FINAL REPORT

U.S. Competitive Position in Automotive Technologies

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EXECUTIVE SUMMARY

We have used patented technology to quantify the competitive position of the US in the following FreedomCAR technologies of near-, mid- and long-term interest. These are: Automotive Fuel Cells, Onboard Hydrogen Storage, Advanced Batteries, HEV, Lightweight Materials, Power Electronics (with Ultracapacitors broken out separately), Direct Injection Combustion, Emission Control, specific combustion topics ("New Combustion Regimes"), and Hydrogen Internal Combustion Engines (ICEs).

Inventive activity in most FreedomCAR technologies is growing at a rapid pace. Figure S1 shows how total inventive activity has grown in each of the categories, which range in size from all-year-totals of over 6,000 inventions in Emissions Control to just 107 in Hydrogen ICE. (We looked at US and European patents invented worldwide, and, in order to avoid double counting of multiple patents for the same invention, the counts are for "patent families.")

Starting from little or no activity just five years ago, categories such as Advanced Batteries, Automotive Fuel Cells, Ultracapacitors and New Combustion Regimes are heating up fast. The same is true for the long-active category Emissions Control. Direct Injection had been declining for a long time but interest in this category has definitely picked up again. Finally, we see that two categories, Lightweight Materials and Hydrogen ICE, are declining. (One would think Lightweight Materials is a fast growing category, but the category as defined covers is very broad, from lightweight metal alloys to carbon fibers and metal matrix structures. Though the category as a whole is not growing, ones such as carbon composites are.

In terms of inventive activity, the US is clear leader in Automotive Fuel Cells, On-board Hydrogen Storage, Lightweight Materials, New Combustion Regimes and Hydrogen ICE. Japan ranks ahead of the US in four categories: Advanced Batteries, HEV, Ultracapacitors and New Combustion Regimes. If current trends continue, in several years Japan will overtake the US in the non-ultracapacitor areas Power Electronics.

There are some areas where neither the US or Japan is the clear leader. Emissions Control activity is fairly evenly divided among the US, Japan and Europe, and Europe ranks well ahead of the US and Japan in Direct Injection (largely diesel) engine technology.

We were asked to track Korea as a possible competitor. Based on the patent data, Korean inventive activity in these areas is non-existent, or, at best, minimal.

More than raw patented technology activity, the quality and innovation speed characteristics of the patented technology can make a difference. For, example, while the US leads Japan in New Combustion Regimes activity, Japanese patents in this category are far more highly cited than those of the US and have much faster cycle times (innovation speed).

In the body of the report we also provide company-level data in each of the categories. In some categories it is the big auto makers that are active players, in others these are far less important than other companies.

In addition to comparing patent portfolios by region and at the company level, we also have endeavored to answer quantitatively the question of how much impact on FreedomCAR technologies comes from scientific research funded by DOE and other US government agencies, versus research funded by other entities.

Each patent includes a list the examiner provides of relevant prior art that bound the claims of the patent. Most of these references (or cites) are to earlier patents, but some are to papers, books, etc. Here we used patent references to prior art in scientific journals. These represent direct bridges (links) between underlying science and the patented technology. In this work we were limited to references from US patents to papers, and the funding source data was limited to US-authored papers for which CHI had gone out and looked up the funding in libraries.

We measure impact by counting numbers of patent-to-paper links, rather than the number of funded papers. A paper that is cited by many patents, i.e., has many links to it from patents, has more impact than one that is cited by only one patent. Figure S2 shows that the US government accounts for over half the impact, that is, over half the patent-to-funded paper links are for papers funded by the US government, and over 10 percent of the links are for papers funded by DOE.

Figure S1. Growth of Inventive Activity in FreedomCAR Technologies

Patent family counts by category and first publication year 1983-2001

Figure S2. U.S. Govt Supports Half the Research
Underpinnings of Freedom Car Technologies
 Percent of Freedom Car technologies U.S. patent to U.S.-authored paper links

1306 total patent-paper links

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INTRODUCTION

CHI Research, Inc was awarded a DOE grant¹ to assess the US competitive position in FreedomCAR technologies. This work has been carried out based on innovations patented in the US Patent and Trademark Office and European Patent Office (EP) systems. Because the findings are based entirely on patenting activity and patent citation analysis, it is both quantitative and objective.

11 FreedomCAR technology categories are covered in this report:

- ◆ Automotive Fuel Cells
- ◆ Hydrogen Storage
- ◆ Advanced Batteries
- ◆ Hybrid Electric Vehicles
- ◆ Lightweight Materials
- ◆ Ultracapacitors
- ◆ Other Power Electronics (excluding Ultracapacitors)
- ◆ Direct Injection Combustion
- ◆ Emissions Control
- ◆ New Combustion Regimes
- ◆ Hydrogen Internal Combustion Engines (Hydrogen ICE)

These are defined in more detail as the findings are presented for each category. Two subcategories were also looked at. Lithium Polymer / Lithium Sulfur Batteries is a subset of Advanced Batteries and Carbon Composites is a subset of Lightweight Materials.²

The report is divided into two parts. In the first part, we present and analyze the patent data for each category. There we compare regional and company patenting trends and patent citation indicators. In the second part, we analyze data on funded research papers, cited as prior art in patents, to measure the relative impact on these technologies of scientific research, funded by DOE and other US government agencies versus other entities.

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² Too few patents were found to do the same for the High-Temperature Membranes subcategory of Automotive Fuel Cell.

PATENT ANALYSIS PROCEDURE

Identify the patents in each category

For each category the first task was to find the relevant US granted patents, and EP granted patents or published patent applications (EP patents for short). We did this for all patents published in years 1983 to 2001. As we shall see, this range of years is more than sufficient; the long-term perspective is useful, but almost all of the action has taken place in the last ten years or even considerably less time than that.

We identify patents in a category using a patent search "filter." Filter development and testing is usually the most difficult and time-consuming part of a patent analysis, and that was certainly the case here. For example, it took a number of filter design iterations to close in on the correct identification of the types of fuel cells that are applicable in mobile power applications, without being inundated in the much larger patent literature on fuel cells in general.

Patent search filters are sometimes relatively simple, but more often complex, combinations of patent invention art classifications (assigned to the patents by the patent examiners) and keywords in titles, abstracts and exemplary claims. Because we were working with a combination of US and EP documents, we used classifications based on the International Patent Classification (IPC) system.

Appendix A fully documents the final designs of the search filters for all the categories. Most of these filters are quite complex, yet the search concepts are really straightforward. For a number of the categories, the filters are of the general form: [(A OR B) AND C] NOT D. "A" is a set of IPC classifications for engines. "B" is a set of fairly explicit engine-related keywords (or keyword combinations). "C" is a set of qualifying keywords that only work well in combination with the right engine classifications or keywords, and "D" is a set of exclusionary keywords or classifications to prevent selection of unwanted material. AND, OR and NOT are logical operators, and the sets within A, B, C and D can be read as (term₁ OR term₂ OR OR term_n).

No filter is perfect; in the real world 95 percent accuracy is an excellent result. When we examine patent-level detailed data for most of these categories, we do encounter a small number of patents that do not appear to be relevant. We were able to delete non-relevant patents by hand for some of the smaller categories, but this was not practical for the categories with larger numbers of patents.

Build patent families and compute patent indicators

Early on the decision was made to include both US and European Patent Office (EP) patents, knowing full well that in many cases we would identify multiple patent documents for the same invention. In order to avoid double counting, we adopted the concept of patent families. When US and EP patent applications are filed for the same invention, the published documents, whether published EP applications or granted US or EP patents, are said to be patent “equivalents,” or members of the same patent family.³ Thus, to avoid double counting of US and EP equivalents, we count patent families, not individual patents.

The following indicators were computed for each category's set of patent families:

Number of Patent Families – Our fundamental indicator of technological activity is the number of patent families. Patent family activity (counts per year) is based on the earliest publication year for any equivalent in the family.⁴ We look at activity trends both overall and broken out by region and by company.

There is more to patent analysis than simply counting patent families and plotting trends in activity. In patent citation analysis, we compute and analyze indicators based on the prior art references on the front pages of patents. These are to earlier patents as well as to earlier published papers and other non-patent references. These enable us to determine whose patents are of higher technological impact (Citation Index), whose patents are closer to basic research (Science Index), and whose patents are in faster-moving areas (Cycle Speed).

Citation Index – Our fundamental indicator of technological quality or impact is how frequently a patent is cited in later patents. When a patent is filed and examined, the inventor or patent examiner will reference (cite) all related prior inventions that bound or limit the claims of the current invention. (For example, if I obtain a patent for an improved motor controller, my patent must cite all of the former motor controller patents whose ideas I claim to have improved upon.)

Patent references of this type are sometimes called backward citations, while the patents that are referenced are said to have received citations or forward citations. It has been shown (see validation discussion below) that key inventions tend to accumulate many forward citations because they spur inventions as companies try to improve upon or build

³ Patent equivalents all have the same “priority,” normally the original patent application filed in the home country.

⁴ The first publication date for EP patents is almost always the date when the application is first published and for U.S patents it is the date when the patent is issued. In 2001 the USPTO began open publication of some of the patent applications 18 months after their priority date. However, most of those that are being published are of foreign origin and are likely to have a published EP application equivalent. So little would have been gained here by including published US applications.

around the key invention. Another way of saying this is that a very highly cited patent is likely to contain an important technological advance that many later patents are built upon.

Since (forward) citations accumulate over time, and at different rates depending on the technology, it is important to normalize the citation frequency to get a meaningful result. Since CHI has all US patents from every technology and every year since 1975, and all EP patents since the inception of the EP in 1978, it is possible to determine the expected number of citations a patent in technology X will have N years after its issue date.

In this study we use the Citation Index, which is a normalized indicator. By dividing a patent's citation frequency by its expected citation frequency, the citation frequency of its principal IPC subclass and year, we obtain a citation index for a given patent with an expected value of 1.0. Thus a patent with a citation index of 1.5 has received 50% more citations than is typical for a patent issued in the same year and general area of technology, in this case a patent in the same IPC subclass.⁵ By summing all of the citations and dividing by the sum of the expected citations we can obtain a normalized citation index for a region or company, or all the patents in a category.

All the US and EP patents in a category are included in the computation of the Citation Index, not just one patent per family. Since EP patents documents as a rule have fewer references and hence fewer expected citations received, we compute the index for the US and EP patents using different norms, one for the US patents and one for the EP patents. Then the combined Citation Index is computed as a weighted average. Since we use both US and EP patents when computing the two indices Science Index and Innovation Speed Index, described next, the same procedure is followed there as well.

Science Index – Science Index is our surrogate for leading edge tendency. A patent when referencing prior art can cite to other non-patent references, as well as prior patents. Generally, patents that cite to many non-patent references, somewhat more than half of which are to journal scientific articles, is said to be science linked. It is a normalized indicator that divides the number of non-patent reference links by the expected number for a patent in the same year and technology. Thus a patent or region that has a Science Index of 1.2 is 20% more science-linked than expected. The idea is that inventors that incorporate journal articles into their inventions are 1) keeping up with the literature and therefore more likely to make a technological breakthrough, and 2) building upon recent developments to make a leading edge invention, rather than an incremental improvement on an existing patented invention.

Innovation Speed Index – This speed index gives an idea of how fast companies are innovating. The index is built around the Technology Cycle Time (TCT). TCT is defined to be the median age of a patent's, (or company's, or region's) references relative to its issue date for U.S patents and first publication date for EP patents. TCT is essentially the cycle time between the prior art and the current technology. This median

⁵ Examples of IPC subclasses are Fxxx (fuel injection) and Fxxx (exhaust systems)

gives an idea of whether the patent or company or region is building upon newer or older technology. TCTs vary widely by industry (computer hardware companies have 3-5 year old cycle times, while ship builders have 10-15 year cycle times).⁶

Innovation Speed Index is the Expected Cycle Time divided by the TCT, so that a patent or company or region with a speed index of 1.25 has a cycle time 25% faster than expected.

Validation of Indicators

CHI and others have extensively validated patent citation analysis. Some key papers on the subject include:

- ◆ Carpenter, et al. showed that patents associated with the IR-100 award received twice as many citations as a control set of patents of the same age and in the same technologies. The IR-100 award, established by the journal *Industrial Research & Development*, "honors the 100 most significant new technical products--and the innovators responsible for them--developed during the year" (*Industrial Research & Development*, 13, p.3, December 1980).
- ◆ Manuel Trajtenberg found that patent citation counts were correlated with independent measures such as sales and profits, which he termed the social value of products. (Trajtenberg, 1990). He also pointed out the significant limitations of simple patent counts as a measure of technological strength.
- ◆ A validation study of patent citation analysis within an industrial context was carried out by CHI Research in cooperation with Eastman Kodak Laboratories. In that study, a collection of nearly 100 Kodak patents in their core area of Silver Halide Technology were divided into sets of 16 each, and the sets given to senior lab staff for evaluation. The Kodak evaluators were senior intellectual property staff, senior lab management, and senior lab scientists. In the case of scientists, the patents they were given to rank were screened, to make sure that they did not rank their own patents. Each person was asked to rank the patents based on how much each has changed the state-of-the-art in the field of the invention. The results showed that whether a patent is cited one, two, or three times does not seem to make much difference in the peer ranking. However, patents cited more than five times were ranked far more highly by the Kodak staff. Of the 15 respondents in the study, eight gave this group of patents the highest average rating. This is a statistically significant result given that, using the binomial model, the probability of this happening randomly is 0.0002 (Albert, Avery, Narin, & McAllister, 1991).
- ◆ A 1998 study used an interesting technique to examine importance versus citation frequency (Harhoff, Narin, Scherer, & Vogel, 1998). This study was based on patents on which profitability information -- that is the private value of the patents -- was obtained. The authors considered only patents for which all the fees had been paid to keep the patents in force in Germany for the full 18 years of the patents. They queried the owners of those patents as to the asset value of the patent--essentially asking, what is the smallest amount they would have been willing to sell this patent to an independent third party for in 1980? In the German

⁶ It has been shown that for companies in the same industry, those with high citation indices and fast cycle times perform better in the stock market than slow moving and weakly cited companies. (Breitzman and Narin, 1991)

patent system the two patents in the highest value category were much more highly cited than the others. In the US patent system the patent citation frequency of the patents with an estimated value of \$20 million or above were substantially more highly cited than the patents with lower estimated values.

- ♦ Thomas found a correlation between patent citation counts and positive renewal decisions (Thomas, 1999). Essentially, he found that patents for which the renewal fees had been paid were more highly cited than their counterparts that were allowed to lapse.

The other metrics have been validated to a lesser extent, but have been developed and refined through years of use in our competitive intelligence practice. More recently, they have been shown to correlate with rises in stock prices. Specifically, it was shown (Breitzman and Narin, 2001) that a scoring method that combined the above indicators (Citation Index, Science Index, TCT) could be developed, such that the stock prices of the higher scoring companies rose faster than those of the lower scoring companies.

Note that patent activity is correlated with R&D spending but is not correlated with any other measure of success. Big companies have a lot of patents, small companies have fewer, but success depends on having a few high impact patents, rather than having a lot of mediocre patents.

Data deliverables for each category

We introduce the indicator data and findings for each category in turn below. For each category we have generated the following figures:

- ♦ top-cited patent list
- ♦ plot of overall activity trend
- ♦ plot comparing trends by region
- ♦ histogram showing companies ranked by total category patent families⁷
- ♦ grouping of bar charts comparing patent citation indicators by region and by top-10 company⁸
- ♦ tables of emerging and fading players
- ♦ set of "life cycle statistics" diagrams

We start each category's data presentation with a listing of about 50 most-highly-cited representative patents, representative because only one representative patent is selected from a given patent family. The list is presented first intentionally, so that the reader may peruse the titles and thereby start off with some confidence in the efficacy of the patent search filters.

⁷ Appendix B provides greater detail, with the counts by company broken out by year.

⁸ Appendix C contains all the numerical values for the indicator data.

Patents are partitioned into regions, based on the home address of the first inventor listed on each patent. The regions are US, Europe, Japan, Korea and Other. (If there are only a very few patent families for Korea, Korea is included in the Other region.) Since we use the home address of the first inventor only, each patent is given one address, and therefore can only be assigned to one region. Thus, patent counts by region are always whole numbers, never fractional.

CHI routinely unifies assignee names of current parent companies and their subsidiaries in our internal databases. In this report, the patent family counts and other indicators are computed and presented by unified current parent company name. (The names in the top-cited patent lists are assignee names, not necessarily the parent name.) Since there are cases where patents are "co-assigned" to several assignees (e.g., to two companies such as Toyota and Denso Corp), patent counts by company can be fractional.

In the indicator comparison bar charts, data for two 5-year periods are shown. In the discussions that follow, we comment almost exclusively on the indicator values for the more recent of the two 5-year periods (1997-2001).

The emerging and fading company analysis is done in two 3-year periods, rather than the two 5-year periods used in the indicator comparisons. Given the fast growth in most of the categories, three years should be a sufficiently long time for this. If a company has not received any patents in the last three years it is probably out of the area.

FINDINGS

Patenting activity is growing rapidly in all but one category

In this report we examine data for each of the categories independently. But it is important to get a perspective of their relative size. Figure 1 compares each of the categories' patent family activity in three 5-year periods. (The categories are arranged in the order in which they are listed in the report.) Patent family size for the eleven categories varies over a very wide range. The two largest categories are Emissions Control and Lightweight Materials, and the smallest are Hydrogen Storage and Hydrogen ICE. Also, we see that the rate of patenting is increasing dramatically in many of the categories, both large and small. Only Lightweight Materials is relatively static and Hydrogen ICE is also not growing.

More patent families as a result of adding EP documents

The rationale for combining US and EP patent data, instead of US data alone, is to get as broad a coverage of each technology as possible. In particular, when we include published EP applications we improve coverage of new inventions for which US patents have yet to be issued. It is true that about half of US patents are of foreign origin, but we believe the inclusion of EP documents creates a more international perspective than we would obtain from US documents alone.⁹

From Figure 2 we can deduce the relative amount of the total patent families in each category that result from inclusion of EP documents (the y-axis is in percent). The top (white) bands represent the percentage of families that are EP-only. Since the families that contain US and EP documents would already be there, even if the EP documents were not included, the percentage of families that are based on US patents is made up of the other two bands combined.

The categories whose patent family expanded the most by inclusion of EP patent data are Automotive Fuel Cells and Emissions Control. Those least affected are New Combustion Regimes and Other Power Electronics.

A small number of patent families are in more than one category each

Different categories covered in this study are not necessarily mutually exclusive; there is some overlap, that is, some inventions identified in one category also wind up being identified in another one. Figure 3 is a matrix showing (1) total counts for each category in the diagonal cells and (2) how many of these same patent families also are counted among patent families in other categories in the off-diagonal cells. There is some combining of the 11 Freedom Car categories here, so, for example, Fuel Cell Systems is a

⁹ Japanese origin patents considered to be any of importance are also usually filed in either the US or the EP systems or both.

combination of Automotive Fuel Cells, Hydrogen Storage and Advanced Batteries and Emissions-Combustion is a combination of the Emissions Control and New Combustion Regimes categories.

By and large the overlap issue is a minor one. There is really only one overlap worth noting, the one between Direct Injection and Emissions-Combustion; in spite of efforts to isolate these from each other, 196 of the 1627 Direct Injection patent families are also Emissions-Combustion patent families.

Automotive Fuel Cells

We call the category "Automotive Fuel Cells" to differentiate this category from fuel cells in general. Automotive Fuel Cells covers fuel cell patent types that are considered to be applicable to vehicles. These are polymer electrolyte membrane or proton exchange membrane (PEM either way), direct methanol, zinc-air fuel cells, solid oxide fuel cells (SOFCs) for mobile applications only, and relevant high-temperature membranes. We also include here (rather than with Hydrogen Storage) on-board fuel reforming system technology for converting various fuels to hydrogen.¹⁰

Phosphoric acid (PAFC), molten carbonate (MCFC), protonic ceramic (PCFC), regenerative and alkaline types of fuel cells are specifically excluded. These types of fuel cells not considered to be suitable for automotive applications.

723 patent Automotive Fuel Cell patent families were constructed, of which 267 are EP only.

Top-cited representative patents - Figure 4 is a listing of the top-cited Automotive Fuel Cell category patents, ranked by the total number of citations each patent has received from later patents. These highly-cited patents include more than one or two from the following organizations: Ballard, DOE, GM, International Fuel Cells, and the University of California.

¹⁰ The patent search for SOFCs required additional manual work. We identified 195 US and 105 EP patents for SOFC technology, but a reading of all the titles and abstracts led us to conclude that none were explicitly for mobile APU (auxiliary power unit) applications. On the contrary, essentially all appear to be for non-mobile power plant applications (from companies such as Siemens Westinghouse, Westinghouse, Gas Research Institute and Allied Signal). DOE suggested that we include SOFC patents from two known SOFC APU research centers, Delphi Automotive Systems and the University of California Davis, but none of the others. Just six patents were added. Thus, SOFC patents make up an insignificant part of the set.

An additional search was conducted for proton-conducting polymer / membrane patents useful for high-temperature fuel cell applications. In our main automotive fuel cell search we intentionally excluded "high temperature" operating conditions. In this case we looked explicitly for high temperature or elevated temperature conditions. Here too we found only six EP and two US patents, none of which refers to applications in any of the specified automotive fuel cell types.

Activity - Figure 5 shows the marked growth in patenting activity started in 1994 and has increased rapidly ever since, most dramatically in the last three years.

Trends by region - In Figure 6 we see that the growth in fuel cell patenting has been taking place across all the regions, with the only US slightly more active than Europe or Japan. Japanese growth in the last several years is relatively slower than in the other regions. (Korea is not shown. So far, no relevant patents come from this region.) ¹¹

Indicators by region - Patent citation analysis provides a much more in-depth picture of the strengths and characteristics of patented technology than a comparison of patenting activity alone. We compare Automotive Fuel Cells patent family indicators in two 5-year time periods in Figure 7. As also was shown in Figure 6, the US holds the most Automotive Fuel Cell patents, but patenting for Europe and Japan is not far behind. The three main regions are also very similar in terms of patent "quality" (Citation Index), with Japan marginally stronger and Europe slightly weaker than the US. US and Japanese Science Index values for the last five years' patents are higher than expected, while those for Europe are significantly lower. And Europe's Innovation Speed Index is slightly less than expected.

Most active companies - The companies with the most Automotive Fuel Cell patent families are ranked in decreasing order in Figure 8. The top three players are Ballard Power Systems, United Technologies and GM. Other top players are Matsushita Electric Ind., DBB Fuel Cell Engines and Toyota. Figure 9 compares patent family activity trends overall and for the top 10 companies. For most of the top players activity increases in the last few years, but DBB activity drops off considerably after 1999.

Indicators by company - Figure 10 compares patent indicators among the top ten Automotive Fuel Cell companies and institutions. In terms of recent activity, the top players are Ballard, GM and Matsushita. By a very wide margin, Toyota has the strongest Citation Index, suggesting a markedly higher "quality" for its patents in this area. The Automotive Fuel Cell patents of Dow Chemical are the most science intensive. Innovation Speed Index values vary widely among the top players and between the two time periods. In 1992-1996, Toyota had the fastest highest Innovation Speed Index. In 1997-2001, GM, Matsushita and DBB's Automotive Fuel Cell patents have had much higher than expected innovation speeds.

Emerging and fading companies - Figure 11 lists emerging Automotive Fuel Cell players based on the largest increases in patent family activity in the last two 3-year time periods (and two or more patents in the last three years.). Decreases are shown for those with two or more patents in 1996-1998, and both lists are ranked by the percentage

¹¹ The question has been raised why "Other" region counts are so low if Ballard has so many Automotive Fuel Cell patents, because Ballard is Canadian, which would put its patents into the Other region. The answer is that the vast majority of the Ballard Advanced Fuel Cell patents are assigned to German company Excelsis, a Ballard subsidiary (since 10/01 Ballard has a majority interest in Excelsis). Therefore Ballard's large set of patents is mostly included in the count for Europe.

change. Strongly "emerging" companies include United Technologies, Matsushita Electric, GM, Siemens, etc. DBB Fuel Cell Systems is flagged as a fading company (see bottom graph), even though the decline is slight.

Life cycle statistics - Figure 12 compares life cycle statistics in the last two 5-year periods. In this case, all the statistics point to a strongly growing area. The number of active companies has more than doubled, the number of patent families has tripled, and average Advanced Fuel Cell patenting activity has nearly doubled per active company. However, the percent of patent families assigned to the top 10 companies has not changed; big player activity growth continues to match the proliferation of companies.

Overall Finding - The US has a slight activity lead over its competitors, but not by a wide margin. Activity is also strong in Europe and to a lesser degree in Japan. In the US top players are United Technologies and GM in Europe it is a Ballard Power Systems subsidiary, and in Japan it is Toyota. Toyota has some very-high-impact recent patents in this technology.

High-Temperature Membranes as a Subarea of Automotive Fuel Cells

The original intent was to generate and analyze data for High-Temperature Membranes, as a subcategory Automotive Fuel Cells. The search for fuel cell high-temperature membranes turned up only a handful of patents, too few to evaluate stand-alone. DOE in-house experts confirm that it is not at all surprising that there aren't many high temperature membrane patents yet. It is reported that no patents are mentioned in any of the articles about high-temperature membranes in the last three years' annual reports.

Hydrogen Storage

This category covers technology applicable to on-board hydrogen storage for fuel cells. For the most part this storage is carried out in various alloys, in microspheres and nanostructures such as carbon nanotubes. In developing the filter we came across many patents relating to hydrogen storage in battery electrodes, and the final version of the filter tries to exclude these as much as possible.

Hydrogen Storage is a small area of technology. The final patent family count is only 108, of which 19 come from including EP patents.

Top-cited representative patents - The most highly cited Hydrogen Storage patents are listed in Figure 13. A number of the patents in the list are those of Koppers Company, Standard Oil of Ohio (BP), Daimler Benz and Energy Conversion Devices (ECD). Only about ten of the patents are anywhere nearly highly cited; the most highly cited patents have received only 17 cites each.

Activity - Figure 14 shows a slowdown in activity from the mid-1980s into the mid-1990s, and then an upswing in activity after 1994.

Trends by region - Because this is such a small area in terms of total number of patents, regional activity year-to-year is quite noisy. Nonetheless, Figure 15 shows that the US has had the most activity, that activity in Japan is now nearly up to US levels in Japan, and that European activity has faded out altogether.¹²

Indicators by region - Figure 16 compares the regional values for the four indicators. The small number of Hydrogen Storage patents limits the usefulness of the indicators; at most we can accept that the US patents in the category are highly cited and have faster innovation speeds than the other regions.

Most active companies - The companies with the most patent families are ranked in Figure 17. Energy Conversion Devices is first and Koppers Company second. When we look at Figure 18, which compares the trends for the top ten of these companies, we observe that Koppers, BP and Daimler Chrysler activity ended by the early 1990s, and Matsushita by 1996. The only significant remaining active player is Energy Conversion Devices.

Indicators by company - Figure 19 compares patent citation indicators for ECD and Matsushita (there are too few patents for any other company), but really there is nothing to compare, because the indicators shown are in different time periods.

Emerging and fading companies - Figure 20 lists two other emerging players, Kiyokawa Plating Industries and McGill University. Koppers is not listed because it is already out of the picture.

Life cycle statistics - In spite of the small size of the set we do see signs of a growth area in the life cycle statistics in Figure 21. The number of active companies and patent families is up, and patent share is diffusing from the larger to smaller players.

Overall Finding - The US appears to be the leader in the very small Hydrogen Storage technology area, but US-based Energy Conversion Devices and Canadian organizations Hydro-Quebec and McGill University appear to be where the action is.

Advanced Batteries

The types of secondary batteries included are: lithium ion, lithium polymer, lithium metal or sulfur, nickel metal hydride (NiMH), nickel zinc (some GM patents), and sodium nickel chloride, . Lead acid and NiCd are excluded, as are lithium sulfur dioxide and other lithium sulfur ion compositions.

Among these types, lithium metal and lithium polymer technologies are thought to be the next generation of advanced batteries. Sodium nickel chloride is still a viable battery technology, especially in Europe (the battery operates at 375 degrees C). Nickel Zinc is

¹² The Other region is mostly made up of Canadian-invented patents.

no longer considered as a battery candidate for propulsion applications although GM worked on it for a long time, but it is included for historical purposes.

There are 1004 patent families in this category, of which 290 come from the inclusion of EP documents, a significant 41 percent increase over the US-only count.

Top-cited representative patents - Figure 22 lists the top-cited patents, led off by a Bell Communications Research (Bellcore) patent that has received 70 cites. Bellcore and Matsushita Electric both appear more than a few times in this list.

Activity - Figure 23 clearly shows very strong growth in this area from 1996 onwards. The drop in the last year is unexplained.

Trends by region - Figure 24 compares regional trends for Advanced Batteries. Clearly Japan is the dominant region, with the US second and Europe third. The drop in patenting from 2000 to 2001 shows up in the trends for all regions except Korea.

Indicators by region - Regional patent indicator values are compared in Figure 25. Not only is Japan ahead in patent counts, it's patents are also the most highly cited (Citation Index), and among the regions with the strongest Innovation Speed Index. The US's Science Index is significantly higher than either Europe's or Japan's, but it is usually the case that Japanese-invented US patents have a relatively low linkage to science, so this is not surprising.

Most active companies - The companies with the most patent families in the category are ranked in descending order in Figure 26. By a wide margin Matsushita Electric Industrial is first with 76 families. Valence Technology with 30.5 and Science Applications International with 26 follow this.¹³ It is observed that seven of the top ten players are Japanese companies. Figure 27 compares patent family trends for the top ten companies. Clearly Matsushita is coming on strong in this area, as are a number of the others such as Sanyo, Samsung, and NGK. This is definitely a growth area, and the growth is coming out of Japan.

Indicators by company - While Matsushita Electric holds by far the most patents, it is not the strongest player in other indicator terms, as is shown Figure 28. Mitsubishi Electric's patents are cited more than the others (Citation Index) and have the fastest innovation speed, while Valence Technology's patents are significantly more linked to science (Science Index).

Emerging and fading companies - The list of emerging players in Figure 29 is long, and includes all of the top players, as well as companies such as the U.K.'s Wilson

¹³ Fractional counts occur when patents are co-assigned to multiple assignees. Science Applications Int'l (SAI) is the parent company of Telcordia, the successor to Bell Communications Research (Bellcore).

Greatbatch, the leading producer of power sources for implantable devices, such as pacemakers. At the top of the list of "fading" companies are Moli Energy and Motorola.

Life cycle statistics - Figure 30 shows the life cycle statistics, and provides additional evidence of the rapid, strong growth of this area. There are many more active companies and patent families, and the concentration of the technology is diffusing away from the top 10 players.

Overall Finding - The US ranks behind Japan in Advanced Batteries, and Europe ranks well behind the US. Matsushita Electric Industrial is the leading company, and many of the other top players are also Japanese.

Advanced Batteries Subcategory: Lithium polymer/lithium sulfur batteries

Lithium polymer and lithium sulfur batteries make up a newer and highly promising area of battery technology. We examined this subset of advanced batteries and found that the number of patents is still relatively small, but growing rapidly.

Activity - Figure 31 shows how activity in this area has grown steadily since the first patent appears in 1992 to 15 patent families in 2001.

Most active companies - Figure 32 is the short list of the companies with the most patent families. Hydro Quebec has more subcategory patents than anyone else, including Motorola and Matsushita Electric.

Hybrid Electric Vehicles (HEV)

The concept of HEVs went through a period of very high interest (PNGV) but recently emphasis has shifting toward fuel cells as the great hope. Yet there now are HEVs out on the road, and HEVs still may prove to be a viable solution to the problem.

The patent filter for HEVs was designed to try to capture any patents that appear to relate in some way, even if general, to HEVs. A number of the raw hits contained the term "hybrid vehicle" and these had to be manually reviewed to eliminate hybrids that have nothing to do with HEVs. We also included patents for regenerative braking here, excluding, of course, any that are for rail transportation.

Top-cited representative patents - 636 HEV patent families were identified, of which 149 resulted from inclusion of EP data. Figure 33 is a list of the top-cited HEV patents. It comes as no surprise that many of the big automobile companies have multiple patents in the list, including VW, GM, Ford and Toyota and Honda. Interestingly, some of the most highly cited patents are unassigned, that is, come from individual inventors. HEVs appear to have been, and may yet be, a great subject for garage inventors.

Activity - Figure 34 shows this area is also one of rapid and substantial growth since the mid 1990s, going from 30 patent families in 1995 to 100 in 2000 and 140 in 2001.

Trends by region - A very large part of this growth has come out of Japan (Figure 35.). Japanese patenting dominates HEV technology.

