows improved performance at low temperatures compared with binary systems such as MgH_2-$LiNH_2$.	Research complete; seeking to license.

Storage Patents Status

Patent Number	Award Date	Organization	Title	Description	Status
7,790,013	09/07/10	Safe Hydrogen, LLC	Storing and transporting energy	A method for safely storing and transporting energy in the form of hydrogen. Hydrogen is released from water by a process such as electrolysis. The released hydrogen is then stored and transported in a metal hydride slurry, which can be mixed with water to release the hydrogen at an end-use location.	Part of an emerging hydrogen storage technology project.
7,781,109	08/24/10	SNL	Hydrogen storage and integrated fuel cell assembly	A system in which housings for hydrogen storage materials are located in close proximity to a fuel cell stack. Heat generated from operation of the fuel cell stack is used to help drive the endothermic dehydrogenation reactions for releasing hydrogen from the storage materials.	Being used in continuing research at SNL.
7,754,641	07/13/10	General Electric Company	Hydrogen storage material and related processes	A hydrogen storage material consisting of a complex hydride and a borohydride catalyst. The catalyst improves the hydrogenation/dehydrogenation kinetics of the complex hydride.	No longer being used.
7,736,531	06/15/10	LANL	Composition and method for storing and releasing hydrogen	A chemical hydrogen storage system that couples an endothermic reaction (which releases hydrogen) to an exothermic reaction to achieve overall thermodynamic neutrality.	Being used in continuing research at LANL.
7,713,506	05/11/10	LANL	Metal aminoboranes	Metal aminoboranes of the formula $M(NH_2BH_3)_n$ have been synthesized. The aminoboranes can be dehydrogenated to form hydrogen and a reaction product. The reaction product can react with hydrogen to form a hydrogen storage material.	Being used in continuing research at LANL.
7,678,362	03/16/10	Ford Motor Company	High density hydrogen storage material	A hydrogen storage material that is a combination of $LiBH_4$ with MH_x, wherein greater than about 50% of M comprises Al.	Being used in ongoing research.

Storage Patents Status

Patent Number	Award Date	Organization	Title	Description	Status
7,666,807	02/23/10	SRNL	Hollow porous-wall glass microspheres for hydrogen storage	Coated hollow glass microspheres are used as part of a hydrogen storage system. The hollow glass microsphere wall defines a series of pores. The pores facilitate the placement of a hydrogen storage material within the interior of the hollow glass microsphere. The porosity of the hollow glass microspheres can be modified by either altering or reducing the overall pore size or by coating the individual hollow glass microspheres. The hydrogen storage material is sealed within the interior of the hollow glass microspheres. The coating and/or the controlled pore size enables the selective absorption of hydrogen gas through the walls of the hollow glass microsphere while isolating the hydrogen storage material encapsulated therein from other external gases and fluids.	No longer being used in research/ no longer being pursued.
7,645,902	01/12/10	LANL	Acid-catalyzed dehydrogenation of amine-boranes	A method of dehydrogenating an amine-borane using an acid-catalyzed reaction. The method may be used to generate hydrogen for portable power sources such as fuel cells.	Being used in continuing research at LANL.
7,625,547	12/01/09	Ford Motor Company	High density hydrogen storage material	A hydrogen storage material that is a combination of $LiBH_4$ with MH_x, wherein greater than about 50% of M comprises Ti, V, Cr, Sc, Fe, or combinations thereof.	Being used in ongoing research.
7,608,233	10/27/09	SNL	Direct synthesis of calcium borohydride	A method for directly preparing an alkaline earth metal borohydride, i.e. $Ca(BH_4)_2$, from the alkaline earth metal hydride and the alkaline earth metal boride. The calcium borohydride product can be used to reversibly store and release hydrogen.	Being used in continuing research at SNL.
7,544,837	06/09/09	LANL	Base metal dehydrogenation of amine-boranes	A method of dehydrogenating an amine-borane using a base metal catalyst. The method may be used to generate hydrogen for portable power sources such as fuel cells.	Being used in continuing research at LANL.
7,521,037	04/21/09	BNL	Regeneration of aluminum hydride	The invention provides methods and materials for the formation of hydrogen storage alanes, AlH_x, where x is greater than 0 and less than or equal to 6 at reduced H_2 pressures and temperatures.	Being used in continuing research at BNL and seeking to license.