Indicators by region - Regional indicators are compared in Figure 36. If we disregard the indicators for the Other region (it has less than ten patent families), then Japanese HEV patents are more most highly cited and have faster innovation speed than any other region.

Most active companies - It is not surprising that by a wide margin the leading players, when ranked by patent family count as in Figure 37, are Honda and Toyota. Aisin Seiki, Ford, Nissan, GM and Daimler Chrysler follow these. Volkswagen is way down the list, yet one of its few patents is tied for first place among the most highly cited HEV patents. As is shown in Figure 38, Honda is the patent invention machine driving the high growth in HEV patenting, with Toyota ranking next but not coming on nearly as strong in recent years.

Indicators by company - Figure 39 provides a comparison of the top companies' HEV patent indicator values. Top Citation Index ratings go to GM and Ford. Toyota and Honda patents are not nearly as highly cited, and Daimler Chrysler, Hitachi and Mitsubishi Motors are less highly cited. Innovation Speed rankings are GM first, Nissan second, Toyota, Honda and Hitachi third and, again, Daimler Chrysler and Mitsubishi Motors rank well below the others.

Emerging and fading companies - Among the emerging and fading data in Figure 40, the most noticeable fact is that, at least in terms of patenting, GM appears to be leaving the field.

Life cycle statistics - As shown in Figure 41, the growth is still dominated by the big companies; the percent of patents assigned to the top 10 companies is relatively static.

Overall Finding - Japanese companies dominate HEV technology, not only in terms of activity, but also impact and innovation speed. For all the quality we see in GM and Ford HEV technology, it will take a great deal more to try to catch up to Honda and Toyota.

Lightweight Materials

This category is intended to cover a wide range of lightweight or stronger materials, presumably applicable to automotive applications, but not necessarily designated in the patents to be for automotive applications. Our intent was to include the following technologies: metal matrix composites, carbon fiber (composites), titanium, magnesium and aluminum alloys, glass fiber composites, glass or carbon fiber reinforced materials,

light weighting of materials, anything lower density than steel, high strength steels, warmforming and hydroforming.

There are nearly 4,300 patent families for Lightweight Materials in this the second largest of the categories after Emissions Control. EP documents account for 1230 of the families, expanding the US-only set by 40 percent. The identified patent set for this category is the most diverse of any of the categories; and the patents are for materials compositions and manufacturing methods, as well as applications.

Top-cited representative patents – Among the top-cited patents listed in Figure 42, many are for carbon composites, carbon fiber reinforced materials and their applications. Others are for ceramics, and are largely applicable to automotive applications. The most highly cited patent is for a shaped article and composite material. While this appears to come from a concrete company, it does entail the use of metal-matrix composites, which is why the patent is included here. Some of the other patents in the list are for cermets. These very strong and hard materials are metal composites with properties that could lead to lightweight automotive parts.

Activity - Unlike every other category in this study, the patent family activity trend for Lightweight Materials, shown in Figure 43, is relatively flat from the mid-1990s on. No doubt, this is not the case at some detailed level, where, for example, one would assume that metal matrix and nanotechnology patenting is growing.

Trends by region - As is shown in Figure 44, among all the Freedom Car categories, this is the one where Europe is growing while the US and Japan are declining.

Indicators by region - Figure 45 compares the regional indicators. Korea's set is so tiny its indicator values are not meaningful. Citation Index values are highest for the US patent families, second highest for Japan's and lower for Europe. The US has the highest Science Index value, while innovation speed is fastest for the Japanese patents.

Most active companies - As shown in Figure 46, Alcoa has the most Lightweight Materials patent families, nearly twice as many as second place players General Electric and Alcan. Automotive manufacturers rank fairly far up in the list; Toyota is fourth and Honda seventh. Patent family trends for the top 10 companies are shown in Figure 47. Almost all reflect the overall flat activity picture of this category, or even declining activity, with the possible exception of a few such as Kobe Steel.

Indicators by company - Figure 48 provides indicator comparisons for these companies. In particular we note the significantly higher Citation Index for Honeywell (AlliedSignal), the high Science Index value is for MSE and the highest Innovation Speed Index value for Toyota.

Emerging and fading companies - Because this is such a large category, the lists of emerging and fading companies in Figure 49 are extensive. Emerging players include

Alcan, Kobe Steel, Boeing and Sandvik. Among the fading players we see the names of MSE Inc., Eastman Kodak, and IBM.

Life cycle statistics - Figure 50 reveals the life cycle characteristics of an area that is fairly static over the last six years. The company count is up, but the patent count is flat, so the count of patent families per company is down.

Overall Finding - As it has been defined, the whole of lightweight materials is not growing; offsetting growth in activity in Europe are declines for the US and Japan. Still, it is mostly in US and Japanese companies that top the list of most active players. Only when we look at a sub-area such as carbon composites (see below) do we see European organizations near the top of the list.

Lightweight Materials Subcategory: Carbon Composites

We identified carbon composites patents by searching patent titles and abstracts for the word carbon in the vicinity of words such as matrix, fiber and reinforce*.

Activity - The upward trend in carbon composite patent families is evident in Figure 51. Having said that it must be recognized that we are only looking at about 15 new patent families per year over the last 5 years. Thus, the resulting set is quite small. While one would think this is a very hot area of technology, perhaps the patentability of new innovations in carbon composites is more limited than we would assume. Or, perhaps there is a great deal more in the pipeline that has yet to see the light of day.

Most active companies - The companies the most carbon composite patent families are shown in Figure 52. The US, Japan and Europe are all well represented. At the top of the list with 12 families is Honeywell (Allied Signal), followed by Nippon Oil, SNECMA, NASA and Dunlop Ltd.

Ultracapacitors

Because ultracapacitors (electric double layer capacitors) is a hot topic, the broader topic of power electronics has been split into two parts, Ultracapacitors and Other Power Electronics. This way we are able to track patenting activity and the other indicators for ultracapacitors separate from the much larger set of other power electronics inventions.

Top-cited representative patents - This category is one of the smaller ones in terms of total patent family counts, and is made up of 249 families (38 result from adding in EP documents). The top-cited Ultracapacitor patents are listed in Figure 53. Matsushita Electric Industrial holds the most highly cited patent in the list as well as a number of

other patents there.¹⁴ This area is relatively new and small, and the cite counts are also relatively low compared to other categories.

Activity - This is a very rapidly growing category. As shown in Figure 54, the patent - family count has shot up from about 10 in 1997 to nearly 60 per year in 2001.

Trends by region - Figure 55 clearly shows that this is another area dominated by Japanese patenting growth.

Indicators by region - Regional indicators are compared in Figure 56, and really it is only the US and Japan that should be compared here. Japan dominates in overall activity and growth, but is matched by the US in Citation Index and Innovation Speed.

Most active companies - Asahi Glass and NEC top the list of companies with the most patent families (Figure 57). Only two of the top ten companies are not Japanese. But, as we see in the trend comparisons in Figure 58, top-10 companies such as Alcatel and Isuzu are not taking part in the current growth. The active and growing players are mainly Asahi Glass, NEC, Honda and GE.

Indicators by company - Company indicators are compared in Figure 59. It would be nice if we could make much of GE's very high Citation Index value for 1992-1996, but this is for just a single patent (which happens to be very highly science linked)! Just the same, GE is definitely a growth player, with only Asahi Glass and NEC more active in 1997-2001. GE is also the Innovation Speed leader, but only by a small margin over NEC and Jeol, the company with the highest Citation Index.

Emerging and fading companies - Figure 60 repeats the list of growth players above, along with other smaller players. The most significant fading player is Emerson Electric.

Life cycle statistics - And this strongly emerging picture is further reinforced by the strong growth life cycle statistics shown in Figure 61. The number of active companies is up 150%, to go along with the strong growth in patenting. Perhaps it is because this is such a niche area, but the concentration of patenting within the top ten players remains fairly high and stable; the strong growth of patenting for Asahi Glass easily balances off the strong increase in total patenting by small players.

Overall Finding - Japan dominates ultracapacitor technology by a wide margin, with Asahi Glass and NEC as the leading companies. GE is one US company that shows increased, recent activity.

¹⁴ Surprisingly, Maxwell Laboratories does not appear in the top-cited list. In fact, Maxwell Labs only holds two patents in this category.

Other Power Electronics

This category covers a grab bag of power electronics technologies exclusive of ultracapacitors. These include automotive integrated power mode / modules (AIPM), more generally power electronics and motor controls, particularly for vehicles, power inverters, DC-DC converters, AC induction motors not 3 phase, switched reluctance motors, motor manufacturing cost reduction, power switches, and so on. No patents were found for AIPMs per se. Many appear to be for electric motor drive sensing and controls, but not always for the drive motor of an HEV.

It is a good thing that this category is treated separately from Ultracapacitors. If the two categories had been combined, the 1157 Other Power Electric patent families we identified would have overwhelmed any data we might have hoped to glean about Ultracapacitors.¹⁵

Top-cited representative patents - Figure 62 lists the top-cited Other Power Electronics patents. From the titles we see that many relate to control of motors, position sensing, and so on, as we would expect, and great many in the list are from GE, Emerson Electric and Bosch.

Activity - Other Power Electronics patenting shot up after the early 1990s. Figure 63 shows patenting rates over 100 per year since 1998, when it peaked around 150. For some reason the trend has been downward ever since.

Trends by region - And we can see from the regional trends in Figure 64 that the post-1998 drop-off occurs relatively the same in both the US and Japan, and finally hits Europe in the last year.

Indicators by region - Figure 65 shows comparisons of regional patent indicators. While the US has more Other Power Electronics patents than second-place Japan, Japan's patents are slightly more highly cited than the US's --- much more than Europe or Korea's patents in the category --- and have the fastest innovation speed.¹⁶ Japanese patents have a much lower Science Index than those of the US, Europe, and are even slightly less science linked than the patents of Korea.

Most active companies - The companies with the most patent families are ranked in order in Figure 66. At the very top are Honda, Emerson Electric and GE. All the big auto companies are present in the list. Figure 67 compares the patent family activity trends for the top 10. By a wide margin, Honda has the strongest recent activity growth.

¹⁵ This category is one of the two with the least enlarging of patent families by inclusion of EP documents. Of the 1157 patent families, only 117 come from the EP, an addition of only 11 percent.

¹⁶ Once again, the Other region's patents are too few in number to put much reliance on these indicators for that region's patents.

Indicators by company - A number of different companies take on leading positions in one aspect or another of the patent indicators, compared in Figure 68. We already know Honda has the most patents. But these are by no mean among the highest cited; it is Aisin Seiki's Other Power Electronics patents that are by far the most highly cited. (Cf. Bosch's, which are the least most cited.)

Emerson's patents are very science linked, way, far and above any of the others, but they also have the slowest Innovation Speed Index. Hitachi and Honda take first and second place in Innovation Speed Index, with GM and Ford tied for in third position. So here it is not just the Japanese that are innovating at a faster than expected speed.

Emerging and fading companies - Honda, Bosch and GE lead the list of emerging companies in Figure 69. Among the fading companies listed in are Emerson Electric, Valeo, Denso, Matsushita Electric and Daimler Chrysler.

Life cycle statistics - Figure 70 shows growth in numbers of companies and patents across the last two 5-year periods, but the other characteristics are relatively flat. The top ten companies have about a one third share of the patents, and that share is static.

Overall Finding - This is another area that has had strong growth, but then an obviously real drop off in activity in the last three years, particularly for the US. Thanks largely to companies like Honda and Aisin Seiki, it appears that Japan will probably overtake the US within a few years. The slide in US activity comes from declines for companies like Emerson and GE, and continued low activity from GM, Ford and others.

Direct Injection Combustion (DI)

This category covers, principally, diesel engine technology, but is slightly broader than diesel because it also includes spark ignited direct injection as well. For direct injection engines that use a spark plug rather compression to ignite the fuel, we endeavored to exclude patents for the engines themselves. We also took steps to keep direct injection used in exhaust control systems out of this category (and to include it in Exhaust Control). Specifically, in the Direct Injection filter we exclude patents in the IPCs for exhaust technology. To a large extent this strategy was successful, but some overlap between Direct Injection and Exhaust Systems still occurred. The other most significant exclusionary term in the filter was added to keep out diesel fuels.

Top-cited representative patents - This is the third largest of the categories, with a total of 2245 patent families (EP-only patent families account for 639 of these). Figure 71 lists the 50 top-cited DI patents. At the top of the list is a patent for a fuel injector from Diesel Technology Co., with 87 cites. Diesel Technology holds other patents in the list. Other companies with more than one or two patents include Denso, Bosch, and Caterpillar. The big auto companies are largely missing from the list.

Activity - This is a category that has had its ups and downs. Figure 72 shows activity declining steadily from the mid-1980s, but starting to heat up again quite strongly starting in 1996. It is too soon to tell if the drop in 2001 is the beginning of a long-term decline or not.

Trends by region - Europe holds more patents than any other region. But, as is shown in Figure 73, all regions share the general pattern of the trends, including the decline and increase, the slowing rate between 1999 and 2000 and a drop-off in the last year. We wonder if last year's drop-off is the result of some external factor, such as a patent office problem, since it appears to be occurring across the board.

Indicators by region - This is the one area where Europe has more activity than any other region (Figure 74). While that may be so, its patents are not nearly as highly cited as those of Japan and the US, nor are its patents in the category as science linked as those of the US, or even of Japan. The innovation speed for Japan is highest, followed by Europe and then the US.

Most active companies - The ranking in Figure 75 of the companies with the most patents is topped by a wide margin by European company Robert Bosch. Toyota, Daimler Chrysler and Nissan rank next, but well below Bosch. Among the top 10 companies, only four are European: Bosch, Daimler Chrysler¹⁷, Fiat, and MAN AG. So, it appears that the strong European overall count is coming from a very large number of smaller players.

Trends for the top 10 companies are compared in Figure 76. Taking the long term view, Bosch is not among those with noticeable increases in patenting activity, but others such as Daimler Chrysler, Nissan, Yamaha Motor, and Ford are. If it were not for the pattern of drop-offs in 2001, we might also add MAN AG and GM to that list.

Indicators by company - Figure 77 provides comparisons of the indicators. In the last two 5-year periods, most of the companies, Robert Bosch excepted, are significantly up in patenting activity. The companies with the higher citation indices are Caterpillar, MAN AG, Fiat, GM and Ford. Caterpillar's Direct Injection patents have a rather high Science Index. Innovation speeds values are all fairly similar, with the exception of a much higher value for Yamaha.

Emerging and fading companies - In Figure 78, the emerging company list is dominated by automobile companies, plus Man AG, Siemens and Hitachi. Toyota is listed among the faders, though the fade is not that strong, and Bosch is listed, but it's activity is more correctly characterized as flat over the last two 3-year time periods.

Life cycle statistics - The histograms in Figure 79 show that patenting is up only 28 percent over the two periods, but the number of companies with patents in the category has nearly doubled. So the average number of patents per company is up significantly.

¹⁷ 88 of Daimler Chrysler's Direct Injection patents are European-invented.

The percent of patents for the top 10 companies is down slightly; the growth of patenting for the top 10 companies does not quite offset that for the 150 smaller companies.

Overall Finding – This is the one technology where Europe ranks highest in activity, though well behind the Japan and the US in average patent quality. After a 10-year decline, in 1995 patenting rates began to increase significantly over the next four years, then slowed down two years ago and actually declined last year. This pattern is the same in all three regions.. The US still remains third, slightly behind Japan.

Emissions Control

This category covers all aspects of the technology to deal with the problem of emissions, from particulates to NOx reduction. Our intent was to include exhaust system direct injection here, rather than in the Direct Injection category. This is the largest of all the categories, with 6064 identified patent families, of which 1980 of the families are EP-only.

Top-cited representative patents – The approximately 50 top-cited Emissions Control patents are listed in Figure 80. At the top of the list are a few patents concerned with emissions noise reduction, in spite of the explicit filter terms to try to exclude them!. Such patents may or may not be relevant, depending on one's point of view, but in any case noise reduction patents constitute a minority of the patents. The vast majority are concerned with emissions reduction, either through catalytic conversion or engine controls. The companies in the list are a mix of major vehicle manufacturers and equipment companies such as W.R.Grace, NGK and Siemens.

Activity – Obviously this is a very major area of technology under any terms of reference. Not only are there thousands of patents, Figure 81 clearly shows that patenting activity is up strongly, and has been climbing throughout the last decade. In 1991 the rate was about 200 a year and in 2001 it is 700 a year.

Trends by region - Regional trends are compared in Figure 82. The amount and growth of patenting activity has been fairly evenly divided among the US, Japan and Europe, with Japan only falling behind in the last several years.

Indicators by region – Indicator comparisons are given in Figure 83. The patent family count for the last five years for the three regions are relatively comparable; Europe has slightly more than the other two. But European patents are not on average of as high impact as the patents of the other two regions. Japanese, US and European Emissions Control patents are respectively 40 percent more highly cited than expected, 10 percent more highly cited than expected, and 20 percent less highly cited than expected (Citation Index). US Emissions Control patent families are more science-linked than those of the other regions (Science Index), while Japanese Emissions Control patents are have at least a 20 percent higher Innovation Speed Index.

Most active companies – The companies the most patent families (see ranking in Figure 84) are led by Toyota, Ford, Honda, Nissan, Daimler Chrysler, and Siemens, GM, Emitec, Bosch and Denso. "Individual Patenter" is not a single inventor, but is the total of all unassigned patents in the set. Figure 85 provides a comparison of the patent family trends for the top 10 companies. None of the top companies is fading out; all are active, with the biggest recent increases for Ford and Honda.

Indicators by company – These are compared for the top 10 companies in Figure 86. All companies except Denso have solid patent activity increases between the two time periods. All show expected or higher Citation Index values (the strongest index values are for Ford and Daimler Chrysler). The one notable exception of Emitec; its patents are cited significantly less. Also, Emitec's innovation speed is much lower than expected. Only Toyota, Siemens and GM have slightly higher than expected science index values.

Emerging and fading companies – The top of Figure 87 lists the emerging players, most notably Ford, Volkswagen (VW's patent count is too small to make into the top 10 here, but the increase in patenting here appears significant)¹⁸, Siemens, Nissan and Daimler Chrysler. Significant fading players indicated in that list are Denso, W. R. Grace (now out of this area entirely?) and Porsche.

Life cycle statistics – The life cycle statistics in Figure 88 show that it is an area that is fast growing in terms of numbers of patents, but not of the number of companies. In fact, this is one of only two categories in which the concentration of patenting among the biggest players is increasing; the top-10-company share of all patents is up from 40 to 45 percent.

Overall Finding – Except in the last two years when Japanese patenting declines, activity is evenly divided among the US, Europe and Japan. Drop-off aside, Japanese patenting has the strongest quality and innovation speed.

New Combustion Regimes

The New Combustion Regimes category is highly focused in the following technologies: fuel-air mixing in CIDI, secondary fuel injection, variable compression ratio, diesel fuel in-cylinder swirl, and variable valve activation. The category title was carefully chosen so as not to confuse it with some broader view of combustion technology.

We identified 715 patent families, of which only 72 were added with the inclusion of EP documents.

Top-cited representative patents - Figure 89 lists approximately 50 top-cited patents for this category. Regrettably, few of the titles reveal why these patents were picked.

¹⁸ Is this a significant new area of emphasis for VW? VW is not among the major patenting auto companies.

Rest assured that there was something in the abstracts and exemplary claims of these patents that caused them to be selected.

Activity - Figure 90 clearly shows that after a long period of gradually increasing activity, there has been significant upswing in New Combustion Regimes patenting in just the last three years. In 2001 the count was over 90, coming up from 50 in 1998.

Trends by region - Regional trends are compared in Figure 91. All regional activity increases over time; but the biggest relative increase is Japanese. There is a drop-off in Japanese patenting in 2001.

Indicators by region - Figure 92 provides comparisons of regional patent indicators. In terms of activity, the regions are ranked US first, Japan second and Europe third. Here again we observe the large relative increase across the two time periods for Japan. And it is the Japanese region's patents in this category that are the most highly cited patents (Citation Index) and have the highest innovation speed.

Most active companies - Figure 93 ranks the most active companies by patent family count, with Toyota, Ford, Nissan and GM at the top of the list. Activity trends for the top 10 companies are compared in Figure 94. While absolute patent counts per year are still relatively small, the recent activity increases are largest for Toyota, Ford and Nissan, but not for GM. (The drop-off in patenting for Toyota in the last year largely explains the regional drop-off for Japan).

Indicators by company - Indicators for the top 10 are compared Figure 95. Among companies with at least ten category patents in a period, Yamaha and Nissan have the highest Citation Index values; in both cases their patents are cited nearly three times more than expected. (Disregard the very high Science Index for Caterpillar's three 1992-96 patent families.)

Emerging and fading companies - In Figure 96 Ford, Nissan, Bosch and Toyota are listed as emerging companies; and Honda, Yamaha and Daimler Chrysler are identified as fading companies.

Life cycle statistics - As Figure 97 shows, this is another category where patenting activity is becoming more concentrated in the top 10 companies larger players. Over the last two 5-year time periods this has increased slightly, from 45 to 49 percent.

Overall Finding - While the US region leads in overall activity, Japanese patenting stands above the US (and Europe) in quality and innovation speed by a wide margin.

Hydrogen ICE

This category covers hydrogen-fueled internal combustion engines, including ones where hydrogen is not combusted alone. The filter searches for explicit references to hydrogen

engines, and also searches more broadly for mention of hydrogen within internal combustion engine patent classes. Patents relating to chemical compositions were successfully kept out by use of terms for fuel cells, batteries, biomass, and so on.

This is a very small area, with just 107 patent families. **Top-cited representative patents** - Figure 98 is a list of top-cited patents, although the set is so small that the ones at the bottom of the list could hardly be termed highly-cited. This is another category where there is a large number of unassigned patents (assignee name is blank or "individual patentee"). Many of the big auto companies have one or two patents in the list, but for the most part these top-cited patents come from other sources.

Activity - As is shown in Figure 99, this is both a small and declining area of patenting. The uptick in activity in the early 1990s probably reflects renewed interest in this area, but the subsequent decline in activity says that interest has gradually flagged ever since.

Trends by region - Figure 100 shows that patenting in this category is almost all coming out of the US. There has been nothing out of Japan since the mid-1990s.

Indicators by region - Figure 101 looks at the regional indicators. While the US is the main region of activity, the US patents in this category are not highly cited. With the decline in activity in such a small, specialized area, it is not surprising that there would be a low level of citations.

Most active companies - The counts per company in Figure 102 are very small. Topping this short list are Mazda Motor, German Aerospace Center and SWRI. The activity plots for the top 10 companies are plotted in Figure 103. Except for one patent family for GM in 2000, nothing is at all recent.

Indicators by company - Indicators for just 3 of the companies are compared in Figure 104. These data are too limited to be of value; there is only one patent in 1997-2001.

Emerging and fading companies - The same limited value applies to Figure 105.

Life cycle statistics - Figure 106 reinforces the view that this technology is declining. There are less companies active in the last five years and less patents.

Overall finding - This is a very small and gradually declining area of activity centered in the US. From the patent record it appears that, if research is going on in this area, it is in places like SWRI and small specialty firms.

PATENT-PAPER LINKAGE ANALYSIS

We have quantified the impact on FreedomCAR technologies of scientific research, funded by DOE and other US government agencies versus other entities. We did this by examining the number and character of patent to paper linkages, specifically US patents and the US-authored papers.

When a US patent is issued it includes on the front page the examiner's list of all relevant prior art, whether contained in patents or other publications. Among the non-patent prior art are references to books, catalogs, newspapers, and, most importantly, to scientific papers in refereed journals and the like. These references to scientific journals represent direct bridges between underlying science and the patented technology.

Patents with large numbers of references to scientific papers are said to be closer to basic research. Companies at the forefront of a technology tend to have higher science linkage than their competitors, and this type of referencing is growing rapidly. The average is roughly one per patent. Drug & medicine patents often have five or more, leading edge biotechnology patents 15 or more (Genentech's patents 25 or more). On the whole, in automotive technology the number is rather low, about 1 per every two patents! That is because so much of automotive technology is very much at the applied end of the spectrum.

As part of our work for NSF, CHI researchers have gone into libraries and looked up by hand the funding information for all US-authored papers in over 2,500 journals, covering most publication years between 1987 and 1999. That information alone would not suffice here, were it not also true that CHI, as an ongoing part of maintaining its in-house patent databases, has unified all the non-patent references on the front pages of US patents (as received these references are not standardized in any way). The unique capability to bring together these two very labor-intensive efforts makes it possible for us to identify the direct patent-to-paper linkages between US patents and US-authored papers.¹⁹

We measure the impact of funding research by counting patent-to-paper links, rather than numbers of papers that are funded. Just as in patent-to-patent and paper-to-paper citation analysis, it would seem reasonable that a paper cited in many different patents would have a higher impact than one cited by only a single patent.

The 12,423 FreedomCAR US patents contain about 6,000 front-page references to scientific publications of all types, of which 3,700 are to journal type publications. But not all these are to papers that are US-authored, and not all are published in the years for

¹⁹ Although EP patents, as well as US patents, make up the category patent sets, we were only able to match funded paper data to the US patents. In addition, be aware that front page patent references are to scientific papers of both US and foreign authorship, but the data available is for US-authored papers only.

which we have found funding data. When all is said and done, we identified 1,306 patent-to-paper links to US-authored papers for which we have valid funding data.²⁰

Funding impact is based on counts of patent-to-paper links, rather than raw counts of numbers of different papers cited. Only by measuring counts of patent-to-paper links are we measuring funding impact. A paper that is referenced by multiple patents is counted multiple times, and should be; its influence is more widespread than that of a paper that is only cited once.

Figure 107 is a pie chart that shows the percent distribution of patent-to-funded-paper links for FreedomCAR technologies patents. US government funding accounts for 52 percent of these links (DOE part is 11.5 %). The next two largest source categories are foreign governments & non-profits (18.2 %) and companies (14.8 %).

Figure 108 shows counts of patent-to-funded paper links broken out by CHI's coding of funding organization (or organization type). Fortunately, each U.S. government agency has been assigned a different code. In the table, the organizations are ranked by total patent-to-paper links. After foreign governments & non-profits and all companies combined, the top-ranked total linkage counts are those for NIH (190 links), DOE (150), Navy (72) and NSF (68). From this we conclude that DOE funding has more impact on FreedomCAR technology than funding from any other single organization except NIH.²¹

In the table the counts have also been broken out into groupings of FreedomCAR categories. The principal impact of Foreign government & non-profits is in Fuel Cell Systems, that of the companies is in Lightweight Materials. Almost all the impact of NIH funding is in Emissions.²²

The column totals show that the patent-to-paper links are mainly in the three groupings, Fuel Cell Systems, Lightweight Materials and Emissions Control/Combustion. The impact of funded papers in the other areas is relatively insignificant. Direct Injection (Diesel), HEV and Hydrogen ICE are surprisingly devoid of patent-to-funded-paper links.²³

Figure 109 is the analogue of Figure 107, but shows that distributions from the groupings shown in the table. US government funding accounts for roughly half the funded paper impact, except in Power Electronics, where it accounts for only 32 percent. In

²⁰ Funding information is not available for all the linked papers. We know that it is not uncommon for a paper to fail to acknowledge the funding source, especially if the inventor is funded by his company or he is working at, say, a DOE lab. If there is no funding acknowledgement, we have no way of identifying the funding source. We assume that there is some undercounting of funded papers as a result of this.

²¹ It is highly unlikely that any single foreign government or private company accounts for as many links.

²² We have been told that NIH has funded heavily in pollution control, notably particulates emissions.

²³ As a sanity check, we went through several years of the diesel patents by hand and looked at their front page references. The relatively few non-patent references that were there were to either books or references that appeared to be "pamphlets" or "brochures."

Automotive Fuel Cell Systems, the US government share is 45 percent (DOE 19 %); foreign government funding impact is second at 27 percent. In Lightweight Materials, the US government sharer is 51 percent (DOE 9 %); private companies, not foreign governments, rank second with 26 percent. Power Electronics impact share is split roughly a third each to US government (DOE 8 %), companies and foreign governments. Finally, in Emissions and New Combustion Regimes, the US government share of the impact is 64 percent (DOE just 3.6 %); US non-profits rank second with 17 percent.

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Figure 1
Number of Patent Families by Category - Three 5 Year Time Periods

Figure 2
Impact of the Addition of EPO Documents to the Patent Families

Figure 3

Extent of Overlap of U.S. Patents Among Categories

Overlap Matrix

Category	Automotive Fuel Cell Systems	HEV	Lightweight Matls	Power Electronics	Direct Injection	Emission Contr / New Combust Regimes	Hydrogen ICE
Automotive Fuel Cell Systems*	1306	3	9	5		1	
HEV	3	497		53	8	17	
Lightweight Matls	9		3162		3		
Power Electronics**	5	53		1228	1	4	
Direct Injection		8	3	1	162	196	4
Emission Contr / New Combust Regimes*	1	17		4	196	4825	18
Hydrogen ICE					4	18	93

* Automotive Fuel Cells, Hydrogen Storage and Advanced Batteries combined

** Ultracapacitors and Other Power Electronics combined

*** Emissions Control and New Combustion Regimes combined

Figure 4

Top Cited Representative Automotive Fuel Cell Patents

Patent	Family Number	Iss. Date	Pub. Date	Cites Rec	Assignee Name	Title
4876115	10035	*****	*****	76	USA ENERGY DEPT	ELECTRODE ASSEMBLY FOR USE IN A SOLID POLYMER ELECTROLYTE FUEL CELL
5248566	10064	*****	*****	56	USA ENERGY DEPT	Fuel cell system for transportation applications
4769297	10028	*****	*****	55	INTERNATIONAL FUEL CELLS CORP	Solid polymer electrolyte fuel cell stack water management system
5234777	9	*****	*****	48	UNIV CALIFORNIA, REGENTS	Membrane catalyst layer for fuel cells
5108849	10048	*****	*****	45	CANADA NAT'L DEFENCE MINISTE	Fuel cell fluid flow field plate
5211984	10055	*****	*****	44	UNIV CALIFORNIA, REGENTS	Membrane catalyst layer for fuel cells
5252410	10065	*****	*****	39	BALLARD POWER SYSTEMS INC.	Lightweight fuel cell membrane electrode assembly with integral reactant flow passages
5084144	10045	*****	*****	38	PHYSICAL SCIENCES INC.	High utilization supported catalytic metal-containing gas-diffusion electrode, process for making it, and cells utilizing it
4647516	10015	*****	*****	37	MITSUBISHI DENKI KK	INTERNAL REFORMING TYPE FUEL CELL
4968583	70	*****	*****	37	CANADA NAT'L DEFENCE MINISTE	Novel fuel cell fluid flow field plate
5316871	10081	*****	*****	36	GENERAL MOTORS CORP.	Method of making membrane-electrode assemblies for electrochemical cells and assemblies made thereby
E0399833	286	**	*****	36	STANDARD OIL CO.	Novel solid multi-component membranes, electrochemical reactor and use of membranes and reactor for oxidation reactions.
4910099	10038	*****	*****	33	USA ENERGY DEPT	PREVENTING CO POISONING IN FUEL CELLS
5599638	10137	*****	*****	32	UNIV SOUTHERN CALIFORNIA	Aqueous liquid feed organic fuel cell using solid polymer electrolyte membrane
5620807	10143	*****	*****	31	DOW CHEMICAL CO.	Flow field assembly for electrochemical fuel cells
5264299	10071	*****	*****	30	INTERNATIONAL FUEL CELLS CORP	Proton exchange membrane fuel cell support plate and an assembly including the same
5242764	10063	*****	*****	29	BCS TECHNOLOGY, INC.	Near ambient, unhumidified solid polymer fuel cell
5262249	10069	*****	*****	27	INTERNATIONAL FUEL CELLS CORP	Internally cooled proton exchange membrane fuel cell device
5271916	10073	*****	*****	27	GENERAL MOTORS CORP.	Device for staged carbon monoxide oxidation
5176966	10050	*****	*****	26	BALLARD POWER SYSTEMS INC.	Fuel cell membrane electrode and seal assembly
5399184	10096	*****	*****	26	CHLORINE ENGINEERS CORP. LTD	Method for fabricating gas diffusion electrode assembly for fuel cells
5635039	10148	*****	*****	26	LYNNTech INC	Membrane with internal passages to permit fluid flow and an electrochemical cell containing the same
E0718903	174	**	*****	26	JAPAN GORE-TEX, INC.	An ion exchange membrane and electrode assembly for an electrochemical cell
5344721	10087	*****	*****	25	TOSHIBA KK	Solid polymer electrolyte fuel cell apparatus
5460905	10110	*****	*****	25	MOLTECH CORP.	High capacity cathodes for secondary cells
4824741	63	*****	*****	24	INTERNATIONAL FUEL CELLS CORP	SOLID POLYMER ELECTROLYTE FUEL CELL SYSTEM WITH POROUS PLATE EVAPORATIVE COOLING
5484666	32	*****	*****	24	BALLARD POWER SYSTEMS INC.	Electrochemical fuel cell stack with compression mechanism extending through interior manifold headers
4746329	10024	*****	*****	23	ENERGY RESEARCH CORP.	Methanol fuel reformer
5525436	37	*****	*****	22	CASE WESTERN RESERVE UNIV.	Proton conducting polymers used as membranes
E0574791	117	*****	*****	21	AVENTIS RESEARCH & TECHNOL	Polymer electrolyte membrane and process for its manufacture
4865926	10034	*****	*****	20	HUGHES AIRCRAFT CO.	GAS PERMEABLE ELECTRODE FOR ELECTROCHEMICAL SYSTEM
4877693	10036	*****	*****	20	ENERGY RESEARCH CORP.	FUEL CELL APPARATUS FOR INTERNAL REFORMING
5187025	10052	*****	*****	20	ANALYTIC POWER CORP.	Utilized fuel cell structure
5350643	10090	*****	*****	20	HITACHI LTD.	Solid polymer electrolyte type fuel cell
4532192	49	*****	*****	19	ENERGY RESEARCH CORP.	FUEL CELL SYSTEM
4751151	10025	*****	*****	19	INTERNATIONAL FUEL CELLS CORP	Recovery of carbon dioxide from fuel cell exhaust
5284718	10076	*****	*****	19	BALLARD POWER SYSTEMS INC.	Fuel cell membrane electrode and seal assembly
5432021	23	*****	*****	19	BALLARD POWER SYSTEMS INC.	Method and apparatus for oxidizing carbon monoxide in the reactant stream of an electrochemical fuel cell
5523177	10125	*****	*****	19	GINER, INC.	Membrane-electrode assembly for a direct methanol fuel cell
5527632	10127	*****	*****	19	ROLLS-ROYCE AND ASSOCIATES	Hydrocarbon fuelled fuel cell power system
4473622	10006	*****	*****	18	UNITED TECHNOLOGIES CORP.	Rapid starting methanol reactor system
4737161	58	*****	*****	18	INTERNATIONAL FUEL CELLS CORP	Compact hydrogen generator
4759997	10027	*****	*****	18	HITACHI LTD.	Air supply apparatus for fuel cell system
5340664	10086	*****	*****	18	CERAMATEC, INC.	Thermally integrated heat exchange system for solid oxide electrolyte systems
5395705	10095	*****	*****	18	DOW CHEMICAL CO.	ELECTROCHEMICAL CELL HAVING AN ELECTRODE CONTAINING A CARBON FIBER PAPER COATED WITH CATALYTIC METAL PART
4918637	10032	*****	*****	17	UNITED TECHNOLOGIES CORP.	HYDROGEN-HALOGEN FUEL CELL WITH IMPROVED WATER MANAGEMENT SYSTEM
5240790	10061	*****	*****	17	ALLIANT TECHSYSTEMS INC.	Lithium-based polymer electrolyte electrochemical cell
5573866	10133	*****	*****	17	INTERNATIONAL FUEL CELLS CORP	Direct methanol oxidation polymer electrolyte membrane power system
5637415	89	*****	*****	17	GENERAL MOTORS CORP.	Controlled CO preferential oxidation
5641596	10151	*****	*****	17	UNIV CALIFORNIA, OFFICE OF TEC	Fuel cell with interdigitated porous flow-field
4657829	10017	*****	*****	16	UNITED TECHNOLOGIES CORP.	Fuel cell power supply with oxidant and fuel gas switching
5543238	10132	*****	*****	16	SIEMENS AG	Fuel cell and method for moistening the electrolyte of the fuel cell
E0560295	10407	**	*****	16	HITACHI LTD.	Polymer electrolyte type hydrogen-oxygen fuel cell.
4788110	10030	*****	*****	15	ENERGY RESEARCH CORP.	Fuel cell with partially shielded internal reformer
5262250	10070	*****	*****	15	WATANABE, MASAHIRO	Structure of electrochemical cell for wetting diaphragm of solid polymer electrolyte
5366819	15	*****	*****	15	CERAMATEC, INC.	Thermally integrated reformer for solid oxide fuel cells
5403675	10098	*****	*****	15	MAXDEM INC.	SULFONATED POLYMERS FOR SOLID POLYMER ELECTROLYTES
5482680	31	*****	*****	15	BALLARD POWER SYSTEMS INC.	Electrochemical fuel cell assembly with integral selective oxidizer
5733347	10173	*****	*****	15	INTERNATIONAL FUEL CELLS CORP	Compact fuel gas reformer assemblage
E0577291	35	*****	*****	15	JOHNSON MATTHEY PLC	Process for the preparation of electrode assemblies

Figure 5
Automotive Fuel Cell Patent Family Activity
1983-2001

Figure 6
Number of Automotive Fuel Cell Patent Families by Region
1983-2001

Figure 7
Patent Family Indicators by Region for Automotive Fuel Cells
Two 5 Year Time Periods

Figure 8
Automotive Fuel Cell Companies With 5 or More Patent Families
1983-2001

Figure 9
Patenting Trends for Top 10 Automotive Fuel Cell Companies

Figure 10
Patent Family Indicators for Automotive Fuel Cell Companies
Two 5 Year Time Periods

Figure 11

Emerging and Fading Automotive Fuel Cell Companies

Two 3 Year Time Periods

Emerging Companies

Companies with the Largest Increase Among Those with 2+ Patents in 1999-2001

Company	1996-98	1999-2001	Increase	% Increase
United Technologies Corp	2	21	19	950%
Matsushita Electric Industrial Co Ltd	5	23.5	18.5	370%
General Motors Corporation	6	23	17	283%
Siemens Ag	1	17.5	16.5	1650%
Ballard Power Systems Inc	11	25	14	127%
California Inst Of Technology	1.5	14.5	13	867%
Plug Power Inc	0	13	13	Infinity
3M	0	9	9	Infinity
Asahi Glass	0	6	6	Infinity
Kernforschungsanlage Julich Gmbh	0	6	6	Infinity
Toyota Motor Corporation	8	13	5	63%
Johnson Matthey	1.5	6	4.5	300%
University Of California	4	8	4	100%
Ferro Corporation	0	4	4	Infinity
Nisshinbo Industries Inc	0	4	4	Infinity
Sumitomo Chemical Co Ltd	0	4	4	Infinity
Magnet-Motor Ges. Fr. Magnetmotorisched. M	0	4	4	Infinity
University Of Chicago	0	4	4	Infinity
W.L. Gore & Assoc., Inc.	0	3.5	3.5	Infinity
Exxon Mobil Corp.	1	4	3	300%
Foster-Miller Inc.	0	3	3	Infinity
Individual Patenter	1.3	3.5	2.2	169%
Daimler Chrysler Ag	6	8	2	33%
Honda Giken Kogyo	6	8	2	33%
US DOE	0	2	2	Infinity
Gas Technology Institute	0	2	2	Infinity
Fuji Electric Co Ltd	0	2	2	Infinity
Honeywell Inc	1	3	2	200%
E.On Ag	1	3	2	200%
Vodafone Group Plc	0	2	2	Infinity
Engelhard Corp	0	2	2	Infinity
Little (Arthur D.), Inc.	0	2	2	Infinity
Manhattan Scientifics Inc	0	2	2	Infinity
De Nora S.P.A.	0	2	2	Infinity
Zentrum Sonnenenergie Wasser-For Baden W	0	2	2	Infinity
Volkswagen Ag	0	2	2	Infinity
Japan Storage Battery	0	2	2	Infinity
Southwest Research Institute	0	2	2	Infinity
UOP Inc	0	2	2	Infinity
Corning Inc	0	2	2	Infinity
NGK Insulators Limited	0	2	2	Infinity
Ztek Corp.	0	2	2	Infinity
Bayerische Motoren Werke Ag	0	2	2	Infinity
Energy Partners LC	0	2	2	Infinity
Ford Motor Company	0	2	2	Infinity
Sorapac S.A.	0	2	2	Infinity
Samsung Group	0	2	2	Infinity
Aventis S.A.	1	2.5	1.5	150%

Fading Companies

Companies with the Largest Decrease Among Those with 2+ Patents in 1996-98

Company	1996-98	1999-2001	Decrease	% Decrease
Fraunhofer Gesellschaft	4	0	4	100%
US Army	3	0	3	100%
Japan Gore-Tex, Inc.	2	0	2	100%
Finmeccanica SPA	2	0	2	100%
Sulzer Ag	3	1	2	67%
Aisin Seiki Company Limited	3	1	2	67%
Dow Chemical Co	6	3	3	50%
Mitsubishi Electric Corp	2.5	1	1.5	60%
Energizer Holdings, Inc.	2	1	1	50%
DBB Fuel Cell Engines Gmbh	12.5	11.5	1	8%
Tanaka Kikinzoku Kogyo	2.5	1.7	0.8	32%
E I DuPont De Nemours & Co	3	2.5	0.5	17%

Figure 12
Automotive Fuel Cell Life Cycle Statistics

Figure 13
Top Cited Representative Hydrogen Storage Patents

Patent	Family Number	Iss. Date	Pub. Date	Cites Rec	Assignee Name	Title
4559413	10041	#####	#####	17	STANDARD OIL CO. (OHIO)	COMPOSITIONALLY GRADED AMORPHOUS METAL ALLOYS AND PROCESS FOR THE SYNTHESIS OF SAME
5853951	10062	#####	#####	17	CATALYTIC MATERIAL LTD	Storage of hydrogen in layered nanostructures
389328	10006	#####	#####	14	AGENCE NATIONALE DE VALORISATION, ETS.	Method of storing hydrogen in intimate mixtures of hydrides of magnesium and other metals or alloys
902579	10042	#####	#####	14	STANDARD OIL CO. (OHIO)	AMORPHOUS METAL ALLOY COMPOSITIONS FOR REVERSIBLE HYDROGEN STORAGE
370163	10001	#####	#####	13	MATSUSHITA ELECTRIC INDUSTRIAL CO. LTD	Hydrogen storage alloy and process for making same
383606	10003	#####	#####	13	JOHNSON MATTHEY INC.	Hydrogen storage system
412982	10010	#####	#####	12	KOPPERS COMPANY, INC.	Zirconium-titanium-manganese-iron alloy characterized by $ZrMn+HD\ 2+B$ stoichiometry
135589	10050	#####	#####	12		Metastable hydrogen storage alloy material
489564	10017	#####	#####	11	THYSSEN INDUSTRIE AG	Hydride storage for hydrogen
396114	10007	#####	#####	10	MPD TECHNOLOGY CORPORATION	Flexible means for storing and recovering hydrogen
457891	10013	#####	#####	10	DAIMLER-BENZ AG	Hydrogen storage alloy
80112548	3	#####	#####	9	STUDIENGESELLSCHAFT KOHLE GMBH	Process for producing active systems for the storage of hydrogen by hydrides of magnesium.
565686	10022	#####	#####	9	CHARLES STARK DRAPER LABORATORY, INC.	METHOD OF STORING HYDROGEN USING NONEQUILIBRIUM MATERIALS AND SYSTEM
716736	10035	#####	#####	9	SYRACUSE UNIV.	Metal assisted carbon cold storage of hydrogen
744946	10038	#####	#####	9	JAPAN METALS & CHEMICALS CO., LTD.	Materials for storage of hydrogen
368143	1	#####	#####	8	BATTELLE MEMORIAL INST.	Composition for the storage of hydrogen and method of making the composition
375257	10002	#####	#####	8	U.S. PHILIPS CORP.	Hydrogen storage and supply device
389239	10005	#####	#####	7	KERNFORSCHUNGSANLAGE JULICH GMBH	Method and pressure container for producing hydrogen-storage metal granulates
446101	10011	#####	#####	7	DAIMLER-BENZ AG	Storage material for hydrogen
566281	10023	#####	#####	7	ERGENICS INC.	REACTION HEAT STORAGE METHOD FOR HYDRIDE TANKS
580404	10027	#####	#####	7	APD CRYOGENICS INC.	METHOD FOR ADSORBING AND STORING HYDROGEN AT CRYOGENIC TEMPERATURES
939902	10043	#####	#####	7		AIR CONDITIONER FOR AN AUTOMOBILE
9002730	10044	#####	#####	7	ENERGY CONVERSION DEVICES, INC.	Preparation of vanadium rich hydrogen storage alloy materials
5678410	10063	#####	#####	7	TOYOTA JIDOSHA KK	Combined system of fuel cell and air-conditioning apparatus
537761	10020	#####	#####	6	LIQUID CARBONIC CORP.	HYDROGEN STORAGE SYSTEM
5080875	10047	#####	#####	6	SAES GETTERS S.P.A.	Process and apparatus for the purification of hydrogen gas
5085944	10048	#####	#####	6	NIPPON YAKIN KOGYO CO. LTD.	Rare earth metal-series alloys for storage of hydrogen
5964965	10073	#####	#####	6	MCGILL UNIV.	Nanocrystalline Mg or Be-based materials and use thereof for the transportation and storage of hydrogen
5158759	10051	#####	#####	5	BATTELLE-INSTITUTE E.V.	Reversible storage for media as well as use of the storage
5864072	10066	#####	#####	5	SHIN-ETSU CHEMICAL CO., LTD.	Hydrogen storage alloy and method for producing the same
80490156	25	#####	#####	4	GOLDSCHMIDT (THOMAS) AG	Process for manufacturing active, reversible, H ₂ accepting magnesium hydride-magnesium-hydrogen storage system.
556551	10021	#####	#####	4	KOPPERS COMPANY, INC.	HYDROGEN STORAGE MATERIALS OF ZIRCONIUM-CHROMIUM-IRON AND TITANIUM ALLOYS
567032	10024	#####	#####	4	KOPPERS COMPANY, INC.	ZIRCONIUM-MANGANESE-IRON ALLOYS
570446	10025	#####	#####	4	JAPAN METALS & CHEMICALS CO., LTD.	FUEL TANK FOR HYDROGEN VEHICLE AND FUEL SUPPLYING SYSTEM
4736779	10036	#####	#####	4	DAIMLER-BENZ AG	Process and apparatus for using a hydride-forming alloy to store hydrogen
814002	10040	#####	#####	4	STANDARD OIL CO. (OHIO)	METHOD OF FORMING AMORPHOUS METAL ALLOY COMPOSITIONS FOR REVERSIBLE HYDROGEN STORAGE
5048299	10046	#####	#####	4		Air conditioner for an automobile
5575831	10061	#####	#####	4	MATSUSHITA ELECTRIC INDUSTRIAL CO. LTD	Method for producing hydrogen storage alloy
4406874	10009	#####	#####	3	KOPPERS COMPANY, INC.	$ZrMn+HD\ 2+B$ -Type alloy partially substituted with cerium/praseodymium/neodymium and characterized by $AB+HD$
4489050	10018	#####	#####	3	U.S. PHILIPS CORP.	Method of preparing a hydrogen-absorbing alloy
512965	10019	#####	#####	3	KOPPERS COMPANY, INC.	HYDROGEN STORAGE MATERIALS OF HYPERSTOICHIOMETRIC ALLOYS
4600525	10030	#####	#####	3		HYDROGEN SORBENT FLOW AID COMPOSITION AND CONTAINMENT THEREOF
4658023	10032	#####	#####	3	KOPPERS COMPANY, INC.	Hyperstoichiometric zirconium-titanium-chromium iron alloys
4663143	10033	#####	#####	3	KOPPERS COMPANY, INC.	HYDROGEN STORAGE MATERIALS OF $CENi+HD\ 5+31\ X+B\ MN+HD\ X+B$ ALLOYS
5028389	10045	#####	#####	3	KOREA ADVANCED INST. OF SCIENCE & TECH	Hydrogen storage materials of Zr-Ti-Cr-Fe
5128003	10049	#####	#####	3	UNITED TECHNOLOGIES CORP.	Method for the conversion of carbon dioxide and hydrogen to variable methane and oxygen ratios
5865874	10067	#####	#####	3	DURACELL INC.	Hydrogen storage alloy
5888317	10069	#####	#####	3	KOREA ADVANCED INST. OF SCIENCE & TECH	Hydrogen-storage material employing ti-mn alloy system
5816381	10071	#####	#####	3	ENERGY CONVERSION DEVICES, INC.	Magnesium mechanical alloys for thermal hydrogen storage
8183929	10076	#####	#####	3	ENERGY CONVERSION DEVICES, INC.	High storage capacity alloys enabling a hydrogen-based ecosystem

Figure 14
Hydrogen Storage Patent Family Activity
1983-2001

Figure 15
Hydrogen Storage Patenting Trends by Region
1983-2001

Figure 16
Patent Family Indicators by Region for Hydrogen Storage
Two 5 Year Periods

Figure 17
Hydrogen Storage Companies With 2 or More Patent Families
1983-2001

Figure 18
Patenting Trends of Top 10 Hydrogen Storage Companies

Figure 19
Patent Family Indicators for Hydrogen Storage Companies
Two 5 Year Time Periods

Figure 20

Emerging and Fading Hydrogen Storage Companies

Emerging Companies

Companies with the Largest Increase Among Those with 2+ Patents in 1999-2001

Company	1996-98	1999-2001	Increase	% Increase
Energy Conversion Devices Inc	2	7	5	250%
Kiyokawa Plating Industries Co Ltd	0	2	2	Infinity
Mcgill University	1	2.5	1.5	150%

Fading Companies

Companies with the Largest Decrease Among Those with 2+ Patents in 1996-98

Company	1996-98	1999-2001	Decrease	%Decrease
Matsushita Electric Industrial Co Ltd	2	0	2	100%
Catalytic Material Ltd	2	0	2	100%

Figure 21
Hydrogen Storage Life Cycle Statistics

Figure 22

Top Cited Representative Advanced Battery Patents

Patent	Family Number	Iss Date	Pub Date	Cites Rec	First Assignee	Title
5296318	10059	3/22/94	3/22/94	70	BELL COMMUNICATIONS RESEARCH, INC.	Rechargeable lithium intercalation battery with hybrid polymeric electrolyte
5350645			9/27/94	39	MICRON COMMUNICATIONS INC.	Polymer-lithium batteries and improved methods for manufacturing batteries
4423125			12/27/81	38	LUCENT REASSIGNED FROM AT&T	Ambient temperature rechargeable battery
5187033			2/16/93	38	MATSUSHITA ELECTRIC INDUSTRIAL CO. LTD	Lithium secondary battery
4816170			10/7/86	34	URSTOGER, RUPERT	ARRANGEMENT AND METHOD FOR OPERATING AN ELECTROCHEMICAL STORAGE DEVICE
5456000			10/10/91	34	BELL COMMUNICATIONS RESEARCH, INC.	Method of making an electrolyte activatable lithium-ion rechargeable battery cell
5429890			7/4/95	33	VALENCE TECHNOLOGY, INC.	Cathode-active material blends of Li+HD x+B Mn+HD 2+B O+HD 4
4550064			10/29/81	30	CALIFORNIA INST. OF TECHNOLOGY	HIGH CYCLE LIFE SECONDARY LITHIUM BATTERY
5211933			5/18/93	30	BELL COMMUNICATIONS RESEARCH, INC.	Method for preparation of LiCoO+HD 2 +B Intercalation compound for use in secondary lithium batteries
5057326			12/8/93	29	TOSHIBA KK	Lithium secondary battery and method of manufacturing carbonaceous material for negative electrode of the battery
5219879	106	12/26/95	6/15/93	29	EIC LABORATORIES, INC.	Solid electrolytes
5286582			2/15/94	28	SEIKO ELECTRONIC COMPONENTS LTD.	Monaqueous electrolyte secondary battery and process for producing positive active materials
5540741			7/30/96	28	BELL COMMUNICATIONS RESEARCH, INC.	Lithium secondary battery extraction method
5437692			8/1/95	27		Method for forming an electrode-electrolyte assembly
5478668			12/26/91	26	BELL COMMUNICATIONS RESEARCH, INC.	Rechargeable lithium battery construction
5196278			3/23/93	26	FUJI PHOTO FILM CO., LTD.	Lithium secondary battery with a cathode comprising lithium, cobalt and vanadium
5324599			6/28/94	25	MATSUSHITA ELECTRIC INDUSTRIAL CO. LTD	Reversible electrode material
5314765			5/24/94	24	MARTIN MARIETTA ENERGY SYSTEMS, INC.	Protective lithium ion conducting ceramic coating for lithium metal anodes and associate method
5370949			12/6/94	24	NATIONAL RESEARCH COUNCIL OF CANADA	Materials for use as cathodes in lithium electrochemical cells
5058217			6/3/98	23	SEIKO INSTRUMENTS INC.	Non-aqueous electrolyte secondary battery and its production method
5348822	10072	9/20/94	9/20/94	23	OVONIC BATTERY CO., INC.	Chemically and compositionally modified solid solution disordered multiphase nickel hydroxide positive electrode for alkaline rechar
5470357			11/28/91	22	BELL COMMUNICATIONS RESEARCH, INC.	Method of making a laminated lithium-ion rechargeable battery cell
5053292			10/1/91	21	TOSHIBA BATTERY CO., LTD.	Nickel-metal hydride secondary cell
4935318			6/19/90	20	MATSUSHITA ELECTRIC INDUSTRIAL CO. LTD	SEALED TYPE NICKEL-HYDRIDE BATTERY AND PRODUCTION PROCESS THEREOF
5498489			3/12/96	20		Rechargeable non-aqueous lithium battery having stacked electrochemical cells
5512399			4/30/96	20		Rechargeable non-aqueous thin film lithium battery
4804596			2/14/89	19	ALLIANT TECHSYSTEMS INC.	ELECTRODE MATERIAL/ELECTROLYTE SYSTEM FOR NON-AQUEOUS CELLS
5494762			2/27/96	19	NIPPON DENSO CO., LTD.	Non-aqueous electrolyte lithium secondary cell
5571634			11/5/96	19	BELL COMMUNICATIONS RESEARCH, INC.	Hybrid lithium-ion battery polymer matrix compositions
5063133			7/25/01	19	CANON KK	Secondary battery
5176969	10040	1/5/93	1/5/93	19	DAI NIPPON PETROCHEMICAL CO., LTD	Electrode for secondary battery
5312611			5/17/94	19	TOSHIBA KK	Lithium secondary battery process for making carbonaceous material for a negative electrode of lithium secondary battery
5370948			12/6/94	19	MATSUSHITA ELECTRIC INDUSTRIAL CO. LTD	Process for production of positive electrode active material for nonaqueous electrolyte lithium secondary cell
5395644			3/7/95	19	BATTELLE MEMORIAL INST.	VACUUM DEPOSITION AND CURING OF LIQUID MONOMERS
5521027			5/28/96	18	MATSUSHITA ELECTRIC INDUSTRIAL CO. LTD	Non-aqueous secondary electrochemical battery
4897917			2/6/90	18	HYDRO-QUEBEC	METHOD OF ASSEMBLING COMPONENTS OF AN ELECTROCHEMICAL GENERATOR USING THIN FILMS OF LITHIUM
5783333			7/21/98	18	POLYSTOR CORP	Lithium nickel cobalt oxides for positive electrodes
5042068			4/3/91	17	TOSHIBA KK	Nickel-metal hydride secondary cell
5587253			12/24/96	17	BELL COMMUNICATIONS RESEARCH, INC.	Low resistance rechargeable lithium-ion battery
4812375			3/14/89	17	USA ARMY SECRETARY	SEPARATOR FOR LITHIUM BATTERIES AND LITHIUM BATTERIES INCLUDING THE SEPARATOR
5240790	10051	8/31/93	8/31/93	17	ALLIANT TECHSYSTEMS INC.	Lithium-based polymer electrolyte electrochemical cell
5252413			10/12/91	17	EIC LABORATORIES, INC.	Solid polymer electrolyte lithium batteries
5496864			3/5/96	17	VARTA BATTERIE AG	Process for producing a positive electrode for lithium secondary batteries
5609975			3/11/97	17	MATSUSHITA ELECTRIC INDUSTRIAL CO. LTD	Positive electrode for non-aqueous electrolyte lithium secondary battery and method of manufacturing the same
5061529			9/14/94	17	SEIKO INSTRUMENTS INC.	Non-aqueous electrolyte secondary battery and method of producing the same
5393617			2/28/95	16	ELECTRO ENERGY INC.	Bipolar electrochemical battery of stacked wafer cells
5344728			9/6/94	16	OVONIC BATTERY CO., INC.	Compositionally and structurally disordered multiphase nickel hydroxide positive electrode for alkaline rechargeable electrochemical
5358805			10/25/94	16	SANYO ELECTRIC CO., LTD	Secondary battery and manufacturing method therefor
5512385			4/30/96	16	MATSUSHITA ELECTRIC INDUSTRIAL CO. LTD	Hydrogen storage alloy and nickel-metal hydride storage battery using the same
5869208			2/9/99	16	FUJI PHOTO FILM CO., LTD.	Lithium ion secondary battery
4985317	10030	1/15/91	1/15/91	15	JAPAN SYNTHETIC RUBBER CO., LTD.	Lithium ion-conductive solid electrolyte containing lithium titanium phosphate
5173362			12/22/91	15	GLOBE-UNION, INC.	Composite substrate for bipolar electrodes
5194341			3/16/93	15	BELL COMMUNICATIONS RESEARCH, INC.	Silica electrolyte element for secondary lithium battery
5278000			1/11/94	15	USA NASA ADMINISTRATOR	Overcharge and overdischarge protection of ambient temperature secondary lithium cells
5478675			12/26/95	15	HIVAL LTD	Secondary battery
5040919			6/22/94	15	MITSUBISHI PETROCHEMICAL CO., LTD	Electrode for secondary battery.

Figure 23
Advanced Battery Patent Family Activity
1983-2001

Figure 24
Advanced Battery Patenting Trends by Region
1983-2001

Figure 25
Patent Family Indicators by Region for Advanced Battery
Two 5 Year Time Periods

Figure 26
Companies With Five or More Advanced Battery Patent Families
1983-2001

Figure 27
Patenting Trends for Top 10 Advanced Battery Companies

Figure 28
Patent Family Indicators for Advanced Battery Companies
Two 5 Year Time Periods

Figure 29

Fading Advanced Battery Companies

Two 3 Year Time Periods

Emerging Companies

Companies with the Largest Increase Among Those with 2+ Patents in 1999-2001

Company	1996-98	1999-2001	Increase	% Increase
NGK Insulators Limited	0	26	26	Infinity
Mitsubishi Electric Corp	4	19.5	15.5	388%
Matsushita Electric Industrial Co Ltd	24.5	38	13.5	55%
Wilson Greatbatch Ltd.	1	14	13	1300%
Samsung Group	5	17	12	240%
Mitsubishi Chemical Corp.	0.5	10.5	10	2000%
Sanyo Electric Co Ltd	6	15.5	9.5	158%
FMC Corp	4	12	8	200%
Koninklijke Philips Electronics N.V.	0	7	7	Infinity
Hitachi Ltd	6	13.5	7.5	125%
Fuji Photo Film Co Ltd	1	8	7	700%
Sony Corporation	2	9	7	350%
Toyota Motor Corporation	0	7	7	Infinity
Individual Patenter	0	6.6	6.6	Infinity
Shin-Kobe Electric Machinery Co., Ltd.	0	5.5	5.5	Infinity
Alcatel	3	8	5	167%
Merck Ag	0	5	5	Infinity
NEC Moli Energy (Canada) Ltd	0	5	5	Infinity
Shin-Etsu Chemical Co Ltd	0	4	4	Infinity
Rohm Co. Ltd.	0	4	4	Infinity
Varta Geraetebatterie GmbH	0	4	4	Infinity
Polypius Battery Co Inc	0	4	4	Infinity
Mitsui Mining Co Ltd	0	4	4	Infinity
Ultralife Batteries, Inc.	0	4	4	Infinity
Fujitsu Limited	1	4.5	3.5	350%
Energy Conversion Devices Inc	3	6	3	100%
Lockheed Martin Corp.	0	3	3	Infinity
BASF Group	0	3	3	Infinity
Korea Kumho Petrochemical Co Ltd	0	3	3	Infinity
Hewlett-Packard Company	0	3	3	Infinity
IBM	0	3	3	Infinity
Mitsubishi Heavy Industries Inc	0	3	3	Infinity
Nissan Motor Co Ltd	0	2.5	2.5	Infinity
Nippon Chemical Industrial Co Ltd	0	2.5	2.5	Infinity
General Motors Corporation	5	7	2	40%
Energizer Holdings, Inc.	0	2	2	Infinity
Ube Industries Ltd	2	4	2	100%
Danionics A/S	2	4	2	100%
Moltech Corp.	1	3	2	200%
Ricoh Company Ltd	1	3	2	200%
NBT GmbH	1	3	2	200%
Pioneer Corp	0	2	2	Infinity
Nanogram Corp	0	2	2	Infinity
Mitsui Mining And Smelting Co. Ltd.	0	2	2	Infinity
University Of Texas	0	2	2	Infinity
E-One Moli Energy (Canada) Ltd	0	2	2	Infinity
E I Dupont De Nemours & Co	0	2	2	Infinity
Sumitomo Electric Industries Ltd	0	2	2	Infinity
Kao Corp	0	2	2	Infinity
Moltech Power Systems Inc	0	2	2	Infinity
Ohara Co., Ltd.	0	2	2	Infinity
Royal Dutch Petroleum Co	0	2	2	Infinity
LG Chemical Co. Ltd.	0	2	2	Infinity
Korea Advanced Institute Of Science	0	2	2	Infinity
Kureha Chemical Industry Co Ltd	0	2	2	Infinity

Figure 29
(Continued)
Fading Advanced Battery Companies
Two 3 Year Time Periods

Fading Companies

Companies with the Largest Decrease Among Those with 2+ Patents in 1996-98

Company	1996-98	1999-2001	Decrease	%Decrease
Moli Energy (1990) Ltd.	10	2	8	80%
Motorola Inc	8	2	6	75%
Sumitomo Chemical Co Ltd	10	5	5	50%
Furukawa Electric Co. Ltd.	5.5	1	4.5	82%
Seiko Instruments Co. Ltd.	4	0	4	100%
Science Applications Int'L	9	5	4	44%
National Research Council Of Canada	3	0	3	100%
Denso Corp.	3	0	3	100%
Grace (WR) & Co	3	0	3	100%
Murata Manufacturing Company Limited	4	1	3	75%
Dow Corning Corp.	5	2	3	60%
Sharp Corporation	2.5	0	2.5	100%
Toshiba Corporation	7.5	5	2.5	33%
Electro Energy Inc.	2	0	2	100%
Mitsubishi Gas Chemical Co	2	0	2	100%
Symbol Technologies	2	0	2	100%
Bridgestone Corp	2	0	2	100%
Marconi Plc	2	0	2	100%
Toray Industries Inc	2	0	2	100%
Honda	3	1	2	67%
Japan Storage Battery	8	6.5	1.5	19%
University Of California	2	1	1	50%
Yardney Technical Products, Inc.	2	1	1	50%
Midwest Research Institute	2	1	1	50%
ZBB Technologies Inc	2	1	1	50%
Invensys Plc	2	1	1	50%
Industrial Technology Research Institute	3	2	1	33%
Mitsubishi Cable Industries Ltd.	3	2	1	33%
Hydro-Quebec	5.5	4.5	1	18%

Figure 30

Advanced Battery Life Cycle Statistics

Figure 31
Lithium Polymer/Lithium Sulfur Patent Family Activity
1983-2001

Figure 32
Lithium Polymer/Lithium Sulfur Battery
Companies With 2 or More Patents
1983-2001