Storage Patents Status

Patent Number	Award Date	Organization	Title	Description	Status
7,402,234	07/22/08	INL	Polymeric hydrogen diffusion barrier, high-pressure storage tank so equipped, method of fabricating a storage tank and method of preventing hydrogen diffusion	An electrochemically active hydrogen diffusion barrier which comprises an anode layer, a cathode layer, and an intermediate electrolyte layer, which is conductive to protons and substantially impermeable to hydrogen.	No licenses issued and no internal research being done with this patent.
7,384,574	06/10/08	SRNL	Hydrogen storage material and process using graphite additive with metal-doped complex hydrides	A hydrogen storage material having improved hydrogen absorption and desorption kinetics is provided by adding graphite to a complex hydride such as a metal-doped alanate. The incorporation of graphite into the complex hydride significantly enhances the rate of hydrogen absorption and desorption and lowers the desorption temperature needed to release stored hydrogen.	Research complete; seeking to license.
7,306,780	12/11/07	SNL	Method of generating hydrogen gas from sodium borohydride	Contacts water with micro-disperse particles of sodium borohydride in the presence of a metal catalyst, thus generating hydrogen gas.	Licensed to Nanodetex but license was terminated.
7,303,736	12/04/07	LLNL	Nanostructured materials for hydrogen storage	A system for hydrogen storage comprising a porous nano-structured material with hydrogen absorbed on the surfaces of the porous nano-structured material. The system of hydrogen storage comprises absorbing hydrogen on the surfaces of a porous nano-structured semiconductor material.	Research complete; seeking to license.
7,191,602	03/20/07	LLNL	Storage of H_2 by absorption and/or mixture within a fluid medium	Provides a container comprising a fixed volume remaining constant to within about 5% due to changes in pressure and temperature with a fluid mixture comprised of a high density of hydrogen molecules. Container will increase the density of the fluid mixture so the mixture can be withdrawn from the container and used as fuel.	Part of an emerging hydrogen storage technology project.
7,160,530	01/09/07	NREL	Metal-doped single-walled carbon nanotubes and production thereof	A method for the production of single-walled carbon nanotubes that can be used for reversibly storing hydrogen at ambient conditions with low energy input requirements.	Being used in research at NREL but no licensees.
7,094,387	08/22/06	SRNL	Complex hydrides for hydrogen storage	Melt a mixture of sodium aluminum hydride mixed with titanium under a combination of heat and pressure to provide a fused hydrogen storage material.	Being used in research at SRNL but no licensees. Part of an emerging hydrogen storage technology project.

Storage Patents Status

Patent Number	Award Date	Organization	Title	Description	Status
7,052,671	05/30/06	Safe Hydrogen, LLC	Storage, generation, and use of hydrogen	Operation of a hydrogen generator with a composition of a carrier liquid, a dispersant, and chemical hydride. A regenerator recovers elemental metal from byproducts of the hydrogen generation process.	Part of an emerging hydrogen storage technology project.
6,918,382	07/19/05	Energy Conversion Devices, Inc.	Hydrogen powered scooter	A scooter powered by a hydrogen fueled internal combustion engine utilizes an on-board metal-hydride hydrogen storage unit and the storage unit may be heated with an exhaust stream from the engine to help liberate the embedded hydrogen.	No licenses issued and no internal research being done with this patent.
6,793,909	09/21/04	SNL	Direct synthesis of catalyzed hydride compounds	Method of producing complex hydride compounds comprising mechanically milling powders of a simple alkali metal hydride material with a metal and a titanium catalyst compound followed by high pressure hydrogenation.	Being used in research at SNL but no licensees.
6,787,007	09/07/04	INL	Polymeric hydrogen diffusion barrier, high-pressure storage tank so equipped, method of fabricating a storage tank and method of preventing hydrogen diffusion	Electrochemically active hydrogen diffusion barrier made of an anode layer and a cathode layer, each including a polymer material conductive to protons and substantially impermeable to hydrogen. There will also be a voltage source operably coupled to the anode layer and the cathode layer and a catalytic material proximate an interface between at least one of the anode layer and the electrolyte layer and the cathode layer and the electrolyte layer.	Not licensed and no research being done at INL with this patent.
6,746,496	06/08/04	SNL	Compact solid source of hydrogen gas	A compact solid source of hydrogen gas, where the gas is generated by contacting water with micro-disperse particles of sodium borohydride in the presence of a catalyst, such as cobalt or ruthenium.	Licensed to Nanodetex but license was terminated.
6,708,502	03/23/04	LLNL	Lightweight cryogenic-compatible pressure vessels for vehicular fuel storage	A lightweight, cryogenic-compatible pressure vessel for flexibly storing cryogenic liquid fuels or compressed gas fuels at cryogenic or ambient temperatures.	Part of an emerging hydrogen storage technology project.
6,616,891	09/09/03	Energy Conversion Devices, Inc.	High capacity transition metal based hydrogen storage materials for the reversible storage of hydrogen	A reversible transition metal-based (including titanium, vanadium, chromium, and manganese) hydrogen storage material is capable of storing up to 4 wt.% hydrogen and reversible delivering up to 2.8 wt.% hydrogen at temperatures up to 150°C.	Being used in ongoing research at Vodik Labs LLC.