Figure 33
Top Cited Representative Hybrid Electric Vehicle Patents

Patent	Family	Issue Date	Pub Date	# Cites	Assignee Name	Title
4533011	10027	8/6/85	8/6/85	80	VOLKSWAGEN WERK AG	HYBRID DRIVE FOR A VEHICLE, IN PARTICULAR AN AUTOMOBILE
4543970	10085		9/6/94	80		Hybrid electric vehicle
4544868	10028	10/1/85	10/1/85	70	GENERAL MOTORS CORP.	BRUSHLESS DC MOTOR CONTROLLER
5172784	10054	12/22/92	12/22/92	59		Hybrid electric propulsion system
5318142	10074	6/7/94	6/7/94	54	FORD MOTOR CO.	Hybrid drive system
4588040	10034	5/13/86	5/13/86	42		HYBRID POWER SYSTEM FOR DRIVING A MOTOR VEHICLE
5327987	10081	7/12/94	7/12/94	40		High efficiency hybrid car with gasoline engine, and electric battery powered motor
4962959	7	10/16/90	10/16/90	39	FORD MOTOR CO.	ADAPTIVE CONTROLLER FOR REGENERATIVE AND FRICTION BRAKING SYSTEM
4671577	10036	6/9/87	6/9/87	36	UTDC INC.	COMBINED REGENERATIVE AND FRICTION BRAKING SYSTEM FOR A VEHICLE
4470476	10022	9/11/84	9/11/84	34		Hybrid vehicles
5255733	10062	10/26/93	10/26/93	32	FORD MOTOR CO.	Hybrid vehicle cooling system
5558588	10136	9/24/96	9/24/96	32	GENERAL MOTORS CORP.	Two-mode, input-split, parallel, hybrid transmission
4923025	10046	5/8/90	5/8/90	31		HYBRID ELECTRIC/ICE VEHICLE DRIVE SYSTEM
5562565	10137	10/8/96	10/8/96	31	EQUOS RESEARCH KK	Power transmission system in a hybrid vehicle
5264764	10063	11/23/93	11/23/93	30	FORD MOTOR CO.	Method for controlling the operation of a range extender for a hybrid electric vehicle
5545928	10130	8/13/96	8/13/96	30	TOYOTA JIDOSHA KK	Electric power generation control method in a hybrid vehicle utilizing detected generator output and engine revolutions
4438342	10018	3/20/84	3/20/84	29		Novel hybrid electric vehicle
5148883	10052	9/22/92	9/22/92	29	AISIN AN CO., LTD.	Regenerative braking electric vehicle with four motors
5270898	10064	12/14/93	12/14/93	29	WESTINGHOUSE ELECTRIC CORP.	Sure chip plus
5323868	10079	6/28/94	6/28/94	29	TOYOTA JIDOSHA KK	Drive apparatus for hybrid vehicle
5410200	10098	4/25/95	4/25/95	29	JAPAN SERVO CO., LTD.	Hybrid type stepping motor
5697466	10177	12/16/97	12/16/97	29	EQUOS RESEARCH KK	Hybrid vehicle
5786640	10206	7/28/98	7/28/98	29	NIPPON SOKEN, INC.	Generator control system for a hybrid vehicle driven by an electric motor and an internal combustion engine
4405029	10006	9/20/83	9/20/83	28		Hybrid vehicles
5713425	10184	2/3/98	2/3/98	28	FORD GLOBAL TECHNOLOGIES INC	Parallel hybrid powertrain for an automotive vehicle
5513719	10125	5/7/96	5/7/96	27	EQUOS RESEARCH KK	Hybrid vehicle
5176213	10055	1/5/93	1/5/93	26	AISIN AWCO., LTD.	Driving force distribution system for hybrid vehicles
5346031	10086	9/13/94	9/13/94	26		Hybrid motor vehicle having an electric motor and utilizing an internal combustion engine for fast charge during cruise mode off con
5550445	10133	8/27/96	8/27/96	26	TOYOTA JIDOSHA KK	Generator controller and controlling method for hybrid vehicle
4908553	10044	3/13/90	3/13/90	25	EATON CORP.	MAGNETIC REGENERATIVE BRAKING SYSTEM
5291960	10071	3/8/94	3/8/94	25	FORD MOTOR CO.	Hybrid electric vehicle regenerative braking energy recovery system
5327992	10083	7/12/94	7/12/94	25	MERCEDES-BENZ AG	Method for controlling a hybrid drive which drives a vehicle
5433282	10103	7/18/95	7/18/95	25	EQUOS RESEARCH KK	Hybrid vehicle powered by an internal combustion engine and an electric motor
5450324	10107	9/12/95	9/12/95	25	FORD MOTOR CO.	Electric vehicle regenerative antiskid braking and traction control system
4401926	10005	8/30/83	8/30/83	24	CABLEFORM LTD.	Pulse controllers
5008572	10049	4/16/91	4/16/91	24	PACIFIC SCIENTIFIC CO.	Encapsulated motor with precision bearing registration
5492192	10117	2/20/96	2/20/96	24	GENERAL MOTORS CORP.	Electric vehicle with traction control
5806617	10215	9/15/98	9/15/98	24	EQUOS RESEARCH KK	Hybrid vehicle
5459506	10118	3/5/96	3/5/96	23	TOYOTA JIDOSHA KK	Controller of hybrid electric vehicle
5839533	10226	11/24/98	11/24/98	23	TOYOTA JIDOSHA KK	Apparatus for controlling electric generator of hybrid drive vehicle to control regenerative brake depending upon selected degree of
4388573	10003	6/14/83	6/14/83	22	HITACHI LTD.	Electric vehicle control device
4744269	10042	5/17/88	5/17/88	22	FORD MOTOR CO.	Automatic transmission with lockup converter clutch controls
5253929	10061	10/19/93	10/19/93	22	TOYOTA JIDOSHA KK	Brake control system of electric vehicle
5588498	10146	12/31/96	12/31/96	22	NISSAN MOTOR CO., LTD.	Electric hybrid vehicle
5566774	81	10/22/96	10/22/96	21	MITSUBISHI JIDOSHA KOGYO KK	Operating method for a hybrid vehicle
5637987	148	6/10/97	6/10/97	21	GENERAL MOTORS CORP.	Regenerative vehicle launch
5301764	10072	4/12/94	4/12/94	21		Hybrid motor vehicle having an electric motor and utilizing an internal combustion engine for fast charge during cruise mode off con
5433512	10104	7/18/95	7/18/95	21	HONDA GIKEN KOGYO KK	Braking system for electric vehicle
5823280	10221	10/20/98	10/20/98	21	NEVCOR INC	Hybrid parallel electric vehicle
5038088	10050	8/6/91	8/6/91	20	AMERICAN PRECISION INDUSTRIES, INC.	Stepper motor system
5285862	10069	2/15/94	2/15/94	20	TOYOTA JIDOSHA KK	Power supply system for hybrid vehicles
5322352	10077	6/21/94	6/21/94	20	HONDA GIKEN KOGYO KK	Electric vehicle regenerative and friction braking control system
4823066	5	4/18/89	4/18/89	19	FANUC LTD.	THREE-PHASE INDUCTION MOTOR CONTROL METHOD
E0543390	60	**	5/26/93	19	TOYOTA JIDOSHA KK	Drive control apparatus of series hybrid vehicle.
4562894	10030	1/7/86	1/7/86	19		COUPLING MULTI DRIVING SYSTEM
5378053	10094	1/3/95	1/3/95	19	ALLIED SIGNAL INC.	Maximized regenerative braking vehicle braking controller
5558175	10135	9/24/96	9/24/96	19	GENERAL MOTORS CORP.	Hybrid power transmission
5571058	10142	11/5/96	11/5/96	19	GENERAL MOTORS CORP.	Four-mode, input-split, parallel, hybrid transmission
5635805	10157	6/3/97	6/3/97	19	TOYOTA JIDOSHA KK	Hybrid vehicle
5898282	10248	4/27/99	4/27/99	19	B.C. RESEARCH INC	Control system for a hybrid vehicle
5249637	29	10/5/93	10/5/93	18	AUDI AG	Hybrid vehicle
5287772	10070	2/22/94	2/22/94	18	HONDA GIKEN KOGYO KK	Transmission control system in electric vehicle
5358317	10089	10/25/94	10/25/94	18	FORD MOTOR CO.	Fuzzy logic electric vehicle regenerative antiskid braking and traction control system
5415603	10101	5/16/95	5/16/95	18	EQUOS RESEARCH KK	Hydraulic control system for hybrid vehicle

Figure 34
Hybrid Electric Vehicle Patent Family Activity
1983-2001

Figure 35
Hybrid Electric Vehicle Patenting Trends by Region
1983-2001

Figure 36
Patent Family Indicators by Region for Hybrid Electric Vehicles
Two 5 Year Time Periods

Figure37
Hybrid Electric Vehicle Companies With 4 or More Patent Families
1983-2002

Figure 38
Patenting Trends of Top 10 Hybrid Electric Vehicle Companies
1983-2001

Figure 39
Patent Family Indicators for Hybrid Electric Vehicle Companies
Two 5 Year Time Periods

Figure 40

Emerging and Fading Hybrid Electric Vehicle Companies

Emerging Companies

Companies with the Largest Increase Among Those with 2+ Patents in 1999-2001

Company	1996-98	1999-2001	Increase	% Increase
Honda Giken Kogyo Kk	13	62	49	377%
Toyota Motor Corporation	20	52	32	160%
Nissan Motor Co Ltd	1	23	22	2200%
Ford Motor Company	2	15.5	13.5	675%
Hitachi Ltd	3	11	8	267%
Lockheed Martin Corp.	0	8	8	Infinity
Peugeot S.A.	0	4	4	Infinity
Fuji Heavy Industries Co Ltd	0	4	4	Infinity
Mitsubishi Motors Corp	4	7	3	75%
Renault, Regie National Des Usines	0	3	3	Infinity
Individual Patenter	2	4.5	2.5	125%
Denso Corp.	8	10	2	25%
Bayerische Motoren Werke Ag	1	3	2	200%
Yamaha Hatsudoki Kk	1	3	2	200%
ZF Friedrichshafen Ag	0	2	2	Infinity
Visteon Corp.	0	2	2	Infinity
Ballard Power Systems Inc	0	2	2	Infinity
Cymer Inc.	0	2	2	Infinity
Nissan Diesel Co., Ltd.	0	2	2	Infinity

Fading Companies

Companies with the Largest Decrease Among Those with 2+ Patents in 1996-98

Company	1996-98	1999-2001	Decrease	%Decrease
Siemens Ag	11	3	8	73%
General Motors Corporation	12	8	4	33%
Isuzu Motors Limited	2	0	2	100%
Minebea Co. Ltd.	2	0	2	100%
Nevcor Inc	2	0	2	100%
Textron Inc	2	0	2	100%
Tenergy L.L.C.	2	0	2	100%
Ecoair Corp.	2	0	2	100%
New York Institute Of Technology	2	0	2	100%
Aisin Seiki Company Limited	18	16	2	11%
Komatsu Limited	2	1	1	50%

Figure 41
Hybrid Electric Vehicle Life Cycle Statistics

Figure 42

Top Cited Representative Lightweight Materials Patents

Patent	Family Number	Issue Date	Pub Date	Cites Rec.	Assignee Name	Title
04588443	10207	05/13/1988	05/13/1988	102	AALBORG PORTLAND-CEMENT-FABRIK, A/S	SHAPED ARTICLE AND COMPOSITE MATERIAL AND METHOD FOR PRODUCING SAME
04605440	2050	08/12/1988	08/12/1988	87	UNIV CALIFORNIA	BORON-CARBIDE-ALUMINUM AND BORON-CARBIDE-REACTIVE METAL CERMETS
04378903	10005	03/15/1983	03/15/1983	86	AEROSPACE CORP., THE	Carbon-reinforced metal-matrix composites
04570316	10194	02/18/1988	02/18/1988	81	NIIPPON PISTON RING CO., LTD.	METHOD FOR MANUFACTURING A ROTOR FOR A ROTARY FLUID PUMP
04378904	10006	03/15/1983	03/15/1983	79	AEROSPACE CORP., THE	Pyrolyzed pitch coatings for carbon fiber
04404282	10039	09/13/1983	09/13/1983	73	INTERNATIONAL HARVESTER CO.	Composite metallic and refractory article and method of manufacturing the article
E0340957	12963	03/16/1994	11/08/1989	73	TOYOTA JIDOSHA KK	Method of producing metal base composite material under promotion of matrix metal infiltration by fine pieces of third material.
04718941	10357	01/12/1988	01/12/1988	67	UNIV CALIFORNIA, REGENTS	Infiltration processing of boron carbide-, boron-, and boride-reactive metal cermets
04700823	10339	10/20/1987	10/20/1987	66	EATON CORP.	Clutch with pyrolytic carbon friction material
E0364963	2376	12/28/1994	04/25/1990	60	CHRYSLER MOTORS CORP.	A method of producing a ceramic reinforced composite automotive component.
04915903	10625	04/10/1990	04/10/1990	60	MARTIN MARIETTA CORP.	PROCESS FOR FORMING COMPOSITES HAVING AN INTERMETALLIC CONTAINING MATRIX
04710348	10349	12/01/1987	12/01/1987	58	MARTIN MARIETTA CORP.	PROCESS FOR FORMING METAL-CERAMIC COMPOSITES
04505767	10147	03/19/1985	03/19/1985	54	RAYCHEM CORP.	NICKEL/TITANIUM/VANADIUM SHAPE MEMORY ALLOY
05090056	10869	01/14/1992	01/14/1992	51	GENERAL MOTORS CORP.	Thermally sprayed aluminum-bronze coatings on aluminum engine bores
E0239520	2087	06/02/1991	09/30/1987	49	LANXIDE TECHNOLOGY CO., LP	Process for preparing self-supporting bodies and products made thereby.
04731298	10371	03/15/1988	03/15/1988	49	MITI/AGENCY FOR INDUSTRIAL SCI. & TECHNOLOGY	Carbon fiber-reinforced light metal composites
04615987	10248	10/07/1988	10/07/1988	47	CORNING GLASS WORKS	REINFORCEMENT OF ALKALINE EARTH ALUMINOSILICATE GLASS-CERAMICS
05445861	11412	08/29/1995	08/29/1995	47	BOEING CO.	Lightweight honeycomb panel structure
04781048	2112	08/14/1989	08/14/1988	45	MARTIN MARIETTA CORP.	Process for forming metal-second phase composites and product thereof
04398952	10034	08/16/1983	08/16/1983	45	REED ROCK BIT COMPANY	Methods of manufacturing gradient composite metallic structures
05169597	10987	12/08/1992	12/08/1992	45	SMITH & NEPHEW RICHARDS, INC.	Biocompatible low modulus titanium alloy for medical implants
04677901	10313	07/07/1987	07/07/1987	44	HONDA GIKEN KOGYO KK (HONDA MOTOR CO. LTD.)	Fiber-reinforced piston for internal combustion engines and associated method of construction
E0146716	89	12/07/1988	07/03/1985	43	AUDI AG	Superstructure.
04478544	10126	10/23/1984	10/23/1984	43	MICRODOT, INC.	Composite rivet
04927579	10647	05/22/1990	05/22/1990	43	DOW CHEMICAL CO.	METHOD FOR MAKING FIBER-REINFORCED PLASTICS
04463043	10110	07/31/1984	07/31/1984	42	ALLIED INSULATION SUPPLY CO., INC.	Building panel
04968645	10742	01/29/1991	01/29/1991	40	USA ENERGY DEPT	Cermet materials prepared by combustion synthesis and metal infiltration
04961778	10700	10/09/1990	10/09/1990	39	DOW CHEMICAL CO.	DENSIFICATION OF CERAMIC-METAL COMPOSITES
04928645	2017	05/29/1990	05/29/1990	38	GRACE (W.R.) & CO.	CERAMIC COMPOSITE VALVE FOR INTERNAL COMBUSTION ENGINES AND THE LIKE
05093174	10895	03/03/1992	03/03/1992	37	TEIJIN LTD.	Optical recording medium
04722870	10361	02/02/1988	02/02/1988	36	INTERPORE INT'L	Metal-ceramic composite material useful for implant devices
04800065	10457	01/24/1989	01/24/1989	35	MARTIN MARIETTA CORP.	PROCESS FOR MAKING CERAMIC-CERAMIC COMPOSITES AND PRODUCTS THEREOF
04818448	10482	04/04/1989	04/04/1989	35	USA ENERGY DEPT	METHOD FOR FABRICATING LIGHT WEIGHT CARBON-BONDED CARBON FIBER COMPOSITES
04847044	10525	07/11/1989	07/11/1989	35	ROCKWELL INT'L CORP.	METHOD OF FABRICATING A METAL ALUMINIDE COMPOSITE
05279787	11148	01/18/1994	01/18/1994	35		High density projectile and method of making same from a mixture of low density and high density metal powders
04394418	10027	07/19/1983	07/19/1983	34	PPG INDUSTRIES INC.	Aqueous sizing composition and glass fibers made therewith for reinforcing thermosetting polymers
04431448	10076	02/14/1984	02/14/1984	34		Tungsten-free hard alloy and process for producing same
04836982	10510	06/06/1989	06/06/1989	34	MARTIN MARIETTA CORP.	RAPID SOLIDIFICATION OF METAL-SECOND PHASE COMPOSITES
04448748	10093	05/15/1984	05/15/1984	33	INTL LEAD ZINC RESEARCH ORGANIZATION INC	Zinc-aluminum alloys and coatings
04795877	10452	01/03/1989	01/03/1989	33	GA TECHNOLOGIES INC.	OXIDATION-INHIBITED CARBON-CARBON COMPOSITES
04425407	10088	01/10/1984	01/10/1984	32	UNITED TECHNOLOGIES CORP.	CVD SIC pretreatment for carbon-carbon composites
04777097	10429	10/11/1988	10/11/1988	32	TOYOTA JIDOSHA KK	Composite material including alumina-silica short fiber reinforcing material and aluminum alloy matrix metal with moderate copper an
04826181	10491	05/02/1989	05/02/1989	32	PRAXAIR TECHNOLOGY INC.	SEAL UTILIZING COMPOSITES OF FLEXIBLE GRAPHITE PARTICLES AND AMORPHOUS CARBON
05104457	10915	04/14/1992	04/14/1992	32	COUNTRY CLUB GOLF EQUIPMENT (PTY.) LTD.	Golf clubs and method of making thereof
05180619	11009	01/19/1993	01/19/1993	32	SUPRACOR SYSTEMS, INC.	Perforated honeycomb
04412854	10050	11/01/1983	11/01/1983	31	UNITED TECHNOLOGIES CORP.	Method of producing fiber reinforced glass matrix composite articles of complex shape
04565589	10186	01/21/1986	01/21/1986	31	RAYCHEM CORP.	NICKEL/TITANIUM/COPPER SHAPE MEMORY ALLOY
04781909	10432	11/01/1989	11/01/1988	31	JUNKOSHA CO., LTD.	Flexible printed circuit board
05056417	10833	10/15/1991	10/15/1991	31	TOYODA JIDUSHOKKI SEISAKUSHO K K	Swesh plate type compressor having a surface coating layer on the surface of swesh plate

Figure 43
Lightweight Materials Patent Family Activity
1983-2001

Figure 44
Lightweight Materials Trends by Region
1983-2001

Figure 45
Patent Family Indicators by Region for Lightweight Material
Two 5 Year Time Periods

Figure 46
Lightweight Materials Companies With 20 or More Patent Families
1983-2001

Figure 47
Patenting Trends for Top 10 Lightweight Materials Companies

Figure 48
Patent Family Indicators for Lightweight Materials Companies
Two 5 Year Time Periods

Figure 49

Emerging and Fading Lightweight Materials Companies

Two 3 Year Time Periods

Emerging Companies

Companies with the Largest Increase Among Those with 2+ Patents in 1999-2001

Company	1996-98	1999-2001	Increase	% Increase
Alcan Aluminum Ltd	9	34.2	25.2	280%
Kobe Steel Limited	6	19.5	13.5	225%
Boeing Co, The	5	17	12	240%
Sandvik Ab	4	15	11	275%
Corus Aluminium Walzprodukte Gmbh	0	9	9	Infinity
Aluminum Company Of America	24.5	33	8.5	35%
Honda Giken Kogyo	10.3	18	7.7	75%
Daimler Chrysler Ag	11	18	7	64%
Bayerische Motoren Werke Ag	2.5	9.5	7	280%
Aluminium Rheinfelden Gmbh	0	7	7	Infinity
General Motors Corporation	4	10	6	150%
Honeywell Inc	6	11	5	83%
Philip Morris Companies Inc	0	5	5	Infinity
Owens-Corning Fiberglass Corp	2	6	4	200%
Mazda Motor Corporation	2	6	4	200%
Masco Corp	0	4	4	Infinity
Volkswagen Ag	5	8.5	3.5	70%
MITI Agency Of Ind Sci & Technol	3	6.5	3.5	117%
Mitsubishi Heavy Industries Inc	1	4.3	3.3	330%
Ford Motor Company	1	4	3	300%
Roechling Industrie Verwaltung Gmbh	1	4	3	300%
Federal-Mogul Corp	1	4	3	300%
Hexcel Corp	1	4	3	300%
Valeo	0	3	3	Infinity
Praxair Inc	0	3	3	Infinity
Sony Corporation	0.5	3.5	3	600%
UT-Battelle LLC	0	3	3	Infinity
Besin B V	0	3	3	Infinity
Nissan Motor Co Ltd	3	5.5	2.5	83%
Rolls-Royce Plc	1	3.5	2.5	250%
Pechiney Sa	7	9	2	29%
Norsk Hydro A/S	4	6	2	50%
Toray Industries Inc	5	7	2	40%
Cytec Industries Inc.	1	3	2	200%
Compagnie De Saint-Gobain	1	3	2	200%
Allegheny Technologies Inc.	3	5	2	67%
UK Department Of Defense	0	2	2	Infinity
Celanese Ag	0	2	2	Infinity
NGK Spark Plug Company Limited	1	3	2	200%
Areva Group	0	2	2	Infinity
Iowa State University	1	3	2	200%
Inco Ltd.	1	3	2	200%
Toyo Kohan Co. Ltd.	1	3	2	200%
Energy Conversion Devices Inc	1	3	2	200%
Dowa Mining Co. Ltd.	1	3	2	200%
MAN Ag	0	2	2	Infinity
Mitsui Mining And Smelting Co. Ltd.	0	2	2	Infinity
University Of Connecticut	0	2	2	Infinity
Teleflex Inc.	0	2	2	Infinity
Koyo Seiko Co. Ltd.	0	2	2	Infinity
Materials Innovation Inc	0	2	2	Infinity
Daiki Aluminium Kogyosho	0	2	2	Infinity
Honsel Gmbh & Co Kg	0	2	2	Infinity
Snap-On Inc	0	2	2	Infinity
Sakura Rubber Co., Ltd.	0	2	2	Infinity
Deere & Company	0	2	2	Infinity
Superior Micropowders Llc	0	2	2	Infinity
Columbia Steel Casting Co. Inc.	0	2	2	Infinity
Thixomat Inc	0	2	2	Infinity
Bronze Acior S.A.	0	2	2	Infinity
Westaim Technologies Inc.	0	2	2	Infinity
South Dakota Sch Mines & Technology	0	2	2	Infinity
Smith International Incorporated	0	2	2	Infinity
Dynamet Technology	0	2	2	Infinity
Waterbury Rolling Mills Inc	0	2	2	Infinity
Merry Corp.	0	2	2	Infinity
Fraunhofer Gesellschaft	0.5	2.3	1.8	360%
Nippon Light Metal Co., Ltd.	1	2.7	1.7	170%
General Electric Co	11	12.5	1.5	14%
NGK Insulators Limited	1.5	3	1.5	100%
Fuji Photo Film Co Ltd	1.5	3	1.5	100%
Citizen Watch Co Ltd	0.5	2	1.5	300%

Figure 49 (Cont.)

Emerging and Fading Lightweight Materials Companies

Two 3 Year Time Periods

Fading Companies

Companies with the Largest Decrease Among Those with 2+ Patents in 1996-98

Company	1996-98	1999-2001	Decrease	%Decrease
MSE Inc.	14	3	11	79%
Eastman Kodak Co	10	3	7	70%
IBM	7	1	6	86%
Yoshida Kogyo	6.1	1	5.1	84%
Maxxam Inc	8	3	5	63%
ITT Industries Inc.	8	3	5	63%
Nippon Steel Corporation	11.8	6.8	5	42%
European Aeronautic Defence And Space Co.	10.5	6	4.5	43%
Sumitomo Chemical Co Ltd	4	0	4	100%
Dunlop Ltd.	4	0	4	100%
Industrial Technology Research Institute	4	0	4	100%
Daido Metal Co Ltd	5	1	4	80%
Rockwell International Corp	5	1	4	80%
Brush Wellman, Inc.	7	3	4	57%
Lockheed Martin Corp.	8	4	4	50%
Thyssen Krupp	3.5	0	3.5	100%
Sumitomo Electric Industries Ltd	8.5	5.3	3.2	38%
Toshiba Corporation	3	0	3	100%
Northrop Grumman Corporation	3	0	3	100%
KB Alloys, Inc.	3	0	3	100%
Dainippon Ink & Chemicals Inc	3	0	3	100%
Aisin Seiki Company Limited	3	0	3	100%
Alyn Corp	4	1	3	75%
TRW Incorporated	6	3	3	50%
NKK Corporation	7	4	3	43%
Daido Steel Co. Ltd.	3	0.2	2.8	93%
Hitachi Ltd	4.8	2	2.8	58%
Sumitomo Metals Industries Ltd	6.8	4	2.8	41%
Nisseki Mitsubishi Oil Corp	4	1.3	2.7	68%
E I Dupont De Nemours & Co	2	0	2	100%
Comalco Aluminum Ltd.	2	0	2	100%
Morgan Crucible Co. Plc	2	0	2	100%
Raytheon Company	2	0	2	100%
Total Fina Elf S.A.	2	0	2	100%
Newell Rubbermaid, Inc.	2	0	2	100%
Ucar Carbon Technology Corp.	2	0	2	100%
Virginia Polytechnic Institute And State U	2	0	2	100%
Metallamics Inc	2	0	2	100%
Fischerwerke Artur Fischer GmbH & Co Kg	2	0	2	100%
EA Technology Ltd	2	0	2	100%
Adidas-Salomon Ag	2	0	2	100%
Isorca Inc	2	0	2	100%
Chisso Corporation	2	0	2	100%
American Bumper & Mfg Co	2	0	2	100%
OTD Products Llc	2	0	2	100%
Consolidated Metal Products, Inc.	3	1	2	67%
Fuji Oozx Inc.	3	1	2	67%
Nisshinbo Industries Inc	3	1	2	67%
Mitsubishi Chemical Corp.	4	2	2	50%
Bayer Ag	4	2	2	50%
Arcelor	4	2	2	50%
Showa Denko	4.5	2.5	2	44%
Goodrich Corp.	5	3	2	40%
PPG Industries Inc	5	3	2	40%
University Of California	2	1	1	50%
US Army	2	1	1	50%
Caterpillar Inc	2	1	1	50%
Korea Institute Of Science & Technology	2	1	1	50%
Konica Corp	2	1	1	50%
Agfa Corp	2	1	1	50%
Miba Gleitlager Aktiengesellschaft	2	1	1	50%
Denso Corp.	2.5	1.5	1	40%
Hunter Douglas Nv	3	2	1	33%
3M	4	3	1	25%
Siemens Ag	4	3	1	25%
US Air Force	5	4	1	20%
United Technologies Corp	6	5	1	17%

Figure 50
Lightweight Materials Life Cycle Statistics

Figure 51
Patent Family Activity for Lightweight Materials
Carbon Composites
1983-2001

Figure 52
Lightweight Materials- Carbon Composites
Companies with 3 or More Patent Families
1983-2001

Figure 53

Top Cited Representative Ultracapacitor Patents

Patent	Family Number	Issue Date	Pub Date	Cites Rec	First Assignee	Title
5150283	10027	9/22/92	9/22/92	38	MATSUSHITA ELECTRIC INDUSTRIAL CO. LTD	Electric double layer capacitor and method for producing the same
5260855	10036	11/9/93	11/9/93	36		Supercapacitors based on carbon foams
4562511	10002	12/31/85	12/31/85	26	MATSUSHITA ELECTRIC INDUSTRIAL CO. LTD	ELECTRIC DOUBLE LAYER CAPACITOR
5345154	10039	9/6/94	9/6/94	25	GENERAL ELECTRIC CO.	Electric continuously variable transmission and controls for operation of a heat engine in a closed-loop power-control n
4737889	10011	4/12/88	4/12/88	24	MATSUSHITA ELECTRIC INDUSTRIAL CO. LTD	Polarizable electrode body and method for its making
4597028	10003	6/24/88	6/24/88	21	MATSUSHITA ELECTRIC INDUSTRIAL CO. LTD	ELECTRIC DOUBLE LAYER CAPACITOR AND METHOD FOR PRODUCING THE SAME
5621607	44	4/15/97	4/15/97	19	MAXWELL LABORATORIES, INC.	High performance double layer capacitors including aluminum carbon composite electrodes
5682288	62	10/28/97	10/28/97	18	JAPAN GORE-TEX, INC.	Electric double-layer capacitor and method for making the same
4810599	17	3/7/89	3/7/89	17	JAPAN SYNTHETIC RUBBER CO., LTD.	STRUCTURE SUITABLE FOR SOLID ELECTROCHEMICAL ELEMENTS
5172307	10030	12/15/92	12/15/92	17	NEC CORP.	Activated carbon/polyacene composite and process for producing the same
5260637	10035	11/9/93	11/9/93	15	MAGNETI MARELLI S.P.A.	Electrical system for a motor vehicle, including at least one supercapacitor
4803597	10016	2/7/89	2/7/89	13	MURATA MFG. CO., LTD.	ELECTRIC DOUBLE-LAYER CAPACITOR
4633372	10006	12/30/86	12/30/86	12	STANDARD OIL COMPANY (OHIO)	POLYOXOMETALATE-MODIFIED CARBON ELECTRODES AND USES THEREFOR IN CAPACITORS
5402306	10044	3/28/95	3/28/95	12	UNIV CALIFORNIA, REGENTS	Aquegel electrode separator for use in batteries and supercapacitors
4616290	10005	10/7/86	10/7/86	11	MURATA MFG. CO., LTD.	ELECTRIC DOUBLE LAYER CAPACITOR
4725927	10010	2/16/88	2/16/88	11	ASAHI GLASS CO., LTD	Electric double layer capacitor
5426561	10045	6/20/95	6/20/95	11	USA NASA ADMINISTRATOR	High energy density and high power density ultracapacitors and supercapacitors
5498951	10049	3/12/96	3/12/96	11	JEOL LTD.	Method and apparatus for charging electric double layer capacitor
5726856	10060	3/10/98	3/10/98	11	GENERAL ELECTRIC CO.	Hexasubstituted guanidinium salts and ultracapacitors employing them as electrolytes
4630176	16	12/16/86	12/16/86	10	STANDARD OIL COMPANY (OHIO)	POLYOXOMETALATE-MODIFIED CARBON ELECTRODES AND USES THEREFOR
4414607	10001	11/8/83	11/8/83	10	MATSUSHITA ELECTRIC INDUSTRIAL CO. LTD	Solid state electric double layer capacitor
5227960	10032	7/13/93	7/13/93	10	MURATA MFG. CO., LTD.	Stacked electric double layer capacitor
5734205	10061	3/31/98	3/31/98	10	JEOL LTD.	Power supply using batteries undergoing great voltage variations
5086373	21	2/4/92	2/4/92	9	ISUZU MOTORS LTD.	Electric double layer capacitor
4697224	10007	9/29/87	9/29/87	9	MURATA MFG. CO., LTD.	Electric double layer capacitor
5099398	10024	3/24/92	3/24/92	9	ISUZU MOTORS LTD.	Electric double layer capacitor
5528121	10051	6/18/96	6/18/96	9	JEOL LTD.	Storage capacitor power supply
4725926	10009	2/16/88	2/16/88	8	ASAHI GLASS CO., LTD	Electric double layer capacitor having high capacity
5136473	10026	8/4/92	8/4/92	8	ISUZU MOTORS LTD.	Electric double layer capacitor
5381303	10041	1/10/95	1/10/95	8	MATSUSHITA ELECTRIC INDUSTRIAL CO. LTD	Electric double layer capacitor and method for manufacture thereof
5545933	10052	8/13/96	8/13/96	8	OKAMURA LABORATORY INC	Electric power storage apparatus
E0680061	10157	**	11/2/95	8	TDK CORP.	Electric double-layer capacitor.
5680292	61	10/21/97	10/21/97	7	T/J TECHNOLOGIES INC	High surface area nitride, carbide and boride electrodes and methods of fabrication thereof
5776637	64	7/7/98	7/7/98	7	KUREHA KAGAKU KOGYO KK	Vinylidene fluoride polymer-based binder solution and electrode-forming composition
4605989	10004	8/12/86	8/12/86	7	STANDARD OIL COMPANY (OHIO)	ELECTRODES FOR DOUBLE LAYER CAPACITORS
5115378	10025	5/19/92	5/19/92	7	ISUZU MOTORS LTD.	Electric double layer capacitor
5428501	10046	6/27/95	6/27/95	7	MARINE MECHANICAL CORP.	Packaging structure and method for solid electrolyte capacitors
5557497	10053	9/17/96	9/17/96	7	ECOND	Capacitor with a double electric layer
E0207167	12	10/26/88	1/7/87	6	MATSUSHITA ELECTRIC INDUSTRIAL CO. LTD	ELECTRIC DOUBLE LAYER CAPACITOR.
E0212572	14	7/10/91	3/4/87	6	ELNA CO. LTD.	Electric double layer capacitor.
4757424	10013	7/12/88	7/12/88	6	ASAHI GLASS CO., LTD	Electric double layer capacitor
5303118	10038	4/12/94	4/12/94	6	NEC CORP.	Electric double layer capacitor
5953204	10081	9/14/99	9/14/99	6	ASAHI GLASS CO., LTD	Electric double layer capacitor
4713731	10008	12/15/87	12/15/87	5	STANDARD OIL CO. (OHIO)	DOUBLE LAYER CAPACITOR
4783723	10015	11/8/88	11/8/88	5	MURATA MFG. CO., LTD.	Electrolytic double-layer capacitor
5284723	10037	2/8/94	2/8/94	5	SOLVAY & CIE S.A.	Electrochemical energy storage devices comprising electrically conductive polymer and their uses
5527640	10050	6/18/96	6/18/96	5	UNIV CALIFORNIA, OFFICE OF TECH. TRANSFE	Electrochemical supercapacitors
5621609	10057	4/15/97	4/15/97	5	USA ARMY SECRETARY	Composite electrode materials for high energy and high power density energy storage devices
5859761	10073	1/12/99	1/12/99	5	NEC CORP.	Electric double-layer capacitor
5877935	10074	3/2/99	3/2/99	5	HONDA GIKEN KOGYO KK	Active carbon used for electrode for organic solvent type electric double layer capacitor
E0731477	10161	1/23/02	9/11/96	5	ASAHI GLASS CO., LTD	Electric double layer capacitor

Figure 54
Ultracapacitor Patent Family Activity
1983-2001

Figure 55
Ultracapacitor Patenting Trends by Region
1983-2001

Figure 56
Patent Family Indicators by Region for Ultracapacitors
Two 5 Year Time Periods

Figure 57
Ultracapacitor Companies With 4 or More Patent Families
1983-2001

Figure 58

Patenting Trends For Top 10 Ultracapacitor Companies

Figure 59
Patent Family Indicators for Ultracapacitor Companies
Two 5 Year Time Periods

1992-1996

1997-2001

Figure 60

Emerging and Fading Ultracapacitor Companies

Emerging Companies

Companies with the Largest Increase Among Those with 2+ Patents in 1999-2001

Company	1996-98	1999-2001	Increase	% Increase
Asahi Glass KK	4.7	23	18.3	389%
NEC Corporation	4	15.5	11.5	288%
Honda Giken Kogyo KK	1	8.5	7.5	750%
General Electric Co	2	9	7	350%
TDK Corporation	0	3.5	3.5	Infinity
Matsushita Electric Industrial Co Ltd	1	4	3	300%
Science Applications Int'L	0	3	3	Infinity
NGK Insulators Limited	0	2.3	2.3	Infinity
Showa Denko KK	1	3	2	200%
Kureha Chemical Industry Co Ltd	1	3	2	200%
Energy Storage Systems Pty Ltd	0	2	2	Infinity
Japan Vilene Co., Ltd.	0	2	2	Infinity
Mitsubishi Chemical Corp.	0	2	2	Infinity
Nippon Sanso KK	0	2	2	Infinity
Kyocera Corporation	0	2	2	Infinity
Meadwestvaco Corporation	0	2	2	Infinity
Jeol Limited	3	4.5	1.5	50%

Company	1996-98	1999-2001	Decrease	%Decrease
Alcatel	2	0	2	100%
Yardney Technical Products, Inc.	2	0	2	100%
Nisshinbo Industries Inc	3	2.5	0.5	17%

Figure 61

Ultracapacitor Life Cycle Statistics

Figure 62

Top Cited Representative Other Power Electronics Patents

Patent	Issue Date	Pub Date	Cites Rec.	Assignee Name	Title
04743815	10098	05/10/1988	149	EMERSON ELECTRIC CO.	Brushless permanent magnet motor system
05343970	10263	09/06/1994	80		Hybrid electric vehicle
05257828	10252	11/02/1993	72	TRW INC.	Method and apparatus for controlling damping in an electric assist steering system for vehicle yaw rate control
04403527	10017	09/13/1993	70	ROBERT BOSCH GMBH	Apparatus for decreasing jolts during gear shifts in automatic transmissions in motor vehicles
05190539	10226	03/02/1993	64	TEXAS A & M UNIV SYSTEM	Micro-heat-pipe catheter
04772839	10107	09/20/1988	53	GENERAL ELECTRIC CO.	Rotor position estimator for switched reluctance motor
05075810	54	12/24/1991	48	HONEYWELL INC.	Switched reluctance motor control circuit with energy recovery capability
04481450	10034	11/06/1984	48	NIPPON DENSO CO., LTD.	System for controlling a vehicle window and the like
04707650	10089	11/17/1987	47	GENERAL ELECTRIC CO.	CONTROL SYSTEM FOR SWITCHED RELUCTANCE MOTOR
04959596	10157	09/25/1990	47	GENERAL ELECTRIC CO.	SWITCHED RELUCTANCE MOTOR DRIVE SYSTEM AND LAUNDERING APPARATUS EMPLOYING SAME
04812378	10140	03/27/1990	46	EMERSON ELECTRIC CO.	THIRD HARMONIC COMMUTATION CONTROL SYSTEM AND METHOD
05111095	60	05/05/1992	45	MAGNA PHYSICS CORP.	Polyphase switched reluctance motor
05142203	10211	08/25/1992	45	KOITO MFG. CO., LTD.	Lighting circuit for high-pressure discharge lamp for vehicles
04896069	10136	01/23/1990	43	GENERAL ELECTRIC CO.	FAULT MANAGEMENT SYSTEM FOR A SWITCHED RELUCTANCE MOTOR
05212428	10233	05/18/1993	43	KOITO MFG. CO., LTD.	Lighting circuit for vehicular discharge lamp
04558281	10055	12/10/1985	42	LUCAS INDUSTRIES, LTD.	BATTERY STATE OF CHARGE EVALUATOR
05196775	10227	03/23/1993	42	HONEYWELL INC.	Switched reluctance motor position by resonant signal injection
04883999	31	11/28/1989	41	PACIFIC SCIENTIFIC CO.	POLYPHASE ELECTRONICALLY COMMUTATED RELUCTANCE MOTOR
04811157	10069	09/09/1989	41	INTEGRATED ENVIRONMENTAL SERVICES	SWITCHED RELUCTANCE MOTOR DRIVE OPERATING WITHOUT A SHAFT POSITION SENSOR
04896068	10135	01/23/1990	41	GENERAL ELECTRIC CO.	FAULT-TOLERANT SWITCHED RELUCTANCE MACHINE
05072166	10196	12/10/1991	41	TEXAS A & M UNIV SYSTEM	Position sensor elimination technique for the switched reluctance motor drive
04500624	10038	02/19/1985	37	GENERAL ELECTRIC CO.	METHOD OF COMMUTATION AND CONVERTER CIRCUIT FOR SWITCHED RELUCTANCE MOTORS
04684867	10062	08/04/1987	37	GENERAL ELECTRIC CO.	REGENERATIVE UNIPOLAR CONVERTER FOR SWITCHED RELUCTANCE MOTORS USING ONE MAIN SWITCHING DEVICE PER PHASE
05097190	10203	03/17/1992	37	GENERAL ELECTRIC CO.	Rotor position estimator for a switched reluctance machine
05140243	63	09/18/1992	36	GENERAL ELECTRIC CO.	Discrete position estimator for a switched reluctance machine using a flux-current map comparator
04514670	10041	04/30/1985	36	ROBERT BOSCH GMBH	ELECTRIC POSITIONING MOTOR CONTROL SYSTEM, PARTICULARLY AUTOMATIC VEHICLE ANTENNA EXTENSION SYSTEM
04851789	10152	08/28/1990	34	ISUZU MOTORS LTD.	MOTOR VEHICLE DRIVING SYSTEM
04399888	10013	08/23/1983	33	SAUER, INC.	Controls for variable displacement motor and motors
04705988	10088	11/10/1987	33	ALPERT, STEVEN	AUTOMATIC WINDOW WIPER CONTROL
05341083	10280	08/23/1994	32	EPR/ELECTRIC POWER RES. INST., INC.	Contactless battery charging system
04595865	10062	09/17/1988	31	GENERAL ELECTRIC CO.	CURRENT-SENSING SCHEME FOR SWITCHED RELUCTANCE MOTOR DRIVES
05107195	10206	04/21/1992	31	GENERAL ELECTRIC CO.	Rotor position estimator for a switched reluctance machine using a lumped parameter flux/current model
05172908	10216	12/15/1992	31	GENERAL ELECTRIC CO.	Auxiliary quasi-resonant dc link converter
04560908	10057	12/24/1985	30	NORTH AMERICAN PHILIPS CO., INC.	HIGH-FREQUENCY OSCILLATOR-INVERTER BALLAST CIRCUIT FOR DISCHARGE LAMPS
04916346	10142	04/10/1990	30	GENERAL ELECTRIC CO.	COMPOSITE ROTOR LAMINATION FOR USE IN RELUCTANCE HOMOPOLEAR, AND PERMANENT MAGNET MACHINES
05449973	10336	09/12/1995	30	KOITO MFG. CO., LTD.	Lighting circuit for vehicular discharge lamp
05097468	10484	12/16/1997	30	EQUOS RESEARCH KK	Hybrid vehicle
05111096	61	05/05/1992	29	EMERSON ELECTRIC CO.	Isolated segmental switch reluctance motor
04679112	10080	07/07/1987	28	GENERAL MOTORS CORP.	Transistor protection circuit for automotive motor control applications
04746845	10100	05/24/1988	28	ALPS ELECTRIC CO., LTD	Circuit for preventing the erroneous operation of a motor control device for lifting and lowering a power window
04933620	33	09/12/1990	27	GENERAL ELECTRIC CO.	CONTROL SYSTEM FOR LOW SPEED SWITCHED RELUCTANCE MOTOR
04815575	10117	03/28/1989	27	GENERAL MOTORS CORP.	ELECTRIC, VARIABLE DAMPING VEHICLE SUSPENSION
05432817	10323	07/11/1995	27	CHRYSLER CORP.	Vehicle communications network transceiver, ground translation circuit therefor
04883982	10131	11/28/1989	26	GENERAL ELECTRIC CO.	ELECTRONICALLY COMMUTATED MOTOR, BLOWER INTEGRAL THEREWITH, AND STATIONARY AND ROTABLE ASSEMBLIES THEREFOR
05038267	10186	08/06/1991	26	GENERAL ELECTRIC CO.	Soft-switching power converter for operation in discrete pulse modulation and pulse width modulation modes
05357181	10290	10/18/1994	26	HITACHI LTD.	Failure detection method for electric vehicles and fail-safe control method using this method
05422548	10320	06/06/1995	26	KOITO MFG. CO., LTD.	Cut-off vehicular discharge lamp circuit having wait and monitor modes
04653285	10074	03/31/1987	25	GENERAL ELECTRIC CO.	Self-calibrating control methods and systems for refrigeration systems
04906553	10139	03/13/1990	25	EATON CORP.	MAGNETIC REGENERATIVE BRAKING SYSTEM
05115181	10208	05/19/1992	25	EMERSON ELECTRIC CO.	Power converter for a switched reluctance motor
05175439	10218	12/29/1992	25	ROBERT BOSCH GMBH	Power supply circuit for motor vehicles
05399950	10307	03/21/1995	25	PROSPECTS CORP.	Automatic venting system for a vehicle with obstruction detection utilizing dynamically modified thresholds
05414613	10315	05/09/1995	25	REM TECHNOLOGIES, INC.	Soft switching active snubber for semiconductor circuit operated in discontinuous conduction mode
05446359	10331	08/28/1995	25	EMERSON ELECTRIC CO.	Current decay control in switched reluctance motor
05450324	10338	09/12/1995	25	FORD MOTOR CO.	Electric vehicle regenerative antiskid braking and traction control system
04583619	10058	01/07/1988	24	CHLORIDE GROUP LTD.	ELECTRIC POWER CONVERTER CIRCUIT
04992014	10134	01/09/1990	24	SPARTON ENGINEERING PRODUCTS INC, KPI GROPU	ELECTRONIC CONTROLLER FOR AUTOMATIC TRANSMISSIONS
04979114	10161	12/18/1990	24	FUJI JUKOGYO KK	MOTOR CONTROL APPARATUS FOR ELECTRIC POWER STEERING SYSTEM
04995159	10171	02/26/1991	24	PACIFIC SCIENTIFIC CO.	Method of making an electronically commutated reluctance motor
05012177	10177	04/30/1991	24	SUNDSTRAND CORP.	Power conversion system using a switched reluctance motor/generator
05047913	10188	09/10/1991	24	GENERAL ELECTRIC CO.	Method for controlling a power converter using an auxiliary resonant commutation circuit
05446365	10332	08/29/1995	24	TOSHIBA KK	Method and apparatus for controlling a battery car
05488740	10358	01/23/1996	24	KOITO MFG. CO., LTD.	Lighting circuit for vehicular discharge lamp having DC/AC converter
05514935	10375	05/07/1996	24	KOITO MFG. CO., LTD.	Lighting circuit for vehicular discharge lamp
05808817	10581	09/15/1998	24	EQUOS RESEARCH KK	Hybrid vehicle

Figure 63
Other Power Electronics Patent Family Activity
1983-2001

Figure 64
Other Power Electronics Patenting Trends by Region
1983-2001

Figure 65
Patent Family Indicators by Region for Other Power Electronics
Two 5 Year Time Periods

Figure 66
Other Power Electronics Companies
With 5 or More Patent Families
1983-2001

Figure 67
Patenting Trends for Top 10 Other Power Electronics Companies

Figure 68
Patent Family Indicators for Other Power Electronics Companies
Two 5 Year Time Periods

Figure 69

Emerging and Fading Other Power Electronics Companies

Two 3 Year Time Periods

Emerging Companies

Companies with the Largest Increase Among Those with 2+ Patents in 1999-2001

Company	1996-98	1999-2001	Increase	% Increase
Honda	19	28	9	47%
Robert Bosch	6	13	7	117%
General Electric Co	2	8	6	300%
TRW Incorporated	3	8	5	167%
Dana Corporation	5	10	5	100%
Tri Delta Industries, Inc.	1	6	5	500%
ITT Industries Inc.	0	5	5	Infinity
Siemens Ag	4	8.5	4.5	113%
Toyota Motor Corporation	3	7.5	4.5	150%
Samsung Group	5	9	4	80%
Rokenbok Toy Co	0	4	4	Infinity
Hitachi Ltd	4.5	7.7	3.2	71%
Ford Motor Company	5	8	3	60%
Mitsuba Electric Mfg. Co. Ltd.	0	3	3	Infinity
Visteon Corp.	0	3	3	Infinity
Electronics & Telecommunications Research	0	3	3	Infinity
Aisin Seiki Company Limited	11	13.5	2.5	23%
Lockheed Martin Corp.	4	6	2	50%
Danaher Corp	0	2	2	Infinity
Fiat S.P.A.	0	2	2	Infinity
Isuzu Motors Limited	0	2	2	Infinity
Renault, Regie National Des Usines	0	2	2	Infinity
Black & Decker Corp, The	1	3	2	200%
ABB Asea Brown Boveri	0	2	2	Infinity
Motorola Inc	0	2	2	Infinity
Cannondale Corp.	0	2	2	Infinity
Okuma Corp.	0	2	2	Infinity
Korea Advanced Institute Of Science	0	2	2	Infinity
Universal Lighting Technologies	0	2	2	Infinity
Mando Machinery Corp.	0	2	2	Infinity
Delta Electronics Inc United States	0	2	2	Infinity
Ballard Power Systems Inc	0	2	2	Infinity
Virginia Polytechnic Institute And State U	0.7	2	1.3	186%
General Motors Corporation	8	9	1	13%
Lear Corp	3	4	1	33%
Koninklijke Philips Electronics N.V.	3	4	1	33%

Fading Companies

Companies with the Largest Decrease Among Those with 2+ Patents in 1996-98

Company	1996-98	1999-2001	Decrease	%Decrease
Emerson Electric Company	24	9	15	63%
Valeo	10	4	6	60%
Denso Corp.	12	6	6	50%
Matsushita Electric Industrial Co Ltd	5.5	0	5.5	100%
Daimler Chrysler Ag	9	4	5	56%
Northrop Grumman Corporation	4.5	0	4.5	100%
Firmeccanica Spa	4	0	4	100%
Honeywell Inc	3	0	3	100%
Texas A&M University	2	0	2	100%
Suzuki Motor Corp	2	0	2	100%
Fanuc Ltd	2	0	2	100%
Leviton Manufacturing Co Inc	2	0	2	100%
US Navy	2	0	2	100%
Progressive Dynamics, Inc.	2	0	2	100%
National Power Systems Inc	2	0	2	100%
Mitsubishi Motors Corp	2	0	2	100%
Koito Manufacturing Co., Ltd.	3	1	2	67%
Bayerische Motoren Werke Ag	3	1	2	67%
Fuji Electric Co Ltd	4	2	2	50%
Continental Ag	2	0.5	1.5	75%
Eaton Corp	2	1	1	50%
Rockwell International Corp	2	1	1	50%
Electric Power Res Institute	2	1	1	50%
Micro Linear Corp.	2	1	1	50%
United Technologies Corp	3	2	1	33%
A O Smith Corporation	3	2	1	33%
LG Electronics Co. Ltd.	3	2	1	33%
Delphi Automotive Systems	5	4	1	20%
Mitsubishi Electric Corp	6	5	1	17%

Figure 70
Other Power Electronics Life Cycle Statistics

Figure 71
Top Cited Representative Direct Injection Patents

Patents	Family	Issue Date	Pub Date	# Cites	Assignee Name	Title
4592612	1122	7/12/83	7/12/83	87	DIESEL TECHNOLOGY CO.	Electromagnetic unit fuel injector
5313924	10713	5/24/94	5/24/94	54	CHRYSLER CORP.	Fuel injection system and method for a diesel or stratified charge engine
4777921	824	10/18/88	10/18/88	53	NIPPON DENSO CO., LTD.	Fuel injection system
4653455	135	3/31/87	3/31/87	51	ROBERT BOSCH GMBH	Electrically controlled fuel injection pump for internal combustion engines
4482094	1104	11/13/84	11/13/84	50	DIESEL TECHNOLOGY CO.	Electromagnetic unit fuel injector
4493303	1108	1/15/85	1/15/85	45	MACK TRUCKS, INC.	ENGINE CONTROL
5166132	10649	10/20/92	10/20/92	40	NIPPON DENSO CO., LTD.	Fuel injection device for diesel engines
4566416	10321	1/28/86	1/28/86	39	GANSER-HYDROMAG AG	ACCUMULATOR NOZZLE FUEL INJECTION SYSTEM
4397285	10056	8/9/83	8/9/83	38	PHYSICS INT'L CO.	Closed loop diesel engine control
4430978	10126	2/14/84	2/14/84	38	SIEMENS-BENDIX AUTOMOTIVE ELECTRONICS L. P.	Direct liquid injection of liquid petroleum gas
4704999	10428	11/10/87	11/10/87	36	NIPPON SOKEN, INC.	Fuel injection control for diesel engine
5123246	10640	6/23/92	6/23/92	34	MACK TRUCKS, INC.	Continuously proportional variable geometry turbocharger system and method of control
5058553	571	10/22/91	10/22/91	33	NIPPON DENSO CO., LTD.	Variable-discharge high pressure pump
4421078	10096	12/20/83	12/20/83	33		Oil changing system
4593714	10346	6/10/86	6/10/86	33		MANHOLE ASSEMBLY WITH WATER BARRIER
5245970	10684	9/21/93	9/21/93	33	NAVISTAR INT'L TRANSPORTATION CORP.	Priming reservoir and volume compensation device for hydraulic unit injector fuel system
4722315	10441	2/2/86	2/2/86	32	M.A.N.-MASCHINENFABRIK AUGSBURG-NURNBERG AG	Method for improved internal exhaust gas recirculation in an internal combustion engine
5106822	10637	5/5/92	5/5/92	32		High pressure electronic common-rail fuel injection system for diesel engines
4545352	430	10/8/85	10/8/85	31	REGIE NAT'L DES USINES RENAULT SOC.	ELECTROMAGNETIC CONTROL INJECTION SYSTEMS FOR DIESEL ENGINES OF THE PRESSURE-TIME TYPE....
4715325	10433	12/29/87	12/29/87	31		POLLUTION CONTROL THROUGH FUEL TREATMENT
5485820	10776	1/23/96	1/23/96	31	NAVISTAR INT'L TRANSPORTATION CORP.	Injection control pressure strategy
5520161	10786	5/28/96	5/28/96	31	ALTERNATIVE FUEL SYSTEMS INC	Exhaust gas recirculation system for a compression ignition engine and a method of controlling exhaust gas recirculation
5553588	10789	9/10/96	9/10/96	31	TOYOTA JIDOSHA KK	Spark-ignited direct cylinder fuel injection engine
5687693	10861	11/18/97	11/18/97	31	CATERPILLAR INC.	Hydraulically-actuated fuel injector with direct control needle valve
5224457	1096	7/6/93	7/6/93	30	DEERE & CO.	Dual fuel electronic control system
4411239	10081	10/25/83	10/25/83	30	KIENZLE APPARATE GMBH	Fuel cooling system for use with a closed fuel injection circuit in a diesel engine
4463729	10182	8/7/84	8/7/84	30	AIL CORP.	Method and apparatus for controlling fuel injection timing in a compression ignition engine
4480919	10207	11/6/84	11/6/84	29	NIPPON SOKEN, INC.	Flow control device
5174247	10658	12/29/92	12/29/92	28	MITSUBISHI JUKOGYO KK	Water injection diesel engine
5669355	10854	9/23/97	9/23/97	28	CATERPILLAR INC.	Hydraulically-actuated fuel injector with direct control needle valve
5697342	10666	12/16/97	12/16/97	28	CATERPILLAR INC.	Hydraulically-actuated fuel injector with direct control needle valve
E0228578	11334	9/25/91	7/15/87	28		Fuel injection device for internal combustion engines.
4397283	10055	8/9/83	8/9/83	27	ROBERT BOSCH GMBH	Ignition onset sensor for internal combustion engines
4474008	10189	10/2/84	10/2/84	27	TOYO KOGYO CO., LTD.	Exhaust gas recirculation system for diesel engine
4955326	10551	9/11/90	9/11/90	27	COOPER INDUSTRIES, INC.	LOW EMISSION DUAL FUEL ENGINE AND METHOD OF OPERATING SAME
4741478	1153	5/3/88	5/3/88	26	DIESEL TECHNOLOGY CO.	Diesel unit fuel injector with spill assist injection needle valve closure
4378775	10023	4/5/83	4/5/83	26	ROBERT BOSCH GMBH	Method and apparatus for fuel injection in internal combustion engines in particular diesel engines
4742801	10454	5/10/88	5/10/88	26		Dual fuel mobil engine system
5738075	10895	4/14/96	4/14/96	26	CATERPILLAR INC.	Hydraulically-actuated fuel injector with direct control needle valve
4372272	10012	2/8/83	2/8/83	25	BENDIX CORP.	Fuel delivery system with feed and drain line damping
4388893	10039	6/21/83	6/21/83	25	CEDCO, INC.	Diesel engine incorporating emulsified fuel supply system
4406785	10074	9/27/83	9/27/83	25	CONTROL DEVICES, INC.	Diesel fuel heater
4544096	10298	10/1/85	10/1/85	25	ENERGY CONSERVATION INNOVATIONS, INC.	ELECTRONICALLY CONTROLLED FUEL INJECTION SYSTEM FOR DIESEL ENGINE
4597364	10353	7/1/86	7/1/86	25	EMCO WHEATON INT'L LTD.	FUEL CONTROL SYSTEM FOR GASEOUS FUELED ENGINES
4665001	10514	9/12/89	9/12/89	25	ENERGY CONVERSIONS, INC.	GASEOUS FUEL INJECTOR VALVE
5170760	10656	12/15/92	12/15/92	25	YAMAHA HATSUDOKI KK	Ignition system for two cycle engine
5327992	10719	7/12/94	7/12/94	25	MERCEDES-BENZ AG	Method for controlling a hybrid drive which drives a vehicle
5333583	10725	8/2/94	8/2/94	25	FUJII JUKOGYO KK	Fuel injection control method and a control apparatus for a cylinder direct-injection engine
5223948	10789	6/4/96	6/4/96	25		Apparatus and method for modifying control of an originally manufactured engine control module
5755198	10898	5/26/98	5/26/98	25	ROBERT BOSCH GMBH	Control device for a gasoline-powered direct injection internal combustion engine

Figure 72
Direct Injection Patent Family Activity
1983-2001

Figure 73

Direct Injection Patenting Trends by Region

1983-2001

Figure 74
Patent Family Indicators by Region for Direct Injection
Two 5 Year Time Periods

Figure 75
Direct Injection Companies With 10 or More Patent Families
1983-2001

Figure 76

Patenting Trends for Top 10 Direct Injection Companies

Figure 77
Patent Family Indicators for Direct Injection Companies
Two 5 Year Time Periods

Figure 78

Emerging and Fading Direct Injection Companies

Two 3 Year Time Periods

Emerging Companies

Companies with the Largest Increase Among Those with 2+ Patents in 1999-2001

Company	1996-98	1999-2001	Increase	% Increase
Nissan Motor Co Ltd	6.5	35	28.5	438%
Ford Motor Company	1.5	27	25.5	1700%
Yamaha Hatsudoki Kk	11	32	21	191%
Isuzu Motors Limited	4	18	14	350%
General Motors Corporation	3	14	11	367%
MAN Ag	7	17	10	143%
Volvo Ab	0	9	9	Infinity
Mazda Motor Corporation	6	14	8	133%
Daimler Chrysler Ag	25	32.5	7.5	30%
General Electric Co	3	10	7	233%
Siemens Ag	11	17.5	6.5	59%
Hitachi Ltd	4	10.5	6.5	163%
Renault, Regie National Des Usines	2	7.5	5.5	275%
Caterpillar Inc	10.5	15	4.5	43%
Bayerische Motoren Werke Ag	0.5	5	4.5	900%
Deutz Ag	1	5	4	400%
Mitsubishi Electric Corp	1	5	4	400%
Scania Cv Ab	0	4	4	Infinity
Fiat S.P.A.	6	9	3	50%
Usui Kokusai Sangyo Kk	0	3	3	Infinity
Bombardier Inc.	0	3	3	Infinity
Turbodyne Systems Inc	0	3	3	Infinity
Hydraulik-Ring Gmbh	0	3	3	Infinity
Valeo	0	2.5	2.5	Infinity
Diesel Technology Co.	0	2	2	Infinity
Borg-Warner Inc	0	2	2	Infinity
Buescher, Alfred J.	1	3	2	200%
Rockford Powertrain, Inc.	1	3	2	200%
Clean Cam Technology Systems	1	3	2	200%
FEV Motorentechnik Gmbh & Co. Kg	0	2	2	Infinity
Exxon Mobil Corp.	0	2	2	Infinity
United Technologies Corp	0	2	2	Infinity
Big Bang Co Ltd	0	2	2	Infinity
Continental Isad Electronic Syst Gmbh & Co	0	2	2	Infinity
Makita Corp.	0	2	2	Infinity
Delphi Automotive Systems	0	2	2	Infinity
Volkswagen Ag	1	2.5	1.5	150%
Komatsu Limited	1	2	1	100%
Motorenfabrik Hatz Gmbh	7	8	1	14%
AVL List Gmbh	6	7	1	17%
Southwest Research Institute	2	3	1	50%
Roechling Industrie Verwaltung Gmbh	1	2	1	100%
Honda Giken Kogyo Kk	1	2	1	100%
Sonex Research Inc.	1	2	1	100%

Fading Companies

Companies with the Largest Decrease Among Those with 2+ Patents in 1996-98

Company	1996-98	1999-2001	Decrease	% Decrease
Individual Patenter	13.5	8	5.5	41%
Toyota Motor Corporation	25	20.8	4.2	17%
Peugeot S.A.	4	0	4	100%
Alstom S.A.	3	0	3	100%
Institut Francais Du Petrole	4	1	3	75%
Navistar International Corp	5	2	3	60%
Fuji Heavy Industries Co Ltd	2	0	2	100%
Woodward Governor Germany Gmbh	2	0	2	100%
Auxiliary Power Dynamics Inc	2	0	2	100%
Nozel Engineering Co Ltd	2	0	2	100%
Smiths Group Plc	2	0	2	100%
TRW Incorporated	3	1	2	67%
Alcan Aluminum Ltd	3	1.5	1.5	50%
Robert Bosch Gmbh	29.5	28	1.5	5%
Denso Corp.	4	2.8	1.2	30%
Magma International Inc.	2	1	1	50%
Kubota Corporation	2	1	1	50%
Kvaerner A.S.A.	2	1	1	50%
Hyundai Corp	3	2	1	33%
Cummins, Inc.	7	6	1	14%
Orbital Engine Co. (Australia) Pty. Ltd.	2.5	2	0.5	20%