Storage Patents Status

Patent Number	Award Date	Organization	Title	Description	Status
6,593,017	09/09/03	Energy Conversion Devices, Inc.	High capacity calcium lithium based hydrogen storage material and method of making the same	Nonreversible metal hydrides can be used to store and release hydrogen. A nano-crystalline, calcium lithium based hydride is capable of storing up to 5% hydrogen by weight and can be easily ground to a fine power to facilitate hydrogen transportation and storage.	No licenses issued and no internal research being done with this patent.
6,471,935	10/29/02	U. of Hawaii	Hydrogen storage materials and method of making by dry homogenation	A method of making such reversible hydrogen storage materials by dry doping is also provided and comprises the steps of dry homogenizing metal hydrides by mechanical mixing, such as be crushing or ball milling a powder, of a metal aluminum hydride with a transition metal catalyst.	Part of a research project for hydrogen storage technology.
6,418,962	07/16/02	John Hopkins University	Low cost compressed gas fuel storage system	A compressed gas vehicle fuel storage system comprised of a plurality of compressed gas pressure cells supported by shock-absorbing bumpers positioned within a low cost, shape-conforming container.	No longer being used.
6,321,775	11/27/01	Johns Hopkins University	Compressed gas manifold	A compressed gas storage cell interconnecting manifold including a thermally activated pressure relief device, a manual safety shut-off valve, and a port for connecting the compressed gas storage cells to a motor vehicle power source and to a refueling adapter.	No longer being used.
6,262,328	07/17/01	SRNL	Container and method for absorbing and reducing hydrogen concentration	A method for absorbing hydrogen from an enclosed environment.	Being used in research at SRNL but no licensees.
6,257,360	07/10/01	Johns Hopkins University	Compressed gas fuel storage system	A compressed gas vehicle fuel storage system comprised of a plurality of compressed gas pressure cells supported by shock-absorbing foam positioned within a shape-conforming container.	No longer being used.
6,017,600	01/25/00	LLNL	Method for forming a bladder for fluid storage vessels	Lightweight, low permeability liner for graphite epoxy composite compressed gas storage vessels. The liner is composed of polymers that may or may not be coated with a thin layer of a low permeability material, such as silver, gold, or aluminum, deposited on a thin polymeric layer or substrate, which is formed into a closed bladder using torispherical or near torispherical end caps.	No licenses issued and no internal research being done with this patent.
5,965,482	10/12/99	SRNL	Composition for absorbing hydrogen from gas mixtures	A hydrogen storage composition that defines a physical sol-gel matrix having an average pore size of less than 3.5 angstroms, which effectively excludes gaseous metal hydride poisons while permitting hydrogen gas to enter.	Being used in research at SRNL but no licensees.

Storage Patents Status

Patent Number	Award Date	Organization	Title	Description	Status
5,798,156	08/25/98	LLNL	Lightweight bladder lined pressure vessels	A lightweight, low permeability liner for graphite epoxy composite compressed gas storage vessels. The liner may be used in most types of gas storage system and is particularly applicable for hydrogen, gas mixtures, and oxygen used for vehicles, fuel cells or regenerative fuel cell applications, high altitude solar powered aircraft, hybrid energy storage/propulsion systems, lunar/Mars space applications, and other applications requiring high cycle life.	No licenses issued and no internal research being done with this patent.
5,411,928	05/02/95	SRNL	Composition for absorbing hydrogen	The composition comprises a porous glass matrix, made by a sol-gel process, having a hydrogen-absorbing material dispersed throughout the matrix. The glass matrix has pores large enough to allow gases having hydrogen to pass through the matrix, yet small enough to hold the particles dispersed within the matrix so that the hydrogen-absorbing particles are not released during repeated hydrogen absorption/desorption cycles.	Being used in research at SRNL but no licensees.
5,296,438	03/22/94	SRNL	Dimensionally stable metallic hydride composition	The invention relates to a metallic hydride composition that can undergo repeated hydrogen absorption/ desorption cycles without disintegrating, and a process for making such a composition.	Research complete; seeking to license. Part of an emerging hydrogen storage technology project.

Appendix C:
Commercially Available Technology Descriptions

Detailed descriptions to be posted online in 2014

Appendix D:
Emerging Technology Descriptions

Detailed descriptions to be posted online in 2014

Appendix E:
Directory of Technology Developers

Detailed descriptions to be posted online in 2014

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