Figure 79

Direct Injection Life Cycle Statistics

Figure 80
Top Cited Representative Emissions Control Patents

Patent	Family Number	Issue Date	Pub. Date	# Cites	First Assignee	Title
04677677	10507	6/30/87	6/30/87	66	NELSON INDUSTRIES, INC.	Active sound attenuation system with on-line adaptive feedback cancellation
04473906	10206	9/25/84	9/25/84	66	NOISE CANCELLATION TECHNOLOGIES, INC.	Active acoustic attenuator
04676926	10688	12/1/80	12/1/80	74	GRACE (W.R.) & CO.	ELECTRICALLY HEATED CATALYTIC CONVERTER
04622609	10440	11/18/86	11/18/86	70	DAIMLER-BENZ AG	METHOD AND APPARATUS FOR MONITORING AND ADJUSTING +80 -PROBE-CONTROLLED CATALYTIC EXHAUST GAS E
04368705	10006	1/18/83	1/18/83	69	CATERPILLAR INC.	Engine control system
04628485	3819	5/29/80	5/29/80	61	GRACE (W.R.) & CO.	METALLIC CORE MEMBER FOR CATALYTIC CONVERTER AND CATALYTIC CONVERTER CONTAINING SAME
04427418	10127	1/24/84	1/24/84	56	TOYOTA CHUO KENKYUSHO KK	Device for collecting particulates in exhaust gases
04748959	10585	6/7/86	6/7/86	55	FORD MOTOR CO.	Regulation of engine parameters in response to vapor recovery purge systems
05445128	11650	8/29/95	8/29/95	55	DETROIT DIESEL CORP.	Method for engine control
04485179	2796	5/10/95	5/13/92	54	NGK INSULATORS, LTD.	Heater and catalytic converter
05657625	12036	6/19/97	6/19/97	54	MITSUBISHI JIDOSHA KOGYO KK	Apparatus and method for internal combustion engine control
05060389	1967	9/20/95	1/26/94	53	TOYOTA JIDOSHA KK	Exhaust gas purification apparatus for an internal combustion engine.
04700806	10536	10/20/87	10/20/87	50	AP PARTS MFG. CO.	Stamp formed muffler
05070694	3903	12/10/91	12/10/91	49	GRACE (W.R.) & CO.	Structure for electrically heatable catalytic core
04404795	10084	9/20/83	9/20/83	49	TOYOTA CHUO KENKYUSHO KK	Method of and apparatus for reducing emitted amount of particulates contained in exhaust gas of diesel engine
04576600	10376	3/16/86	3/16/86	48	GRACE (W.R.) & CO.	CATALYTIC CONVERTER FOR AN AUTOMOBILE
04662866	10720	9/5/89	9/5/89	47	ISUZU MOTORS LTD.	CONTROL SYSTEM OF EVAPORATED FUEL
05063029	1832	11/5/91	11/5/91	46	NGK INSULATORS, LTD.	Resistance adjusting type heater and catalytic converter
05207058	11197	5/4/93	5/4/93	46	TOYOTA JIDOSHA KK	Internal combustion engine
05315824	11399	5/31/94	5/31/94	46	TOYOTA JIDOSHA KK	Cold HC adsorption and removal apparatus for an internal combustion engine
04493303	10244	1/15/85	1/15/85	45	MACK TRUCKS, INC.	ENGINE CONTROL
05414994	11579	5/16/95	5/16/95	44	FORD MOTOR CO.	Method and apparatus to limit a midbed temperature of a catalytic converter
04456091	10186	6/26/84	6/26/84	43	INDUSTELER	Silencer in stainless material for exhaust systems of automobile vehicles
05053882	13816	9/21/94	9/16/92	43	TOYOTA JIDOSHA KK	Exhaust gas purification system for an internal combustion engine.
05077970	3945	1/7/92	1/7/92	41	FORD MOTOR CO.	Method of on-board detection of automotive catalyst degradation
04759423	10603	7/26/88	7/26/88	41	AP PARTS MFG. CO.	Tube and chamber construction for an exhaust muffler
05087423	10969	2/11/92	2/11/92	41	OLYMPUS OPTICAL CO., LTD.	Automatic analyzing apparatus comprising a plurality of analyzing modules
05483927	11716	1/16/96	1/16/96	41	DETROIT DIESEL CORP.	Method for engine control
05060991	1976	7/30/97	9/22/93	40	TOYOTA JIDOSHA KK	DEVICE FOR PURIFYING EXHAUST OF INTERNAL COMBUSTION ENGINE
04664146	10360	1/14/86	1/14/86	40	AI SAN INDUSTRY CO., LTD	ELECTROMAGNETIC FUEL INJECTOR
04765437	10606	8/23/88	8/23/88	40	AP PARTS MFG. CO.	Stamp formed muffler with multiple low frequency resonating chambers
04544398	10329	10/1/85	10/1/85	39	FORD MOTOR CO.	APPARATUS FOR PERIODICALLY OXIDIZING PARTICULATES COLLECTED FROM EXHAUST GASES
05265417	11292	11/30/93	11/30/93	39	FORD MOTOR CO.	Method and apparatus for determining the hydrocarbon conversion efficiency of a catalytic converter
05758493	12218	6/2/86	6/2/86	38	FORD GLOBAL TECHNOLOGIES INC	Method and apparatus for desulfating a NO+HD x+B trap
04396090	10065	8/2/83	8/2/83	37	CONSTRUCTION METALLURGIQUE DE WISSEMBOURG S.A.	Muffler
04535589	10311	8/20/85	8/20/85	37	NIPPON SOKEN, INC.	EXHAUST GAS CLEANING DEVICE FOR INTERNAL COMBUSTION ENGINE
05094074	10997	3/10/92	3/10/92	37	NISSAN MOTOR CO., LTD.	Catalytic converter with metallic carrier and method for producing same
05201802	11183	4/13/93	4/13/93	37	TOYOTA JIDOSHA KK	Exhaust gas purification system for an internal combustion engine
05492068	11731	2/20/96	2/20/96	37	CATERPILLAR INC.	Flexible injection rate shaping device for a hydraulically-actuated fuel injection system
05595060	11914	1/21/97	1/21/97	37	MITSUBISHI JIDOSHA KOGYO KK	Apparatus and method for internal-combustion engine control
04373330	10017	2/15/83	2/15/83	36	GENERAL MOTORS CORP.	Diesel engine dual path exhaust cleaner and burner system
04735046	10573	4/5/88	4/5/88	36	SANSHIN KOGYO KK	Oil remover from exhaust gas of marine propulsion unit
04805733	10654	2/21/89	2/21/89	36	NIPPON DENSO CO., LTD.	ACTIVE SILENCER
05245975	11262	9/21/93	9/21/93	36	TOYOTA JIDOSHA KK	Direct injection type internal combustion engine
05363437	3876	1/24/86	1/24/86	35	SIEMENS AUTOMOTIVE LTD.	Integrity confirmation of evaporative emission control system against leakage
04382323	10035	5/10/83	5/10/83	35	GENERAL MOTORS CORP.	Method for manufacturing a wound foil structure comprising distinct catalysts
04736817	10576	4/12/88	4/12/88	35	AP PARTS MFG. CO.	Stamp formed muffler
05097923	11003	3/24/92	3/24/92	35	NOISE CANCELLATION TECHNOLOGIES, INC.	Active sound attenuation system for engine exhaust systems and the like
05711147	3800	1/27/86	1/27/86	34	UNIV CALIFORNIA, REGENTS	Plasma-assisted catalytic reduction system
04656628	3817	4/14/87	4/14/87	34	GENERAL MOTORS CORP.	System for predicting catalytic converter temperature
04931636	10684	5/23/89	5/23/89	34	TOYOTA JIDOSHA KK	DOUBLE AIR-FUEL RATIO SENSOR SYSTEM CARRYING OUT LEARNING CONTROL OPERATION
05345761	11432	9/13/94	9/13/94	34	FORD MOTOR CO.	Energy management system for hybrid vehicle
05426934	11611	6/27/95	6/27/95	34	HITACHI AMERICA, LTD.	Engine and emission monitoring and control system utilizing gas sensors
05635630	11995	6/3/97	6/3/97	34	CHRYSLER CORP.	Leak detection assembly
05771686	12250	6/30/99	6/30/99	34	MERCEDES-BENZ AG	Method and apparatus for operating a diesel engine
05061098	2782	4/28/89	7/5/85	33	NGK INSULATORS, LTD.	Exhaust gas purification
05499614	3870	3/18/86	3/18/86	33	SIEMENS ELECTRIC LTD.	Means and method for operating evaporative emission system leak detection pump
04403473	10061	9/13/83	9/13/83	33	CATERPILLAR INC.	Ammonia/fuel ratio control system for reducing nitrogen oxide emissions
05065194	10968	2/14/92	2/14/92	33	HONDA GIKEN KOGYO KK (HONDA MOTOR CO. LTD.)	Method of detecting abnormality in an evaporative fuel-purging system for internal combustion engines
04662911	10485	5/5/87	5/5/87	32	NIPPON DENSO CO., LTD.	EQUIPMENT FOR TRAPPING PARTICULATES IN ENGINE EXHAUST GAS
04760694	10606	8/2/88	8/2/88	32	AP PARTS MFG. CO.	Exhaust muffler with angularly aligned inlets and outlets
04813231	10665	3/21/89	3/21/89	32	SOUTHWEST RESEARCH INSTITUTE	ENGINE EXHAUST AFTER-TREATMENT DEVICE
05255733	11278	10/26/93	10/26/93	32	FORD MOTOR CO.	Hybrid vehicle cooling system

Figure 81
Emissions Control Patent Family Activity
1983-2001

Figure 82
Emissions Control Patenting Trends by Region
1983-2001

Figure 83
Patent Family Indicators by Region for Emissions Control
Two 5 Year Time Periods

Figure 84
Emissions Control Companies With 20 or More Patent Families
1983-2001

Figure 85
Patenting Trends For Top 10 Emissions Control Companies

Figure 86
Patent Family Indicators for Emissions Control Companies
Two 5 Year Time Periods

Figure 87

Emerging and Fading Emissions Control Companies

Two 3 Year Time Periods

Emerging Companies

Companies with the Largest Increase Among Those with 4+ Patents in 1999-2001

Company	1996-98	1999-2001	Increase	% Increase
Ford Motor Company	70	144	74	106%
Volkswagen Ag	15.9	72.7	56.8	357%
Siemens Ag	32.5	82.5	50	154%
Nissan Motor Co Ltd	25	60.5	35.5	142%
Daimler Chrysler Ag	45.9	73.9	28	61%
Mazda Motor Corporation	5	30.5	25.5	510%
Delphi Automotive Systems	0	20.5	20.5	Infinity
Renault, Regie National Des Usines	7	25.3	18.3	261%
Engelhard Corp	9	25.5	16.5	183%
Peugeot S.A.	6	19.2	13.2	220%
Bayerische Motoren Werke Ag	8.3	19.9	11.6	140%
Cummins, Inc.	7.5	18.3	10.8	144%
Johnson Matthey Plc	3	13	10	333%
Emitec Ges. Fur Emissionstechnologie	27	36	9	33%
Hitachi Ltd	16	25	9	56%
Individual Patenter	35.7	44.5	8.8	25%
Avramitor, Inc.	2	10	8	400%
E.On Ag	5	13	8	160%
General Electric Co	0	8	8	Infinity
Man Ag	3	10.5	7.5	250%
Aea Technology Plc	0	7	7	Infinity
Komatsu Limited	1	7	6	600%
Uitex Inc	0	6	6	Infinity
Institut Francais Du Petrole	5	10.5	5.5	110%
Clean Diesel Technologies Inc	3	8	5	167%
Andreas Stihl	0	5	5	Infinity
Ti Automotive	0	5	5	Infinity
Zeuna-Starker Gmbh & Co Kg	1	6	5	500%
Fraunhofer Gesellschaft	0	5	5	Infinity
Accentus Plc	0	5	5	Infinity
Honda Giken Kogyo Kk	89.5	94.3	4.8	5%
Volvo Ab	9.3	13.5	4.2	45%
Mann & Hummel	0	4	4	Infinity
Eaton Corp	1	5	4	400%
Swissauto Engineering Sa	1	5	4	400%
Federal-Mogul Corp	0	4	4	Infinity
Kemira Metalkat Oy	0	4	4	Infinity
Faurecia Abgastechnik Gmbh	0	4	4	Infinity
Industrial Power Generating Corp	0	4	4	Infinity
Mitsubishi Motors Corp	13.5	17	3.5	26%
Fev Motorentechnik Gmbh & Co. Kg	2	5.5	3.5	175%

Fading Companies

Companies with the Largest Decrease Among Those with 4+ Patents in 1996-98

Company	1996-98	1999-2001	Decrease	%Decrease
Denso Corp.	37	12.5	24.5	66%
Toyota Motor Corporation	132.6	113.5	19.1	14%
Grace (Wt) & Co	12	0	12	100%
Coming Inc	23	14	9	39%
General Motors Corporation	36	28	8	22%
Porsche Ag	9.8	1.9	7.9	81%
Calsonic Kasei Corp	11	4	7	64%
Sumitomo Electric Industries Ltd	9	2.5	6.5	72%
Yamaha Hatsudoki Kk	19	13	6	32%
Ngk Insulators Limited	28.5	23	5.5	19%
Briggs & Stratton Corp	4	0	4	100%
Fuji Oozx Inc.	4	0	4	100%
Ap Parts Mfg. Co.	5	1	4	80%
Mitsubishi Electric Corp	8	4	4	50%
Isuzu Motors Limited	12	8	4	33%
Caterpillar Inc	23	19	4	17%
Benteler Ag	4	1	3	75%
Northrop Grumman Corporation	6	3	3	50%
Unisia Jecs Corp.	7	4	3	43%
Witzenmann Gmbh Metallschlauch-Fabrik Pfor	8	5	3	38%
Fuji Heavy Industries Co Ltd	4	2	2	50%
Us Navy	4	2	2	50%
University Of Chicago	4	2	2	50%
Motorola Inc	5	3.5	1.5	30%
Tenneco Automotive, Inc.	5.3	4	1.3	25%
Abb Asea Brown Boveri	4	3	1	25%
Kloritz Corporation	4	3	1	25%
Southwest Research Institute	5	4	1	20%
Heraeus Holding Company Gmbh	10	9	1	10%
J Eberspacher Gmbh & Co	4	3.5	0.5	13%

Figure 88

Emissions Control Life Cycle Statistics

Figure 89

Top Cited Representative New Combustion Regimes Patents

Patent Family	Patent Family	Issue Date	Pub. Date	# Cites	Assignee Name	Title
0488074	10158	01/29/1991	01/29/1991	42	HI-RAM INC.	Proportional variable force solenoid control valve
04485788	10035	12/04/1984	12/04/1984	35		Scotch yoke engine with variable stroke and compression ratio
85051631	10171	09/24/1991	09/24/1991	32	SPX CORP.	Electromagnetic solenoid valve with variable force motor
5277694	10242	01/11/1994	01/11/1994	28	BORG-WARNER TRANSMISSION & ENGINE COMPONENTS	Hydraulic tensioner with a molded valve base and cap
5315973	10248	05/31/1994	05/31/1994	29	UNIV BRITISH COLUMBIA, CANADA	Intensifier-injector for gaseous fuel for positive displacement engines
5115782	10189	05/28/1992	05/28/1992	25	ROBERT BOSCH GMBH	Method for controlling a spark-ignition engine without a throttle flap
5211370	10216	05/18/1993	05/18/1993	25		Variable orifice seating valve
4440134	10018	04/03/1984	04/03/1984	24	KOMATSU SEISAKUSHO KK	Fuel injection system for internal combustion engines
5259820	10237	11/09/1993	11/09/1993	24	BORG-WARNER TRANSMISSION & ENGINE COMPONENTS	Hydraulic tensioner having a variable orifice check valve and a double helix internal ratchet
4377279	10002	03/22/1983	03/22/1983	23	STEADLEY CO INC	Steel wire foundation
4543930	10053	10/01/1985	10/01/1985	23	SOUTHWEST RESEARCH INSTITUTE	STAGED DIRECT INJECTION DIESEL ENGINE
4546739	10054	10/15/1985	10/15/1985	23	DIESEL KIKI CO., LTD.	FUEL INJECTION VALVE WITH VARIABLE DISCHARGE AREA OF NOZZLE HOLES
4951637	10144	08/28/1990	08/28/1990	23	SIEMENS-BENDIX AUTOMOTIVE ELECTRONICS L. P.	PURGE FLOW REGULATOR
5578521	10355	10/21/1997	10/21/1997	23	CUMMINS ENGINE CO., INC.	System and methods for electronic control of an accumulator fuel system
5775288	49	07/07/1998	07/07/1998	22	YAMAHA HATSUDOKI KK	Combustion chamber
4476817	10031	10/16/1984	10/16/1984	22	OWEN, WICKERSHAM & ERICKSON	Combustion and pollution control system
5057467	10175	11/29/1991	11/29/1991	21	UNIV BRITISH COLUMBIA, CANADA	Intensifier-injector for gaseous fuel for positive displacement engines
4660382	10063	04/29/1987	04/29/1987	20	NISSAN MOTOR CO., LTD.	DEVICE FOR CONTROLLING THE SUPERCHARGING PRESSURE OF A TURBOCHARGER
4802508	10113	02/07/1989	02/07/1989	20		FLOW CONTROL DEVICE FOR ADMINISTRATION OF INTRAVENOUS FLUIDS
4887580	10135	12/18/1989	12/18/1989	20		CRANKSHAFT ASSEMBLY FOR VARIABLE STROKE ENGINE FOR VARIABLE COMPRESSION
4465172	10024	08/14/1984	08/14/1984	19	BORG-WARNER TRANSMISSION & ENGINE COMPONENTS	Clutch disc with a variable torsional damper
5497737	41	03/12/1998	03/12/1998	18	NISSAN MOTOR CO., LTD.	Intake and exhaust valves control of internal combustion engine
4663142	10127	09/08/1989	09/08/1989	18	SEALED POWER CORPORATION	ELECTROMAGNETIC SOLENOID VALVE WITH VARIABLE FORCE MOTOR
5389048	10271	02/14/1995	02/14/1995	18	FORD MOTOR CO.	Automatic transmission control system
4535728	7	08/20/1985	08/20/1985	17	PROPANE CARBURETION COMPANY, INC.	FUEL FEED CONTROL SYSTEM AND CONTROL VALVE FOR DUAL FUEL OPERATION OF AN INTERNAL COMBUSTION ENGINE
4618005	10074	10/14/1985	10/14/1985	17	CUMMINS ENGINE CO., INC.	TWO-CYCLE ENGINE WITH IMPROVED SCAVENGING
4988243	10153	01/22/1991	01/22/1991	17	SIEMENS AUTOMOTIVE L.P.	Mass air flow engine control system with mass air event integrator
5482023	10293	01/09/1996	01/09/1996	17	HITACHI AMERICA LTD., RES. & DEV. DIV.	Cold start fuel control system
5517978	10304	05/21/1996	05/21/1996	17	MOTOREN TURBINEN-UNION FRIEDRICHSHAFEN GMBH	Diesel engine equipped for reducing harmful substances in its operation
5709180	10366	01/20/1998	01/20/1998	17	YAMAHA HATSUDOKI KK	Combustion chamber and induction system for engine
5771857	10390	09/30/1998	09/30/1998	17	CATERPILLAR INC.	Control system for exhaust gas recovery system in an internal combustion engine
5778674	10385	07/14/1998	07/14/1998	17	NISSAN MOTOR CO., LTD.	Turbocharged diesel engine
4615307	10073	10/07/1986	10/07/1986	16	ASIN SEIKI CO., LTD.	HYDRAULIC VALVE LIFTER FOR VARIABLE DISPLACEMENT ENGINE
4789000	10108	12/08/1988	12/08/1988	16		Flow control device for administration
5325842	10249	07/05/1994	07/05/1994	16	MONROE AUTO EQUIPMENT CO.	Tunable hydraulic valve for shock absorber
5330031	10250	07/19/1994	07/19/1994	16	CLARK MATERIAL HANDLING CO.	Alternative fuel system for powered industrial vehicle
4401072	10007	08/30/1983	08/30/1983	15	TOYOTA JIDOSHA KOGYO KK	Combustion chamber of a compression-ignition type internal combustion engine
4485843	10037	12/04/1984	12/04/1984	15		Variable pressure relief and control valve
4739715	10089	04/12/1989	04/12/1989	15	MEDICOR SCIENCE, N.V.	Engine with a six-stroke cycle, variable compression ratio, and constant stroke
4823756	10120	04/25/1989	04/25/1989	15	NORTH DAKOTA STATE UNIVERSITY OF AGRICULTURE A	NOZZLE SYSTEM FOR ENGINES
5080951	10185	02/25/1992	02/25/1992	15	BRITISH TECHNOLOGY GROUP LTD.	Hydraulic control circuits for continuously-variable-ratio transmissions
5370097	10263	12/08/1994	12/08/1994	15	DAVIS FAMILY TRUST	Combined diesel and natural gas engine fuel control system and method of using such
5580632	10325	01/07/1997	01/07/1997	15	TOYOTA JIDOSHA KK	Apparatus for computing the amount of intake air in internal combustion engine
5937850	10425	09/17/1999	09/17/1999	15	ALLIED SIGNAL INC.	Exhaust gas recirculation system employing a turbocharger incorporating an integral pump, a control valve and a mixer
4448177	10019	05/15/1984	05/15/1984	14	HONDA GIKEN KOGYO KK (HONDA MOTOR CO. LTD.)	Exhaust gas recirculation control system having variable valve lift correcting speed for exhaust gas recirculation valve
4518537	10046	05/14/1985	05/14/1985	14	DAIHATSU MOTOR CO., LTD.	VARIABLE COMPRESSION SYSTEM FOR INTERNAL COMBUSTION ENGINES
5105782	10187	04/21/1992	04/21/1992	14	JENARA ENTERPRISES LTD.	Compression release brake with variable ratio master and slave cylinder combination
5163621	10202	11/17/1992	11/17/1992	14	NIPPON DENSO CO., LTD.	Fuel injection valve having different fuel injection angles at different opening amounts
5201295	10213	04/13/1993	04/13/1993	14	AIL CORP.	High pressure fuel injection system
5249421	10231	10/05/1993	10/05/1993	14	CATERPILLAR INC.	Hydraulic control apparatus with mode selection
5357990	10262	11/29/1994	11/29/1994	14	FORD MOTOR CO.	Part load gas exchange strategy for an engine with variable lift camless valvetrain
5540201	10313	07/30/1998	07/30/1998	14	CATERPILLAR INC.	Engine compression braking apparatus and method
50449240	10808		10/02/1991	14	MAZDA MOTOR CORP.	Multi-valve internal combustion engine.

Figure 90
New Combustion Regimes Patent Family Activity
1983-2001

Figure 91
New Combustion Regimes Patenting Trends by Region
1983-2001

Figure 92
Patent Family Indicators by Region for New Combustion Regimes
Two 5 Year Time Periods

Figure 93
New Combustion Regimes Companies With 4 or More Patent Families
1983-2001

Figure 94
Patenting Trends for Top 10 New Combustion Regimes Companies

Figure 95
Patent Family Indicators for New Combustion Regimes Companies
Two 5 Year Time Periods

Figure 96

Emerging and Fading New Combustion Regimes Companies Two 3 Year Time Periods

Emerging Companies

Companies with the Largest Increase Among Those with 2+ Patents in 1999-2001

Company	1996-98	1999-2001	Increase	% Increase
Ford Motor Company	3	15	12	400%
Nissan Motor Co Ltd	4	13.5	9.5	238%
Robert Bosch Gmbh	0	9	9	Infinity
Toyota Motor Corporation	11	19	8	73%
Mitsubishi Electric Corp	0	7	7	Infinity
Saturn Electronics & Engineering Inc	0	5	5	Infinity
Honeywell Inc	0	3	3	Infinity
Volvo Ab	0	3	3	Infinity
Bayerische Motoren Werke Ag	0	3	3	Infinity
Hyundai Corp	0	3	3	Infinity
Siemens Ag	0	2.5	2.5	Infinity
Cummins, Inc.	2	4	2	100%
Borg-Warner Inc	0	2	2	Infinity
Denso Corp.	0	2	2	Infinity
United Technologies Corp	0	2	2	Infinity
Toyoda Automatic Loom Works, Ltd.	0	2	2	Infinity
AVL List Gmbh	0	2	2	Infinity
Husco Int'L Inc.	0	2	2	Infinity
Visteon Corp.	0	2	2	Infinity
Komatsu Limited	1	2	1	100%
Eaton Corp	1	2	1	100%
Tokico Ltd	2	3	1	50%
Fiat S.P.A.	1	2	1	100%

Fading Companies

Companies with the Largest Decrease Among Those with 2+ Patents in 1996-98

Company	1996-98	1999-2001	Decrease	%Decrease
Toyoda Machine Works Limited	3	0	3	100%
Samsung Group	2	0	2	100%
Honda Giken Kogyo	3	1	2	67%
Unisia Jecs Corp.	4	2	2	50%
Mitsubishi Motors Corp	2	1	1	50%
Individual Patenter	4	3	1	25%
Yamaha Hatsudoki	6	5	1	17%
Daimler Chrysler Ag	3.5	3	0.5	14%

Figure 97

New Combustion Regimes Life Cycle Statistics

Figure 98

Top Cited Representative Hydrogen Internal Combustion Patents

Patent	Family	Issue Date	Appl Date	Pub Date	# Cites	Assignee Name	Title
4567857	10031	2/4/86	8/16/82	2/4/86	26	USA NASA ADMINISTRATOR	COMBUSTION ENGINE SYSTEM
5207185	10057	5/4/93	3/27/92	5/4/93	26	HYDROGEN BURNER TECHNOLOGY INC	Emissions reduction system for internal combustion engines
4442801	10018	4/17/84	12/16/81	4/17/84	17		Electrolysis fuel supplementation apparatus for combustion engines
5139002	10049	8/18/92	10/30/90	8/18/92	17	HYDROGEN CONSULTANTS, INC.	Special purpose blends of hydrogen and natural gas
5159900	10052	11/3/92	8/9/91	11/3/92	17		Method and means of generating gas from water for use as a fuel
5156114	10051	10/20/92	8/3/91	10/20/92	15		Aqueous fuel for internal combustion engine and method of combustion
4876988	10040	10/31/89	8/13/88	10/31/89	13		COMBINED FUEL ENGINE
4446160	10019	5/15/84	3/15/82	5/15/84	12		Fuel injector
5143025	10050	9/1/92	1/25/91	9/1/92	11		Hydrogen and oxygen system for producing fuel for engines
4369737	10003	1/25/83	8/2/80	1/25/83	10		Hydrogen-oxygen generator
4570578	10032	2/18/86	11/21/84	2/18/86	10	DEUTSCHE FORSCHUNGS-U. VERSUCHSANSTALT FUR LUF	METHOD AND DEVICE FOR OPERATING A HYDROGEN MOTOR
5343699	10067	9/5/94	12/14/92	9/5/94	10		Method and apparatus for improved operation of internal combustion engines
5394852	10074	3/7/95	9/5/91	3/7/95	10		METHOD AND APPARATUS FOR IMPROVED COMBUSTION ENGINE
5406957	10075	4/25/95	4/28/93	4/25/95	10		Continuous combustible gas injection into conventionally fueled internal combustion engines
4573435	10033	3/4/86	6/29/85	3/4/86	9		APPARATUS AND METHOD FOR GENERATING HYDROGEN GAS FOR USE AS A FUEL ADDITIVE IN DIESEL ENGINES
5105773	10045	4/21/82	10/21/81	4/21/82	9	ALTERNATE FUELS, INC.	Method and apparatus for enhancing combustion in an internal combustion engine through electrolysis
5183011	10055	2/2/93	4/17/92	2/2/93	9	HONDA GIKEN KOGYO KK	Method of controlling the supply of fuel in hydrogen-fueled engine
5513600	10082	5/7/98	8/15/94	5/7/98	9		Water fuel converter for automotive and other engines
5549902	10084	8/20/98	11/7/94	8/20/98	9	ORBITAL ENGINE CO. (AUSTRALIA) PTY. LTD.	Fuel/gas delivery system for internal combustion engines
5611307	10087	3/18/97	7/20/94	3/18/97	9	UNIV MELBOURNE	Internal combustion engine ignition device
5353776	10069	10/11/94	3/22/93	10/11/94	8	SOUTHWEST RESEARCH INSTITUTE	Method and apparatus for controlling fuel flow to lean burn engines
4366696	10002	1/18/83	7/29/80	1/18/83	7		Electrolytic supplemental fuel generation for motor vehicles
4380970	10004	4/26/83	3/27/81	4/26/83	7		Combustion engines
4369991	10007	6/28/83	2/17/82	6/28/83	7		Hydrogen gas injector system for internal combustion engine
4520764	10027	6/4/85	8/28/80	6/4/85	7	NISSAN MOTOR CO., LTD.	STARTER FOR AN ALCOHOL ENGINE
4547356	10029	10/15/85	1/3/83	10/15/85	7	UNIQUE ENERGY SYSTEMS, INC.	METHOD OF GENERATING HYDROGEN AND USING THE GENERATED HYDROGEN
4584530	10041	12/5/89	11/27/87	12/5/89	7	ATLANTIC RICHFIELD CO.	METHOD FOR ADAPTING AN INTERNAL COMBUSTION PISTON ENGINE TO RUN AT OPTIMUM COMPRESSION RATIOS.....
5297515	10062	3/29/94	8/3/93	3/29/94	7	SOUTHWEST RESEARCH INSTITUTE	Fuel supply systems for engines and combustion processes therefor
4506064	3	4/2/85	9/28/82	4/2/85	6	KATSUJI BABA	INTERNAL COMBUSTION ENGINE OF HYDROGEN GAS
4456634	10021	7/10/84	2/11/83	7/10/84	6		Internal combustion engine with hydrogen producing device having water and oil interface level control
4480595	10023	11/6/84	11/7/83	11/6/84	6		Internal combustion engine
4548186	10030	10/22/85	9/5/84	10/22/85	6	MAZDA MOTOR CORP.	METHOD AND DEVICE FOR PREHEATING AN ENGINE OR AN ENGINE INTAKE AIR
5178119	10054	1/12/93	12/11/91	1/12/93	6	SOUTHWEST RESEARCH INSTITUTE	Combustion process and fuel supply system for engines
5305714	10063	4/26/94	7/2/92	4/26/94	6	TOYOTA JIDOSHA KK	Fuel supply system for an internal combustion engine
5515814	10063	5/14/96	9/6/95	5/14/96	6	TRANSGLOBAL TECHNOLOGIES, LTD.	Apparatus and method for supplying fuel to internal combustion engines
5082048	5	1/21/92	12/12/90	1/21/92	5	NIPPON STEEL CORP.	Hydrogen engine system with metal hydride container
4762093	10037	8/9/88	4/10/87	8/9/88	5	GENERAL MOTORS CORP.	Compact catalytic dissociator system for cold starting methanol-fueled cars
4834062	10039	5/30/89	9/8/87	5/30/89	5	NISSAN DENSO CO., LTD.	INTERNAL COMBUSTION ENGINE HAVING AIR/FUEL MIXTURE WITH ANTI-REDUCING SEMICONDUCTING PORCELAIN...
5293857	10061	3/15/94	6/24/92	3/15/94	5		Hydrogen gas fuel and management system for an internal combustion engine utilizing hydrogen gas fuel
5305715	10064	4/26/94	8/17/93	4/26/94	5	ALIRA INC.	Supplement fuel generator for vehicle engines
E0431357	10131		11/13/90	6/12/91	5	INDIVIDUAL PATENTER	Method of combustion of an aqueous fuel in an internal combustion engine
RE035237	10143	5/14/96	10/20/94	5/14/96	5		Aqueous fuel for internal combustion engine and method of combustion
4441461	10017	4/10/84	9/15/83	4/10/84	4	CONSOLIDATION COAL CO.	Alcohol dissociation and waste heat recovery process for automobiles
4476818	10022	10/16/84	10/19/83	10/16/84	4	CONSOLIDATION COAL CO.	Constant air feed alcohol dissociation process for automobiles
4486517	10024	12/18/84	4/15/83	12/18/84	4	CONSOLIDATION COAL CO.	Cold start method with start-up gaseous fuel generation system for methanol fueled cars
4496863	10025	2/19/85	11/4/82	2/19/85	4	FORD MOTOR CO.	METHOD OF OPERATING AN INTERNAL COMBUSTION ENGINE ON A METHANOL FUEL
5119768	10048	6/9/92	10/12/90	6/9/92	4		Petroleum and hydrogen driven engine
5413075	10076	5/9/95	12/27/93	5/9/95	4	MAZDA MOTOR CORP.	Gaseous fuel engine and air-fuel ratio control system for the engine
4416224	10011	11/22/83	1/18/82	11/22/83	3		Internal combustion engine
4526947	10026	7/16/85	11/15/83	7/16/85	3	UNI-ENERGY SYSTEMS, INC.	SOLAR OXY-HYDROGEN VEHICLE
4622924	10034	11/18/86	6/20/83	11/18/86	3		HYDROGEN ENGINE
5115768	10046	5/26/92	2/7/91	5/26/92	3	DEUTSCHE FORSCHUNGS-U. VERSUCHSANSTALT FUR LUF	Combustion engine for hydrogen
5452698	10080	9/26/95	12/27/94	9/26/95	3		Method and apparatus for enhancing combustion in internal combustion engines
5785136	10091	7/28/96	3/15/95	7/28/96	3	MERCEDES-BENZ AG	Hybrid drive and operating method therefor
5887554	10096	3/30/99	1/19/96	3/30/99	3		Rapid response plasma fuel converter systems

Figure 99
Hydrogen Internal Combustion Engine Patent Family Activity
1983-2001

Figure 100
Hydrogen Internal Combustion Engine Patenting Trends
by Region 1983-2001

Figure 101
Patent Family Indicators by Region for New Combustion Regimes
Two 5 Year Time Periods

1992-96
 1997-2001

Figure 102
Hydrogen Internal Combustion Engine Companies
With 2 or More Patent Families
1983-2001

Figure 103
Patenting Trends for Top 10 Hydrogen Internal Combustion Engine
Companies

Figure 104
Patent Family Indicators for
Hydrogen Internal Combustion Engine Companies
Two 5 Year Time Periods

Figure 105

Emerging and Fading Hydrogen Internal Combustion Engine Companies

Two 3 Year Time Periods

Emerging Companies

Companies with the Largest Increase Among Those with 2+ Patents in 1999-2001

Company	1996-98	1999-2001	Increase	% Increase
Southwest Research Institute	0	1	1	Infinity

Fading Companies

Companies with the Largest Decrease Among Those with 2+ Patents in 1996-98

Company	1996-98	1999-2001	Decrease	%Decrease
University Of Melbourne	2	0	2	100%
University Of Central Florida	2	0	2	100%

Figure 106
Hydrogen Internal Combustion Engine Life Cycle Statistics

Figure 107. U.S. Govt Supports Half the Research Underpinnings of Freedom Car Technologies

Percent of Freedom Car technologies U.S. patent to U.S.-authored paper links

5044 total patent-paper links

Figure 108. DOE Funding Has More Impact on Freedom Car Technology Than Funding From Any Other Single Organization Except NIH*

(Counts of patent-paper links between Freedom Car technology U.S. patents and funded, U.S.-authored papers)

Funding Organizations	No. of Patent to Funded Paper Links	Category:				
		Fuel Cell Sys	Lightwt Matls	Power Electrnics	Emiss Control/ Combust	Other
All Foreign Gov'ts. & Non-Profits Combined	229	126	63	8	32	
All Companies Combined	192	46	114	8	21	3
NIH (all institutes combined)	190	5	13	1	170	1
Dept. of Energy	150	94	40	2	12	2
Navy	72	34	33	3	2	
Nat'l Science Foundation	68	35	27	2	4	
Advanced Research Projects Agency	55	17	30		8	
Army	50	16	34			
Funded, but specifics not avail.	37	21	14		2	
Air Force	35	9	25		1	
All other US private non-profits combined	31	7	4		20	
Nat'l Aero & Space Admin	30	16	14			
All US Univ & Med. Schls (State) combined	30	11	11	1	6	1
Welch Fdn. (Rob't. Welch)	19	14	4		1	
All US Univ. & Med. Schls (Priv.) combined	17	13	4			
Amer. Heart Assn. (St. & Loc.)	14				14	
Amer. Cancer Soc.	11	1			10	
All United Nations/Sup. Nat'l. Org. combined	9				9	
All Other USGovt / Other'l Gov't combined	9	7	1		1	
All State or Local Gov't. combined	8	4	1		3	
All Foreign Univ., Med., Tech. Schls. combin	7	7				
Petroleum Research Fdn.	7		7			
Nat'l Acad of Science	7	7				
Arthritis Foundation	5		1		4	
Nat'l Ctr for Research Resources	5				5	
Dept of Defense	4		3		1	
Sloan Fdn. (Alfred P. Sloan)	4	2	2			
Amer. Chemical Soc.	3	3				
Nat'l. Fdn. March of Dimes	3				3	
Muscular Dystrophy Assn.	2				2	
Dept. of Interior	1		1			
Office of Education (old)	1	1				
Res. Corp. (James Cottrell Gr)	1	1				
	1306	497	446	25	331	7

*NIH funding is focused in one area, emissions control, where the concern is the harmful effects of particulate emissions.

Figure 109. U.S. Govt Support of Research Underpinnings at the Freedom Car Category Level
Percent of Freedom Car technologies U.S. patent to U.S.-authored paper links

Automotive Fuel Cell Sys

Lightweight Materials

Power Electronics

Emissions & New Combustion Regimes Combined

Appendix A
Filter Definitions

APPENDIX A PATENT SEARCH FILTERS

FUEL CELL FILTER¹

Search #1:

[IPC] H01M008*²

[title/abs/claim] (PEM OR proton adj1 exchange adj1 membrane OR proton adj1 conducting adj1 electrolyte OR polymer adj1 electrolyte adj1 membrane OR SPE OR polymer adj1 electrolyte OR zinc adj1 air OR direct adj1 methanol OR DMFC) NOT ((high adj1 temperature adj1 polymer OR cogen* OR alkaline OR ((operat* OR subject* OR endure*) near5 (high adj1 temperature)))

Search #2:

[title/abs/claim] (fuel adj1 cell* OR electrochemical adj1 cell*) AND (PEM OR proton adj1 exchange adj1 membrane OR proton adj1 conducting adj1 electrolyte OR polymer adj1 electrolyte adj1 membrane OR SPE OR polymer adj1 electrolyte OR zinc adj1 air OR direct adj1 methanol OR DMFC) NOT ((high adj1 temperature adj1 polymer) OR cogen* OR alkaline OR ((operat* OR subject* OR endure*) near5 (high adj1 temperature))))

Combine these two and eliminate duplicates

For high-temperature membranes subcategory the following search strategy was tried:

Search #1

[IPC] H01M008*

[title/abs/claim] membrane AND ((high OR elevated) adj1 temp*) AND (PEM OR proton adj1 exchange adj1 membrane OR proton adj1 conducting adj1 membrane OR proton adj1 conducting adj1 electrol* OR polymer adj1 electrolyte OR SPE OR zinc adj1 air OR direct adj1 methanol OR DMFC)

¹ Definition of logical operators used in all the filters shown in this appendix:

Each filter is either IPC AND keywords or keywords alone

AND = logical and

OR = logical or

NOT = logical not

"*" = wildcard, any number of characters

adjn = adjacent within n words in the same direction

nearn = nearby within n words in either direction

² H01M008* covers fuel cells and related materials

Search #2

[title/abs/claim] (fuel adj1 cell* OR electrochemical adj1 cell*) AND membrane AND ((high OR elevated) adj1 temp*) AND (PEM OR proton adj1 exchange adj1 membrane OR proton adj1 conducting adj1 membrane OR proton adj1 conducting adj1 electrol* OR polymer adj1 electrolyte OR SPE OR zinc adj1 air OR direct adj1 methanol OR DMFC)

Combine these two and eliminate duplicates

HYDROGEN STORAGE FILTER

[title/abs/claim] (hydrogen near3 stor*) AND (alloy OR aluminum OR Al OR carbon OR compressed OR cycloalkane* OR dehydrid* OR fullerene* OR hydrid* OR intermetallic OR LaNi5 OR liquified OR magnesium OR Mg OR microsphere* OR nano* OR reversible OR solubility near2 hydrogen OR TiNi) not (electrode* OR peroxide* OR nickel adj1 metal OR nickel adj2 hydride OR metal adj1 hydride) [IPC] not H01M*³

ADVANCED BATTERIES FILTER

Search #1

[IPC]H01M*

[title/abs/claim] lithium adj1 ion OR Li adj1 ion OR lithium near3 secondary OR lithium near3 polymer OR NiMH OR nickel adj1 metal OR nickel adj2 hydride OR NiZn* OR nickel adj1 zinc OR ZnBr* OR Zn adj1 Br* OR zinc adj1 brom* OR NaNiCl* OR Na adj1 NiCl* OR sodium adj1 nickel adj1 chloride

Search #2

[title/abs/claim] battery OR batteries OR secondary OR accumulator*

[title/abs/claim] lithium adj1 ion OR Li adj1 ion OR lithium near3 secondary OR lithium near3 polymer OR NiMH OR nickel adj1 metal OR nickel adj2 hydride OR NiZn* OR nickel adj1 zinc OR ZnBr* OR Zn adj1 Br* OR zinc adj1 brom* OR NaNiCl* OR Na adj1 NiCl* OR sodium adj1 nickel adj1 chloride

Combine these two and eliminate duplicates

³ Filters out IPC=H01M* (batteries and fuel cells IPC) to exclude electrodes

Subcategory: Lithium polymer and lithium sulfur:

Searched for the subset of Advanced Batteries patents that contained the keywords (lithium or Li) near2 polymer and (lithium or Li) near2 sulfur

HEV FILTER

IPC's included:

B60H* - ??????????

B60K* - mounting of propulsion units

B60L* - Electric Equip or propulsion of electrically-propelled vehicles OR electrodynamic brake systs for vehicles in general

B60R* - ?????????

B60T* - Vehicle brake control systs or parts thereof

B62D* - Motor vehicles; trailers

F02D* - ????????

F16* - ????????

H02* - Generation OR conversion or distrib of electric power

H01M* - Batteries and fuel cells

[IPC] (B60H* OR B60K* OR B60L* OR B60R* OR B60T* OR B62D* OR F02D* OR F16* OR H01M* OR H02*)

[TITLE/ABS/CLAIM] (((hybrid* AND electric*) AND (car OR cars OR automobil* OR automotiv* OR vehic* OR motor* OR engine*)) OR hybrid* adj2 vehic* OR hybrid* adj car OR ((motor adj vehic*) AND hybrid*) OR HEV OR (regenerat* near2 brak*)) NOT (railway OR railcar OR train OR locomotive OR compressor* OR airbag* OR air adj bag* OR inflat*)

LIGHTWEIGHT MATERIALS FILTER

Search #1

[title/abs/claim] (((high adj strength OR ultralight OR lightweight* OR light adj weight* OR honeycomb* OR light*) near5 (metal* OR alloy*)) AND (car OR cars OR vehic* OR automo*)) OR (((carbon OR glass) near2 fib*) near10 (reinforc* OR prepreg)) OR (honeycomb adj3 (panel OR sandwich)

[IPC] (B22F* OR B29* OR B32B* OR B60B* OR B60D* OR B60G* OR B60J* OR B60K* OR B60R* OR B62D* OR C01B031* OR C04B035* OR C04B037* OR C08J* OR C21D* OR C22C* OR C22F* OR F01* OR F02* OR F16*) NOT (C30* OR E* OR F01N* OR F41* OR H0*)

Search #2

[title/abs/claim] ((high adj strength) near5 (aluminum OR magnesium OR titanium OR steel)) OR ((aluminum OR magnesium OR titanium) near5 alloy) OR ((carbon* OR alloy* OR metal* OR alumin* OR titanium OR magnesium OR steel) near2 (matrix OR composite*))

[IPC] (B22F* OR B29* OR B32B* OR B60B* OR B60D* OR B60G* OR B60J* OR B60K* OR B60R* OR B62D* OR C01B031* OR C04B035* OR C04B037* OR C08J* OR C21D* OR C22C* OR C22F* OR F01* OR F02* OR F16*) NOT (C30* OR E* OR F01N* OR F41* OR H0*)

Search #3 ("DISCARDS")

[title OR abs OR claim] (air adj bag* OR airbag OR cataly* OR exhaust OR foil OR mask OR mat OR mats* OR matting OR pipe OR rail* OR rubber OR screw* OR semic* OR silicon OR spacecraft OR spring* OR stainless OR tire* OR turbine* OR tyre* OR wood)

[IPC] (B22F* OR B29* OR B32B* OR B60B* OR B60D* OR B60G* OR B60J* OR B60K* OR B60R* OR B62D* OR C01B031* OR C04B035* OR C04B037* OR C08J* OR C21D* OR C22C* OR C22F* OR F01* OR F02* OR F16*) NOT (C30* OR E* OR F01N* OR F41* OR H0*)

COMBINE FIRST AND SECOND PULL OR ELIMINATE DUPLICATES OR THEN DELETE ANY THAT ARE IN THIRD PULL.

Carbon Composites subcategory: run pat filter abs on pulled set:

carbon adj2 matrix

carbon adj2 composite*

carbon near2 fib* near10 reforc*

carbon near2 fib* near10 prepreg

ULTRACAPACITORS FILTER

Search #1:

[IPC]h01g009155

Search #2:

[IPC] H01G* OR H02J* OR H01M* OR H02P*

[Title/abs/claim] ultracapacitor* OR supercapacitor* OR pseudocapacitor* OR ((ultra* OR super* OR pseudo* OR (high adj power)) adj1 capacitor*) OR edlc OR (electric adj1 double adj1 (dual OR layer) adj1 capacitor*) OR ((carbon OR (conducting adj1 polymer*)) near3 capacitor*)

Combine these two and eliminate duplicates

POWER ELECTRONICS OTHER THAN ULTRACAPACITORS

Search #1:

[title/abs/claim] ((power adj1 electronics OR motor adj1 control*) AND (vehic* OR automo* OR car OR cars)) OR (((dc adj1 dc) AND convert* AND (auto* OR vehic* OR car OR cars)) NOT (rail* OR locomot*)) OR ((ac adj1 induction adj1 motor) NOT ((three OR 3) adj1 phase)) OR ((microheat OR micro adj1 heat) adj1 pipe*) OR ((soft adj1 switch*) AND (invert* OR snubber)) OR (resonant adj1 snubber OR ((resonant adj1 tank) AND invert*)) OR ((soft adj1 commut*) AND (dc adj1 motor*)) OR ((homopolar adj1 motor*) AND (high adj1 power adj1 density))

Search #2:

[title/abs/claim] (((permanent adj1 magnet OR PM) adj1 motor*) AND (switch* OR field adj1 weaken* OR traction OR magnet* adj1 retention OR inverter adj1 control OR doubly adj1 salient)) NOT (brush OR brushes)) OR ((switch* adj1 reluctance adj1 motor*) NOT (pump OR compressor)) OR (ac adj1 motor OR adj1 convert*) OR ((electric adj1 motor*) AND (manufactur* OR produc*) AND (low* adj1 cost OR cost adj1 efficient OR cheaper OR reduced adj1 cost)) OR (((IGBT OR integrated adj1 gate adj1 bipolar adj1 transistor) AND (power adj1 switch*)) NOT (steer* OR rail* OR locomot*))

Search #3:

[title/abs/claim] (((motor adj1 control*) AND (vehic* OR automo* OR car OR cars)) NOT (steer* OR cool* OR fluid* OR rail* OR locomot*))
[IPC] (B60K* OR B60L*) NOT (E* OR F* OR B60N*)

Search #4:

[title/abs/claim] (((high adj1 speed high adj1 rpm) AND (induction adj1 motor)) NOT (low* adj1 speed OR reduction))
[IPC] H02P*

Combine these four and eliminate duplicates

DIRECT INJECTION FILTER

F01N – exhaust apparatus for IC engines, etc.

F02B – internal combustion piston engines, combustion engines in general

F02D – controlling internal combustion engines

F02F - cylinders, pistons, etc.

F02M – supplying combustion engines in general with combustible mixtures

F16 – engineering elements or units, e.g. valves, pistons, constructional elements, (F16N – lubricating)

B60 – motor vehicles

search #1:

[IPC] (F02B* OR F02D* OR F02F* OR F02M* OR F02N* OR F15* OR F16* OR B60*) NOT F01N*

[TITLE/ABS/CLAIM] diesel OR CIDI OR 4SDI OR direct near3 inject* OR ((fuel near3 inject*) AND (DME OR dimethyl adj1 ether OR fisher adj1 tropsch))

search #2:

[IPC] F02B* NOT F01N*

[TITLE/ABS/CLAIM] spark

The desired set is all patents in Search #1 that are not found in Search #2

EMISSIONS CONTROL

F01L – cyclically operating valves for engines

F01N - ... exhaust apparatus for IC engines -- obviously where most of Emissions Control patents are placed

F01N 3/xx, 5/xx, 7/xx, and 9/xx are fuel injection

F02B – internal combustion engines

F02D – controlling combustion engines

F02F – cylinders, pistons or casings, sealings

F02M – supplying combustion engines with combustible mixtures

F02N – starting of combustion engines

B60K – ????

Search #1 for F01N:

[IPC] F01N* NOT (F02M039* OR F02M04* OR F02M05* OR F02M06* OR F02M071*)

[title/abs/claim] NOT (noise* OR noisy OR silenc* OR muffl*)

Search #2 for other than F01N:

[IPC] (F01L* OR F02B* OR F02D* OR F02F* OR F02M* OR F02N* OR B60K*)
NOT (F01N* OR F02M039* OR F02M04* OR F02M05* OR F02M06* OR F02M071*)
[title/abs/claim] ((pollut* OR emiss* OR NOx OR soot OR carbon adj monoxide OR purif* near2 (exhaust OR waste adj gas)) OR nitrogen adj oxide*) near6 (abat* OR absorb* OR attenuat* OR contain* OR control* OR decreas* OR eliminat* OR improv* OR less OR limit* OR low OR lower OR lowering OR lowest OR minim* OR performance OR prevent* OR purif* OR reduc* OR rate OR treatment OR worsen*))
NOT (noise* OR noisy OR silenc* OR muffl*)

Combine these two and eliminate duplicates

NEW COMBUSTION REGIMES

topics:

fuel – air mixing in CIDI
secondary fuel injection
variable compression ratio
diesel fuel in-cylinder swirl
late cycle air injection
variable valve activation

[IPC] F02B* OR F02D* OR F02M* OR F16
[title/abs/claim] (((CIDI OR diesel OR compression adj1 ignition OR direct adj1
injection) AND (fuel OR hydrocarbon*) AND (air) AND (mix OR mixes OR mixing
OR combine* OR soot)) NOT (spark OR filtration OR filter*)) OR ((secondary near3
fuel AND inject*) NOT turbine*) OR
((vary* vari*) near5 compression) OR (late near5 cycle) OR
((CIDI OR diesel OR compression adj1 ignition OR direct adj1 injection) AND swirl)
OR (variable near3 valv*)

HYDROGEN ICE FILTER

Search #1:

[IPC] (F02B* OR F02M*) NOT F01N*
[title/abs/claim] hydrogen NOT (fuel adj1 cell* OR electrochem* adj1 cell* OR batter*
OR biomass OR biogas OR peroxide OR magnet*)

Search #2:

[title/abs/claim] hydrogen adj1 engine*

Combine these two and eliminate duplicates

Appendix B

Patent Family Counts by Distributions

Figure B1. Advanced Fuel Cells Patent Families by Co. and Year

Rank	Company	All Famil	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
1	BALLARD POWER SYSTEMS INC	46	0	0	0	0	0	0	0	0	0	0	2	3	5	2.5	5	3.5	3	10	12
2	UNITED TECHNOLOGIES CORP	39	0	1	1	0	1	4	4	1	0	0	3	0	1	1	0	1	3	9	9
3	GENERAL MOTORS CORPORATION	33	0	0	0	0	0	0	0	0	0	0	2	2	0	0	2	4	4	8	11
4	MATSUSHITA ELECTRIC INDUSTRIAL CO L	29.5	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	4	7.5	10	6
5	DBB FUEL CELL ENGINES GMBH	25	0	0	0	0	0	0	0	0	0	0	0	0	1	0	4	8.5	8	3.5	0
6	TOYOTA MOTOR CORPORATION	21	0	0	0	0	0	0	0	0	0	0	0	0	0	4	1	3	2	5	6
7	SIEMENS AG	19.5	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	9	2	6.5
8	DOW CHEMICAL CO	18	0	0	0	0	4	2	1	0	0	1	0	0	2	1	3	1	2	0	1
9	DAIMLER CHRYSLER AG	17	0	0	0	0	0	0	0	0	0	0	0	1	2	1	4	1	1	6	1
10	CALIFORNIA INST OF TECHNOLOGY	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	1	1.5	4	9
11	UNIVERSITY OF CALIFORNIA	15	0	0	0	0	0	0	0	0	0	0	2	0	1	1	2	1	2	2	4
12	HONDA GIKEN KOGYO KK	15	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	5	0	2	6
13	MOTOROLA INC	15	0	0	0	0	0	0	0	0	0	0	0	0	1	2	5	0	2	4	1
14	LOCKHEED MARTIN CORP.	14	0	0	1	2	1	3	1	1	0	1	0	0	0	0	2	0	0	1	1
15	PLUG POWER INC	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	5	5
16	H-POWER CORP.	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	1	2	3	0
17	MMM/MINNESOTA MINING & MFG CO	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	3
18	JOHNSON MATTHEY PLC	8.5	0	0	0	0	0	0	0	0	0	0	0	1	0	0.5	0	1	2	1	3
19	US DOE	8	0	2	0	1	0	0	1	1	0	0	1	0	0	0	0	0	1	1	0
20	HITACHI LTD	7	0	0	1	0	1	1	0	0	0	0	2	1	0	1	0	0	0	0	0
21	GAS TECHNOLOGY INSTITUTE	7	0	0	0	0	1	1	0	0	2	0	1	0	0	0	0	0	1	0	1
22	TANAKA KIKINZOKU KOGYO KK	6.7	0	0	0	0	0	0	0	0	0	0.5	0.5	1.5	0	0.5	0.3	1.7	0.7	1	0
23	MITSUBISHI ELECTRIC CORP	6.5	0	0	0	0	2	0	0	0	0	0	0	0	1	1	0	1.5	0	0	1
24	INDIVIDUAL PATENTER	6.2	0	0	0	0	0	0	0	0	0	0.5	0	0.8	0	0	0.3	1	1	2.5	0
25	ASAHI GLASS KK	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	5
26	KERNFORSCHUNGSANLAGE JULICH GMB	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	4
27	E I DUPONT DE NEMOURS & CO	5.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	2.5	0	0
28	EXXON MOBIL CORP.	5.5	0	0	0	0	0	0	0	0	0.5	0	0	0	0	1	0	0	2	1	1
29	US ARMY	5	0	0	0	0	0	0	0	0	0	0	0	1	1	2	0	1	0	0	0
30	FUJI ELECTRIC CO LTD	5	0	0	0	0	0	0	0	0	1	0	2	0	0	0	0	0	1	1	0
31	SANYO ELECTRIC CO LTD	5	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	3	0
32	AVENTIS S.A.	4.5	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	1	1.5
33	VALENCE TECHNOLOGY INC.	4	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	1	0	0	0
34	FRAUNHOFER GESELLSCHAFT	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0
35	FERRO CORPORATION	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3
36	RAYTHEON COMPANY	4	0	0	0	0	0	0	2	0	0	0	1	1	0	0	0	0	0	0	0
37	NISSHINBO INDUSTRIES INC	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	3
38	HONEYWELL INC	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	3
39	SUMITOMO CHEMICAL CO LTD	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	1	1
40	CASE WESTERN RESERVE UNIVERSITY	4	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	2	0
41	SULZER AG	4	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	1
42	E.ON AG	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	0
43	MAGNET-MOTOR GES. FR. MAGNETMOTO	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	0
44	IMPERIAL CHEMICAL INDUSTRIES PLC	4	0	0	0	0	1	0	1	0	1	0	1	0	0	0	0	0	0	0	0
45	UNIVERSITY OF CHICAGO	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	1
46	AININ SEIKI COMPANY LIMITED	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0	1
47	W.L. GORE & ASSOC., INC.	3.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.5	0	2
48	STONEHART ASSOC. INC.	3.2	0	0	0	0	0	0	0	0	0	0	0	1	0	0.5	0.3	0.7	0.7	0	0
49	FOSTER-MILLER INC.	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2
50	BCS TECHNOLOGY, INC.	3	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0
51	YAMAHA HATSUDOKI KK	3	0	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0
52	ISHIKAWAJIMA-HARIMA HEAVY INDUSTRIE	3	0	0	0	0	0	0	0	0	1	0	1	0	0	1	0	0	0	0	0
53	VODAFONE GROUP PLC	3	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	2	0
54	UK ATOMIC ENERGY AUTHORITY	3	0	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0
55	ROLLS-ROYCE PLC	3	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0
56	CERAMATEC, INC.	3	0	0	0	0	0	0	0	0	0	0	2	0	1	0	0	0	0	0	0
57	ENERGIZER HOLDINGS, INC.	3	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0
58	LYNNTECH INC	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0
59	PHYSICAL SCIENCES INC.	3	0	0	0	0	0	0	0	0	0	2	0	1	0	0	0	0	0	0	0
60	ENGELHARD CORP	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
61	LITTLE (ARTHUR D.), INC.	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
62	CANADA NATIONAL DEFENCE MINISTRY	2	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
63	MOLTECH CORP.	2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
64	DAIKIN INDUSTRIES LTD	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
65	BOC GROUP PLC, THE	2	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
66	MANHATTAN SCIENTIFICS INC	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
67	DE NORA S.P.A.	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0

Figure B2. Hydrogen Storage Patent Families by Co. and Year

Rank	Company	All Famil	1993	1994	1995	1996	1997	1998	1999	2000	2001
1	ENERGY CONVERSION DEVICES INC	10	0	0	0	0	0	0	0	1	4
2	KOPPERS COMPANY, INC.	7	2	0	2	1	2	0	0	0	0
3	BP P.L.C.	5	0	0	0	2	0	0	2	1	0
4	MATSUSHITA ELECTRIC INDUSTRIAL CO L	5	1	1	0	0	0	0	0	0	0
5	DAIMLER CHRYSLER AG	4	0	2	0	1	0	1	0	0	0
6	MCGILL UNIVERSITY	3.5	0	0	0	0	0	0	0	0	0
7	BATTELLE MEMORIAL INSTITUTE	3	1	0	0	0	0	0	1	0	2
8	HYDRO-QUEBEC	2.5	0	0	0	0	0	0	0	0	0
9	MITI AGENCY OF IND SCI & TECHNOL	2.5	1	0	0	0	0	0	0	0	1
10	KERNFORSCHUNGSANLAGE JULICH GMB	2	2	0	0	0	0	0	0	0	0
11	MAZDA MOTOR CORPORATION	2	0	0	0	0	0	0	0	0	0
12	STUDIENGESELLSCHAFT KOHLE GMBH	2	0	1	0	0	0	0	0	0	0
13	KOREA ADVANCED INSTITUTE OF SCIENC	2	0	0	0	0	0	0	1	0	0
14	VODAFONE GROUP PLC	2	0	0	0	2	0	0	0	0	0
15	SANYO ELECTRIC CO LTD	2	0	0	0	0	0	0	0	0	0
16	KONINKLIJKE PHILIPS ELECTRONICS N.V.	2	1	1	0	0	0	0	0	0	0
17	KIYOKAWA PLATING INDUSTRIES CO LTD	2	0	0	0	0	0	0	0	0	0
18	E.ON AG	2	0	0	0	0	0	0	0	0	0
19	CATALYTIC MATERIAL LTD	2	0	0	0	0	0	0	0	0	0
20	JAPAN METALS & CHEMICALS CO., LTD.	1.5	0	0	0	0.5	0	1	0	0	0
21	TOYOTA MOTOR CORPORATION	1.2	0	0	0	0	0	0	0	0	0
22	JOHNSON MATTHEY PLC	1	1	0	0	0	0	0	0	0	0
23	ELECTRON TRANSFER TECHNOLOGIES, I	1	0	0	0	0	1	0	0	0	0
24	MPD TECHNOLOGY CORPORATION	1	1	0	0	0	0	0	0	0	0
25	THYSSEN KRUPP	1	0	1	0	0	0	0	0	0	0
26	AGENCE NATIONALE DE VALORISATION, E	1	1	0	0	0	0	0	0	0	0
27	NIPPON STEEL CORPORATION	1	0	1	0	0	0	0	0	0	0
28	ERGENICS INC.	1	0	0	0	1	0	0	0	0	0
29	MINISTRY OF EDUCATION, CULTURE, SPO	1	1	0	0	0	0	0	0	0	0
30	CHARLES STARK DRAPER LABORATORY I	1	0	0	0	1	0	0	0	0	0
31	INSTITUTT FOR ENERGITEKNIKK	1	0	0	0	0	0	0	0	0	0
32	APD CRYOGENICS INC.	1	0	0	0	1	0	0	0	0	0
33	GFE-GESELLSCHAFT FUER ELEKTROMET	1	0	0	0	0	1	0	0	0	0
34	BENTELER-WERKE AG	1	0	0	0	0	1	0	0	0	0
35	SYRACUSE UNIV.	1	0	0	0	0	0	1	0	0	0
36	GESELLSCHAFT FR ANLAGEN & REAKTOR	1	0	0	0	0	0	0	0	0	0
37	KVAERNER A.S.A.	1	0	0	0	0	0	0	0	0	0
38	SAES GETTERS SPA	1	0	0	0	0	0	0	0	0	0
39	NIPPON YAKIN KOGYO CO. LTD.	1	0	0	0	0	0	0	0	0	0
40	UNITED TECHNOLOGIES CORP	1	0	0	0	0	0	0	0	0	0
41	PRAXAIR INC	1	0	0	1	0	0	0	0	0	0
42	US DOE	1	0	0	0	0	0	0	0	0	0
43	HONEYWELL INC	1	0	0	0	0	0	0	0	0	0
44	GENERAL MOTORS CORPORATION	1	0	0	0	0	0	0	0	0	0
45	UNIVERSITY OF HAWAII	1	0	0	0	0	0	0	0	0	0
46	TRW INCORPORATED	1	0	0	0	1	0	0	0	0	0
47	SHIN-ETSU CHEMICAL CO LTD	1	0	0	0	0	0	0	0	0	0
48	GILLETTE CO THE	1	0	0	0	0	0	0	0	0	0
49	LOCKHEED MARTIN CORP.	1	0	0	0	0	0	0	0	0	0
50	SUMITOMO ELECTRIC INDUSTRIES LTD	1	0	0	0	0	0	0	0	0	0
51	MITSUBI MINING AND SMELTING CO. LTD.	1	0	0	0	0	0	0	0	0	0
52	INSTITUTE OF METAL RESEARCH ACADE	1	0	0	0	0	0	0	0	0	0
53	KERNFORSCHUNGSZENTRUM KARLSRUH	1	0	0	0	0	0	0	0	0	0
54	LINDE AG	1	1	0	0	0	0	0	0	0	0
55	AIR PRODUCTS & CHEMICALS INC	1	0	0	1	0	0	0	0	0	0
56	JAPAN STEEL WORKS, LTD.	0.5	0	0	0	0	0.5	0	0	0	0
57	UNIVERSITY OF CONNECTICUT	0.5	0	0	0	0	0	0	0	0	0
58	E I DUPONT DE NEMOURS & CO	0.5	0	0	0	0	0	0	0	0	0
59	CHIYODA CORPORATION	0.5	0	0	0	0	0.5	0	0	0	0
60	INDIVIDUAL PATENTER	0.5	0	0	0	0	0	0	0	0	0
61	MITSUBI & CO. LTD.	0.5	0	0	0	0.5	0	0	0	0	0
62	TOHOKU TECHN ARCH CO LTD	0.5	0	0	0	0	0	0	0	0	0
63	TOYODA AUTOMATIC LOOM WORKS, LTD.	0.3	0	0	0	0	0	0	0	0	0
	No Assignees	5	0	0	0	1	0	0	1	1	1
	All Companies Combined	108	13	7	4	12	5	4	2	3	13

Figure B3. Advanced Batteries Patent Families by Co. and Year

Rank	Company	All Famil	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
1	MATSUSHITA ELECTRIC INDUSTRIAL CO L	75	1	0	1	0	0	0	1	2	0	1	3.5	3	0	7.5	9.5	7.5	9	13	16
2	VALENCE TECHNOLOGY INC.	30.5	0	0	0	0	0	0	0	0	0	0	1	0	1	0	6	8	4	6	4.5
3	NGK INSULATORS LIMITED	26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	11	6
4	SCIENCE APPLICATIONS INT'L	26	0	0	0	1	1	1	0	0	0	0	3	2	4	4	3	2	2	3	0
5	SANYO ELECTRIC CO LTD	25.5	0	0	0	0	0	0	0	0	0	0	0	3	1	1	3	2	2	6	7.5
6	MITSUBISHI ELECTRIC CORP	23.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	5.5	8	6
7	SAMSUNG GROUP	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	3	2	6	9
8	HITACHI LTD	20.5	0	0	0	1	0	0	0	0	0	0	0	0	0	2	3	1	4	5.5	4
9	TOSHIBA CORPORATION	20	0	0	0	0	0	0	0	0	3	0	1	2	1.5	2	1	4.5	0	4	1
10	ALCATEL	17	0	0	0	0	0	0	0	0	0	2	0	1	3	1	0	2	4	2	2
11	JAPAN STORAGE BATTERY	16.5	0	0	0	0	0	0	0	0	1	0	0	1	0	1	4	3	1.5	3	2
12	FMC CORP	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	4	3	5
13	HYDRO-QUEBEC	15.5	0	0	0	0	0	0	0.5	0.5	0	0.5	1	2	1	3	1	1.5	1	3.5	0
14	MOLI ENERGY (1990) LTD.	15	0	0	0	0	0	0	0	0	0	0	0	1	2	3	4	3	1	0	1
15	WILSON GREATBATCH LTD.	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	8	6
16	SUMITOMO CHEMICAL CO LTD	15	0	0	0	0	0	0	0	0	0	0	0	0	0	2	4	4	0	3	2
17	FUJI PHOTO FILM CO LTD	15	0	0	0	0	0	0	0	0	0	1	2	2	1	0	1	0	4	3	1
18	ENERGY CONVERSION DEVICES INC	14	0	0	0	0	0	0	1	0	1	0	3	0	0	2	1	0	3	1	2
19	MITSUBISHI CHEMICAL CORP.	13.5	0	0	0	0	0	0	0	0	1	0	1.5	0	0	0.5	0	0	5	3	2.5
20	SONY CORPORATION	13	0	0	0	0	0	0	0	0	1	0	0	0	1	0	1	1	2.5	2.5	4
21	VARTA AG	13	0	0	1	0	0	0	0	0	0	1	0	0	3	1	3	0	0	3	1
22	GENERAL MOTORS CORPORATION	12	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	1	2	4	1
23	MOTOROLA INC	12	0	0	0	0	0	0	0	0	0	0	0	0	2	2	4	2	0	2	0
24	US ARMY	10	0	0	0	0	0	0	1	0	0	2	0	1	2	1	1	0	0	0	2
25	GILLETTE CO THE	9	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	3	0	3	0
26	CANON INC	9	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	3	3	0	1
27	TOYOTA MOTOR CORPORATION	9	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	3.5	2	1.5
28	PETCOA LTD.	8	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0	2	1.5	1	3	0
29	KONINKLIJKE PHILIPS ELECTRONICS N.V.	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	5
30	LOCKHEED MARTIN CORP.	7	0	0	0	1	0	0	0	1	0	0	0	1	1	0	0	0	2	0	1
31	S.E.A./STUDIENGESellschaft. FR ENERGIE	7	0	0	0	3	1	2	0	0	1	0	0	0	0	0	0	0	0	0	0
32	DOW CORNING CORP.	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	2	1	0	1
33	ENERGIZER HOLDINGS, INC.	7	1	0	0	0	0	0	0	0	0	0	1	1	2	0	0	0	0	1	1
34	INDIVIDUAL PATENTER	6.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1.5	4.1
35	FURUKAWA ELECTRIC CO. LTD.	6.5	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3.5	1	0	0	0
36	UBE INDUSTRIES LTD	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0.5	3	0.5
37	DANIONICS A/S	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	3	0	1
38	SHIN-KOBE ELECTRIC MACHINERY CO., LT	5.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2.5	2
39	SHARP CORPORATION	5.5	0	0	0	0	0	0	0	0	1	0	0	1	1	1	1	0.5	0	0	0
40	FUJITSU LIMITED	5.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1.5	1	2
41	SEIKO INSTRUMENTS CO. LTD.	5.5	0	0	0	0	0	0	0	0	0	0	0	1.5	0	2	0	2	0	0	0
42	SANTOKU METAL INDUSTRY CO. LTD.	5	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2	1	0	1
43	INDUSTRIAL TECHNOLOGY RESEARCH IN	5	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	1	1	0	1
44	YUASA CORP.	5	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	1	1	0
45	EXXON MOBIL CORP.	5	0	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
46	MEIDENSHA CORPORATION	5	0	0	1	1	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0
47	MERCK AG	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	3	0
48	NEC MOLI ENERGY (CANADA) LTD	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	1	0
49	MURATA MANUFACTURING COMPANY LIM	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	0	0	1
50	MITSUBISHI CABLE INDUSTRIES LTD.	5	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2	1	1	0
51	TDK CORPORATION	4.5	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	1	1.5
52	SHIN-ETSU CHEMICAL CO LTD	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2
53	NATIONAL RESEARCH COUNCIL OF CANA	4	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	0	0	0
54	ROHM CO. LTD.	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	1
55	MOLTECH CORP.	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	3	0	0
56	RICOH COMPANY LTD	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2	1	0
57	UNIVERSITY OF CALIFORNIA	4	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	1	0
58	VARTA GERAETEBATTERIE GMBH	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	1
59	POLYPLUS BATTERY CO INC	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	1
60	ELECTRO ENERGY INC.	4	0	0	0	0	0	0	0	0	0	0	0	0	2	1	1	0	0	0	0
61	ELTRON RESEARCH, INC.	4	0	0	0	0	2	1	1	1	0	0	0	0	0	0	0	0	0	0	0
62	EIC LABORATORIES, INC.	4	0	0	0	0	0	0	0	0	0	0	2	0	1	0	0	0	1	0	0
63	ELIN ENERGIEANWENDUNG GMBH	4	0	0	0	0	0	0	2	0	0	0	0	1	1	0	0	0	0	0	0
64	MITSUBISHI GAS CHEMICAL CO	4	0	0	0	0	0	0	0	0	0	0	2	0	0	1	1	0	0	0	0
65	MITSUMI MINING CO LTD	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	1
66	ULTRALIFE BATTERIES, INC.	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	1
67	NBT GMBH	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	3	0

Figure B4. HEV Patent Families by Co. and Year

Rank	Company	All Famil	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
1	HONDA GIKEN KOGYO KK	84	0	0	0	0	0	0	0	0	1	0	0	3	5	5	6	2	8	20	34
2	TOYOTA MOTOR CORPORATION	81	0	0	0	0	0	0	0	0	0	1	2	3	3	4	7	9	20.5	16	15.5
3	AININ SEIKI COMPANY LIMITED	40	0	0	0	0	0	0	0	0	0	1	2	0	3	5	3	10	5.5	3	7.5
4	FORD MOTOR COMPANY	27.5	0	1	0	0	0	1	0	1	0	0	2	4	1	0	0	2	2	3	10.5
5	NISSAN MOTOR CO LTD	27	0	0	0	0	0	0	0	2	0	1	0	0	0	1	0	0	5	9	9
6	DAIMLER CHRYSLER AG	24	0	0	0	0	0	0	0	0	0	0	0	2	1	1	3	6	4	4	3
7	GENERAL MOTORS CORPORATION	24	0	2	1	1	0	0	0	0	0	0	0	0	0	6	3	3	2	4	2
8	HITACHI LTD	21	2	1	0	0	0	0	0	0	0	2	0	0	2	1	0	2	2	0	9
9	DENSO CORP.	18	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	4	2	2	6
10	MITSUBISHI MOTORS CORP	15	0	0	0	0	0	0	0	0	0	0	2	2	0	1	2	1	1	1	5
11	SIEMENS AG	14	0	0	0	0	0	0	0	0	0	0	0	0	0	7	2	2	3	0	0
12	INDIVIDUAL PATENTER	9.5	0	0	0	0	0	0	0	0	1	1	0	1	0	0	1	1	1	1	2.5
13	ISUZU MOTORS LIMITED	8	0	0	0	0	1	0	0	2	1	2	0	0	0	0	2	0	0	0	0
14	SWATCH GROUP AG	8	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	3	3	0	1
15	LOCKHEED MARTIN CORP.	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	1	1
16	ROBERT BOSCH GMBH	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	2	2
17	MITSUBISHI ELECTRIC CORP	6	0	1	0	0	1	0	0	0	0	0	1	1	0	0	1	0	0	0	1
18	BAYERISCHE MOTOREN WERKE AG	5	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	2	0	1
19	RENAULT, REGIE NATIONAL DES USINES	4	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	2	1
20	VOLKSWAGEN AG	4	0	0	1	0	0	0	0	0	0	0	1	1	0	0	0	1	0	0	0
21	YAMAHA HATSUDOKI KK	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	2
22	MINEBEA CO. LTD.	4	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	2	0	0	0
23	PEUGEOT S.A.	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	1
24	FUJI HEAVY INDUSTRIES CO LTD	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
25	SEIKO EPSON CORPORATION	3	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0.5	0	0	0.5	0
26	KOMATSU LIMITED	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0
27	SEKOGIKEN KK	3	0	0	0	0	0	0	0	0	1	0	0	2	0	0	0	0	0	0	0
28	WESTINGHOUSE ELECTRIC (OLD)	3	0	1	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0
29	DANAHER CORP	3	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0
30	JM VOITH GMBH	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1
31	FANUC LTD	3	0	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
32	NEVCOR INC	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
33	TEXTRON INC	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
34	DELPHI AUTOMOTIVE SYSTEMS	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0
35	ITT INDUSTRIES INC.	2	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0
36	GENERAL ELECTRIC CO	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
37	HONEYWELL INC	2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0
38	TENERGY L.L.C.	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
39	BTG INTERNATIONAL LTD.	2	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40	ECOAIR CORP.	2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
41	ZF FRIEDRICHSHAFEN AG	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
42	NEW YORK INSTITUTE OF TECHNOLOGY	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
43	JEOL LIMITED	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0
44	UTDC INC.	2	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45	VISTEON CORP.	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
46	BALLARD POWER SYSTEMS INC	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
47	LAUZUN CORP.	2	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
48	CYMER INC.	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
49	NISSAN DIESEL CO., LTD.	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
50	FUJI ELECTRIC CO LTD	1.5	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0.5	0	0
51	NISSAN DIESEL MOTOR CO., LTD.	1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0	1
52	TOKYO R & D CO., LTD.	1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0	1	0
53	FRANK TRANSPORTATION TECHNOLOGY	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
54	PEI 1991 ACQUISITION, INC.	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
55	PAICE CORP	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
56	SIG SCHWAZERISCHE INDUSTRIE-GESEL	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
57	COMPUTER GRAPHICS SYSTEMS DEVELO	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
58	BEHR GMBH	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
59	MAN AG	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
60	EATON CORP	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
61	LEAR CORP	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
62	OKOMOBIL GESELLSCHAFT FUR OKOLOGI	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
63	CALIFONE INT'L INC.	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
64	JEFFERSON PROGRAMMED POWER LLC	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
65	TOWN CREEK INDUSTRIES, INC.	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
66	STEINBOCK GMBH	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
67	TEXAS A&M UNIVERSITY	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0

Figure B5. Lightweight Material Patent Families by Co. and Year

Rank	Company	All Famil	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
1	ALUMINUM COMPANY OF AMERICA	170	5	4	3	5	8	5	16	8	10	15.5	10.5	11.5	11	6	7.5	11	14	9	10
2	GENERAL ELECTRIC CO	95.5	2	1	0	3	1	2	2	15	7	4	12	16	7	5	3	3	2	2	8.5
3	ALCAN ALUMINUM LTD	95.2	0	2	0	3	3	7	11	2	4	4	6	6	4	2	2	5	9	15.7	9.5
4	TOYOTA MOTOR CORPORATION	86.8	3.5	8	6	12.5	13	1.5	5	3	2.5	2.5	3.1	4.8	5.5	4	2.5	1	1	2.3	5
5	HONEYWELL INC	84	2	1	5	6	3	2	4	9	5	12	9	8	1	4	0	2	4	3	4
6	MSE INC.	82	0	0	0	0	1	3	6	22	9	4	7	6	7	6	6	2	1	1	1
7	HONDA GIKEN KOGYO KK	64.1	0	0	0	3	3.5	3.3	3.5	4.5	3.8	1.5	5.5	1.5	5.8	5.3	3	2	1.5	9	7.5
8	INDIVIDUAL PATENTERS	52.4	0	1	1	0.5	1	4.5	7	2.5	2	1.8	3.6	2.3	1.2	2.2	5	3.6	4	4.3	4.9
9	UNITED TECHNOLOGIES CORP	51.5	3	5	0	1	3	4	4	3	4	4	1.5	3	5	3	3	0	1	2	2
10	SUMITOMO METALS INDUSTRIES LTD	51.2	1	2	1	4	2.8	1	2	5	6	8	2	3	2.5	1.5	1.5	3.8	0	2.5	1.5
11	KOBE STEEL LIMITED	51	0	0	1	0	4	4	3	4	3	1	2	1	2.5	2	0	4	3	8	8.5
12	BOEING CO, THE	50	1	0	4	3	1	2	2	1	1	4	2	2	5	0	2	3	7	6	4
13	NIPPON STEEL CORPORATION	48.5	1	1	1	1	1	3	2.8	3	5	3	0	5	3	3.5	5	3.3	1	4.5	1.3
14	SUMITOMO ELECTRIC INDUSTRIES LTD	46.7	1	0	2	3.5	1	1	1.5	0.3	1	5.5	8	4.5	3.5	6	0	2.5	1.5	3.8	0
15	DOW CHEMICAL CO	46	2	2	1	1	2	3	4	5	4	1	1	2	2	3	2	3	6	1	1
16	US AIR FORCE	46	1	2	1	1	3	4	7	2	5	2	3	1	5	3	1	1	1	1	2
17	YOSHIDA KOGYO KK	44.6	0	0	0	0.5	0	0.5	2.3	3.5	3.6	3.2	15.3	5.8	2.8	1.3	2.5	2.3	1	0	0
18	DAIMLER CHRYSLER AG	43.5	0	0	1	0	1	3	0	2	1	3	1.5	2	0	2	4	5	3.5	6	8.5
19	LOCKHEED MARTIN CORP.	43.5	0	0	0	1	2	2	3	9	3	0.5	4	1	6	3	2	3	4	0	0
20	SANDVIK AB	40	0	0	0	0	0	1	1	0	0	7	6	5	1	3	1	0	6	7	2
21	KAWASAKI STEEL CORPORATION	39.2	1	0	1	0	1	1	2.3	0	3	4	1	4.3	4.5	5	2	0.5	5	2	1.5
22	PECHINEY SA	36.5	2	4	1	1	1.5	3	1	1	2.5	2.5	1	0	0	3	3	1	1	4	4
23	NKK CORPORATION	30.5	0	0	0	0	0.5	1	1	5	5	1	1	1.5	3.5	2.5	3	1.5	1	1	2
24	VOLKSWAGEN AG	30.5	0	0	1	0	0	0	1	0	0	0	6	5	4	2	1	2	4	3.5	1
25	HITACHI LTD	30.3	0	1	1.5	1.5	1.5	0	1	1	2	4	4	4	2	3	1	0.8	0	1	1
26	FURUKAWA ELECTRIC CO. LTD.	29.8	0.3	0.5	0	0	0.5	0	2	2	0	1	2	2.4	3.5	5.5	0	2	3	3.5	1.5
27	NGK INSULATORS LIMITED	28.5	1	0	4	3	4	3	4	2	1	2	0	0	0	0.5	1	0	1	1	1
28	EXXON MOBIL CORP.	27.5	0	0	0	2	2	1	0	1	1	0	2	1	1	3	5	0	1	6.5	1
29	EUROPEAN AERONAUTIC DEFENCE AND	27.5	0	1	0	0	1	0	1	1	1	0	0	3	3	5	4	1.5	3	2	1
30	NASA/US NATL AERONAUTIC & SPACE AD	26	1	0	1	0	0	1	2	4	1	3	1	1	0	1	1	3	3	3	0
31	US NAVY	25.5	0	1	0	1	2	1	2	2	2	3	3	3.5	1	2	0	0	2	0	0
32	NORSK HYDRO A/S	25.5	1	0.5	0	2	1	2	0	1	2.5	2.5	2	0	1	3	0	1	2	2.5	1.5
33	DAIDO METAL CO LTD	25	1	0	0	0	0	1	0	0	1	3	1	6	6	3	1	1	0	0	1
34	NISSAN MOTOR CO LTD	24.3	1	1	3	0	1	1	1	2.5	0.8	0.5	2	0	2	0.5	1.5	1	0	2.5	3
35	GENERAL MOTORS CORPORATION	24	0	0	0	0	0	1	0	1	0	2	4	1	1	1	1	1	2	2	4
36	SHOWA DENKO KK	23.5	1	0.5	1	1	0	4	2	3	1	1.5	0	0.5	1	0	2	2.5	1.5	0	1
37	GOODRICH CORP.	23	4	0	0	1	0	1	1	2	2	0	1	3	0	1	2	2	2	1	0
38	PPG INDUSTRIES INC	23	3	3	0	1	1	2	2	1	0	0	1	0	1	1	2	2	2	1	0
39	ROCKWELL INTERNATIONAL CORP	22	0	2	0	1	0	3	3	0	0	2	2	0	3	4	0	1	0	1	0
40	INCO ALLOYS INT'L. INC.	21	1	1	2	3	2	4	3	0	2	2	1	0	0	0	0	0	0	0	0
41	MITI AGENCY OF IND SCI & TECHNOL	20	0	0	0	1	3	4	1	1.5	0	0	0	0	0	0	2	1	1	1	4.5
42	BP P.L.C.	20	1	3	0	1	1	2	2	1	1	4	2	1	0	1	0	0	0	0	0
43	SNECMA/SOC NAT'L D'ETUDE ET CONSTR	19.3	0	1.5	0	0	2	1	0	1	1	1	3	0.5	1	0	1	2	1.3	1	2
44	MITSUBISHI CHEMICAL CORP.	19.3	2	0	0	1	1	1.5	0.3	0	1	2	1	3	0.5	3	1	0	0	2	0
45	MITSUBISHI MATERIALS CORP.	18.8	0	0	0	2	2	0	3	0	2	0	1	1.5	3.5	0	0	1.3	0	1	1.5
46	FORD MOTOR COMPANY	18	1	0	1	0	1	0	2	2	0	3	1	1	1	0	1	0	1	1	2
47	ABB ASEA BROWN BOVERI	18	2	0	0	4	3	2	1	2	0	1	0	1	1	0	0	1	0	0	0
48	VERIZON COMMUNICATIONS	17	1	0	0	2	4	3	2	1	1	3	0	0	0	0	0	0	0	0	0
49	MAXXAM INC	17	0	0	0	2	0	2	0	0	0	0	0	1	1	3	1	4	1	1	1
50	NISSEKI MITSUBISHI OIL CORP	16.1	0	0	0	0	0	0	1.3	0	4.5	0	2	1	2	2	1	1	1	0	0.3
51	MMM/MINNESOTA MINING & MFG CO	16	0	0	2	0	0	1	0	2	0	1	3	0	0	3	0	1	1	1	1
52	TORAY INDUSTRIES INC	15.5	0.5	0	1	0	0	0	0	1	0	0	0	0	1	1	1	3	4	3	0
53	ROEHLING INDUSTRIE VERWALTUNG G	15.3	0	0	1	1	2	1	1	1	1.3	2	0	0	0	0	1	0	0	3	1
54	EASTMAN KODAK CO	15	0	0	0	0	0	0	0	0	1	0	0	0	1	1	4	5	2	0	1
55	BAYERISCHE MOTOREN WERKE AG	15	0	0	0	0	0	0	0	0	1	2	0	0	0	0	1.5	1	1	6.5	2
56	UBE INDUSTRIES LTD	14.5	0	0	1	1	0	1	4	2.5	0	0	0	0.5	0	1	0.5	0.5	1	0.5	1
57	BAYER AG	14	0	1	1	0	2	0	0	2	0	1	1	0	0	3	1	0	0	1	1
58	OWENS-CORNING FIBERGLASS CORP	14	0	1	1	1	1	0	0	0	0	1	1	0	0	0	0	2	3	1	2
59	ITT INDUSTRIES INC.	14	0	0	0	0	0	0	0	1	0	0	1	1	0	1	3	4	1	0	2
60	FEDERAL-MOGUL CORP	14	0	0	1	0	0	2	3	0	2	1	0	0	0	0	0	1	2	0	2
61	FUJI PHOTO FILM CO LTD	13.8	0	0.5	0.5	0	1.3	1	0.5	0	0	0.5	0	1	4	1	0	0.5	0.5	0.5	2
62	SUMITOMO CHEMICAL CO LTD	13	2	1	1	0	0	1	2	1	0	0	0	1	0	2	0	2	0	0	0
63	BRUSH WELLMAN, INC.	13	0	0	0	0	0	0	0	0	0	1	0	1	1	3	2	2	2	1	0
64	DUNLOP LTD.	13	1	0	0	0	0	2	0	0	0	2	2	2	0	3	1	0	0	0	0
65	MAZDA MOTOR CORPORATION	12.5	0	0	0	0	0.5	0	0	0	0	1	0	1	2	0	2	0	1	3	2
66	PORSCHE AG	12	0	1	0	0	0	0	0	0	2	1	1	0	0	1	1	1	2	0	2
67	CYTEC INDUSTRIES INC.	12	0	0	0	0	0	0	3	3	0	0	1	1	0	0	1	0	2	0	1

Figure B6. Ultra Capacitor Patent Families by Co. and Year

Rank	Company	All Famil	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
1	ASAHI GLASS KK	32.7	0	0	0	0	2	3	0	0	0	0	0	0	0	1.7	0	3	6	9.5	7.5
2	NEC CORPORATION	26.5	0	0	0	0	0	0	0	0	0	2	1	2	2	0	0	4	4.5	6	5
3	MATSUSHITA ELECTRIC INDUSTRIAL CO L	13.5	1	0	1	1	1	1	0.5	0	0	1	0	1	1	1	0	0	1	2	1
4	GENERAL ELECTRIC CO	12	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2	0	3	6
5	MURATA MANUFACTURING COMPANY LIM	11	0	0	0	1	1	3	3	1	0	1	1	0	0	0	0	0	0	0	0
6	ISUZU MOTORS LIMITED	11	0	0	0	0	0	0	0	0	6.5	3.5	0	0	0	1	0	0	0	0	0
7	HONDA GIKEN KOGYO KK	9.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	1	4.5
8	JEOL LIMITED	7.5	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	1	1	1.7	1.8
9	NISSHINBO INDUSTRIES INC	7.5	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	2	0	0	2.5
10	ALCATEL	4.8	0	0	0	0	0	0	0	0	0.3	0	1	0.5	1	2	0	0	0	0	0
11	TDK CORPORATION	4.5	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	1.5
12	SHOWA DENKO KK	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	2
13	KUREHA CHEMICAL INDUSTRY CO LTD	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2	1
14	BP P.L.C.	4	0	0	0	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	COLGATE PALMOLIVE CO	4	0	0	0	0	0	0	0	1	1	0	2	0	0	0	0	0	0	0	0
16	SCIENCE APPLICATIONS INT'L	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
17	NGK INSULATORS LIMITED	2.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.3	0
18	RENAULT, REGIE NATIONAL DES USINES	2.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.3	0	0	1
19	ENERGY STORAGE SYSTEMS PTY LTD	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
20	JAPAN VILENE CO., LTD.	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
21	MITSUBISHI CHEMICAL CORP.	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
22	FIAT S.P.A.	2	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0
23	US AIR FORCE	2	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0
24	YARDNEY TECHNICAL PRODUCTS, INC.	2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
25	FUJI HEAVY INDUSTRIES CO LTD	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0
26	UNIVERSITY OF CALIFORNIA	2	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
27	NIPPON SANSO KK	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
28	MITSUBISHI RAYON CO LTD	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
29	TAKEDA CHEMICAL INDUSTRIES LTD	2	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0
30	MOTOROLA INC	2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0
31	KYOCERA CORPORATION	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
32	MEADWESTVACO CORPORATION	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
33	NAUCHNO-PROIZVODSTVENNOE PREDPR	1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	1	0
34	HYDRO-QUEBEC	1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0	0	1	0
35	OKAMURA LABORATORY INC	1.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0.3	0	0	0	0.7	0.3
36	MARINE MECHANICAL CORP.	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
37	TAGAWASYOUJI CO LTD	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
38	THOMSON S.A.	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
39	ECOND	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
40	SOLVAY & CIE SA	1	0	0	0	0	0	0	0	0	0.5	0	0	0.5	0	0	0	0	0	0	0
41	FUJI ELECTROCHEMICAL CO. LTD.	1	0	0	0	0	0	0	0	0	0.5	0.5	0	0	0	0	0	0	0	0	0
42	TOYOTA MOTOR CORPORATION	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
43	JOHNSON CONTROLS INCORPORATED	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
44	WILSON GREATBATCH LTD.	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
45	MAXWELL LABORATORIES, INC.	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
46	INTERPLEX ENERGY LTD	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
47	HEWLETT-PACKARD COMPANY	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
48	UK DEPARTMENT OF DEFENSE	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
49	JAPAN GORE-TEX, INC.	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
50	INORGANIC SPECIALISTS INC	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
51	NAUCHNO-PROIZVODSTVENNOE PREDPR	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
52	U.S. NANOCORP INC	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
53	TELEFLEX INC.	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
54	JOHNS HOPKINS UNIVERSITY	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
55	SOLATROL, INC.	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
56	US ARMY	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
57	PETCOA LTD.	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
58	KOREA KUMBO PETROCHEMICAL CO LTD	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
59	PINNACLE RESEARCH INST. INC.	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
60	PRI AUTOMATION INC	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
61	HITACHI LTD	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
62	MAXWELL TECHNOLOGIES INC	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
63	BECROMAL S.P.A.	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
64	T/J TECHNOLOGIES INC	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
65	NASA/US NATL AERONAUTIC & SPACE AD	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
66	DANIONICS A/S	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
67	RAYTHEON COMPANY	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0

Figure B7. Power Electronics Patent Families Excl. Ultracapacitors

[illegible]

Figure B8. Direct Injection Combustion Patent Families by Co. and Year

Rank	Company	All Years	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
1	ROBERT BOSCH GMBH	202.5	10	17	15	16	9	6	11	10	22	7	7	6	9	9	11	9.5	3	12	13
2	TOYOTA MOTOR CORPORATION	109.8	3.5	12	10.5	12	7.5	4.5	2.5	0	6	3	1	1	0.5	8	10	7	13.3	5.5	2
3	DAIMLER CHRYSLER AG	103.5	2	1	3	4	4	2	4	2	5	4	1	8	6	8	6.5	10.5	14	14.5	4
4	NISSAN MOTOR CO LTD	88.5	11	11	4	4	3	1	3	0	3	5	2	0	0	0	2	4.5	19.5	10.5	5
5	GENERAL MOTORS CORPORATION	63	7	11	5	3	3	2	2	2	0	3	1	5	2	3	0	0	5	8	1
6	YAMAHA HATSUDOKI KK	61	0	0	0	0	1	0	1	2	3	3	5	1	2	2	4	5	4	13	15
7	FIAT S.P.A.	50	2	6	1	1	2.5	1	7	4	5	1	0	2.5	2	1	2	3	2	4	3
8	MAN AG	46	0	2	4	0	0	3	0	0	3	4	3	2	1	1	2	4	6	11	0
9	FORD MOTOR COMPANY	45.5	1	3	1	3	2	0	3	1	1	0	1	1	0	1	0	0.5	9	9	9
10	CATERPILLAR INC	43.5	1	1	2	1	1	1	0	4	2	2	1	0	2	1	4	5.5	4	7	4
11	SIEMENS AG	43.5	2	2	0	1	2	1	1	0	1	2	1	0	2	1	4	6	7	2.5	8
12	DENSO CORP.	35.8	0.5	5	3.5	2	4.5	5.5	1.5	1	1	2	2	0	0.5	0	1	3	0.3	1.5	1
13	MAZDA MOTOR CORPORATION	31	0	1	2	2	3	0	1	0	0	0	0	0	2	1	2	3	5	7	2
14	ISUZU MOTORS LIMITED	29	0	0	1	0	1	1	0	0	0	2	0	0	2	3	1	0	6	5	7
15	RENAULT, REGIE NATIONAL DES USINES	27.5	1	5	5	2	0	0	0	1	1	1	1	1	0	1	0	1	4	3.5	0
16	CUMMINS, INC.	27	0	1	2	0	0	0	0	2	0	2	0	3	4	2	3	2	2	3	1
17	DEUTZ AG	26	1	3	1	5	0	2	2	4	2	0	0	0	0	0	1	0	4	1	0
18	GENERAL ELECTRIC CO	24	0	0	0	1	2	0	0	0	0	2	1	5	0	2	0	1	2	1	7
19	HITACHI LTD	22	2	1	2	1	0	0.5	0	0	0	0	0	1	0	0	0	4	2	5.5	3
20	HONEYWELL INC	20	9	5	4	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
21	WARTSILA NSD OY AB	38.5	0.5	0	0	0	0	0	0	1	0	1	1	2	3	8	5	2	11	4	0
22	VOLVO AB	18	2	0	3	0	1	0	0	0	0	1	0	2	0	0	0	0	0	4	5
23	NAVISTAR INTERNATIONAL CORP	16	0	0	0	0	0	0	0	3	0	0	4	1	1	2	3	0	0	0	2
24	TRW INCORPORATED	15	3	3	0	0	0	0	0	3	1	1	0	0	0	1	2	0	0	0	1
25	BAYERISCHE MOTOREN WERKE AG	13.5	0	2	1	2	0	0	0	2	0	0	0	0	1	0	0.5	0	1	4	0
26	MITSUBISHI HEAVY INDUSTRIES INC	13	0	0	0	0	0	2	1	1	1	2	3	0	2	1	0	0	0	0	0
27	KOMATSU LIMITED	13	5	1	0	2	1	0	1	0	0	0	0	0	0	0	1	0	0	2	0
28	MAGMA INTERNATIONAL INC.	12	0	2	2	4	0	1	0	0	0	0	0	0	0	0	1	1	1	0	0
29	MOTORENFABRIK HATZ GMBH	17	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	3	5	2	1
30	MITSUBISHI MOTORS CORP	11.5	0	0	0	0	0	1	0.5	0.5	0	1	3	0	0	0.5	0	2	0	2	1
31	SULZER AG	11	0	0	0	1	3	3	4	0	0	0	0	0	0	0	0	0	0	0	0
32	FUJI HEAVY INDUSTRIES CO LTD	11	0	0	0	0	0	0	0	1	2	1	1	3	1	0	0	2	0	0	0
33	AVL LIST GMBH	21.5	0.5	0	0	0	1	1	1	1	1	1	2	0	0	0	3	3	2	2	3
34	PEUGEOT S.A.	10	0	0	1	0	0	1	2	0	0	0	1	1	0	0	1	3	0	0	0
35	KUBOTA CORPORATION	10	0	2	0	0	1	0	2	0	1	1	0	0	0	1	0	1	0	1	0
36	DIESEL TECHNOLOGY CO.	10	1	2	1	1	0	1	0	0	0	0	1	0	1	0	0	0	0	2	0
37	SOUTHWEST RESEARCH INSTITUTE	9	1	0	1	0	0	0	1	0	0	1	0	0	0	0	0	2	2	1	0
38	ROECHLING INDUSTRIE VERWALTUNG G	9	0	0	0	0	0	1	1	1	0	3	0	0	0	0	1	0	1	1	0
39	DAVCO INC.	13	3	1	0	4	0	0	2	0	0	0	2.5	0.5	0	0	0	0	0	0	0
40	VOLKSWAGEN AG	8.5	0	1	0	0	1	1	1	1	0	0	0	0	0	0	0	1	2	0	0.5
41	KANZAKI KOKYUKOKI MANUFACTURING C	8	1	1	1	1	1	0	0	1	0	0	0	0	0	0	1	0	0	1	0
42	AIL CORP.	8	1	3	2	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0
43	DEERE & COMPANY	8	3	2	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0
44	USUI KOKUSAI SANGYO KK	7	0	1	0	0	0	0	0	0	0	0	1	1	1	0	0	0	1	1	1
45	MITSUBISHI ELECTRIC CORP	7	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2	3
46	ABB ASEA BROWN BOVERI	7	2	1	0	1	0	2	0	0	0	0	0	0	0	0	0	1	0	0	0
47	UNISIA JECS CORP.	6.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	2.5	1	0
48	INSTITUT FRANCAIS DU PETROLE	6	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	4	0	1	0
49	AUTOMOTIVE DIESEL GMBH	6	0	0	0	0	0	1	2	3	0	0	0	0	0	0	0	0	0	0	0
50	TEXAS INSTRUMENTS INCORPORATED	6	1	1	1	0	0	0	1	0	1	0	0	0	0	0	0	1	0	0	0
51	ALSTOM S.A.	6	1	0	0	1	0	0	0	1	0	0	0	0	0	0	1	2	0	0	0
52	BORG-WARNER INC	6	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1
53	INVENSYS PLC	6	1	1	1	0	0	0	0	1	0	0	0	0	0	1	0	0	0	1	0
54	ORBITAL ENGINE CO. PTY. LTD	6	0	0	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0
55	VOEST-ALPINE STAHL AG	5.5	1.5	0	1	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0
56	GERMAN AEROSPACE CENTER	5	0	1	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
57	THYSSSEN KRUPP	5	0	0	0	0	0	0	1	0	0	0	1	1	2	0	0	0	0	0	0
58	HYUNDAI CORP	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	2	0
59	AEPLC	5	0	0	2	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60	TYCO INTERNATIONAL LTD	5	1	0	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
61	BUESCHER; ALFRED J.	5	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	2	1	0
62	PARKER-HANNIFIN CORP	5	0	0	0	0	0	2	1	1	0	0	1	0	0	0	0	0	0	0	0
63	HONDA GIKEN KOGYO KK	5	0	0	0	0	1	0	0	1	0	0	0	0	0	1	0	0	0	0	2
64	ALCAN ALUMINUM LTD	4.5	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0	1	0.5
65	ORBITAL ENGINE CO. (AUSTRALIA) PTY. L	4.5	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0.5	1	0	1	1
66	SCANIA CV AB	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	1

Figure B9. Emissions Control Patent Families by Co. and Year

Rank	Company	All Years	1993	1994	1995	1996	1997	1998	1999	2000	2001
1	TOYOTA MOTOR CORPORATION	382.3	9	9	5.5	2.5	2	5	10	2	14.3
2	FORD MOTOR COMPANY	331	3	0	5	5	5	3	4	2	2
3	HONDA GIKEN KOGYO KK	275.3	8	15	7	11	1	2.5	4.5	0.5	3
4	NISSAN MOTOR CO LTD	193	10.5	15.5	9	12	7	4	10.5	9	4
5	DAIMLER CHRYSLER AG	177.3	0	1	0	3	6	5	3.5	7.5	8
6	SIEMENS AG	156	0	3	2	0.5	12	1	0	1	2
7	INDIVIDUAL PATENTER	154.2	0	1.5	3	4.5	3	10	16	8.7	7
8	GENERAL MOTORS CORPORATION	133	9	7	3	2	3	3	4	7	10
9	EMITEC GES. FUR EMISSIONSTECHNOLO	120	0	0	0	0	0	2	4	5	7
10	ROBERT BOSCH GMBH	116.5	2	3	8	5	3	3	5	6	5
11	DENSO CORP.	105	3	6	9	3.5	4	0	1	0	11
12	NGK INSULATORS LIMITED	101.5	1	1	1	0	0	4	2.5	4.5	5
13	VOLKSWAGEN AG	101.1	0	1	0	0.5	1	2	1	0	1
14	HITACHI LTD	79	0	4	1	2	1	2	2	1	2
15	YAMAHA HATSUDOKI KK	76	3	3	1	2	1	4	6	2	1
16	MAZDA MOTOR CORPORATION	71	4	0	1	5	4	1	1	1	5
17	CATERPILLAR INC	61	3	0	1	1	0	0	1	1	3
18	CORNING INC	58	5	1	1	0	0	0	0	1	1
19	GRACE (WR) & CO	57	0	0	0	2	4	5	1	3	5
20	PEUGEOT S.A.	55.5	2	1	0	2	1	3.7	3	3	4
21	CUMMINS, INC.	52.8	0	3	1	1	4	0	1	2	5
22	MITSUBISHI MOTORS CORP	52.5	0	0	1.5	0.5	1	0	1.5	1	1
23	BAYERISCHE MOTOREN WERKE AG	51.1	2	0	0	3	2	1	3	2	2
24	RENAULT, REGIE NATIONAL DES USINES	42.7	1	0	1	0	1	0	2	0	1
25	MMM/MINNESOTA MINING & MFG CO	42	1	0	0	1	0	0	3	2	2
26	ISUZU MOTORS LIMITED	40	0	0	0	0	2	0	2	6	1
27	ENGELHARD CORP	40	0.5	0	2	0	0	0	0	0	0
28	ARVINMERITOR, INC.	39	0	2	1	5	2	2	2	3	3
29	FIAT S.P.A.	37.7	1	0	2	0	1	1	2	4	0
30	AP PARTS MFG. CO.	36	0	4	2	0	2	4	2	7	1
31	MITSUBISHI ELECTRIC CORP	34	0	1	3.5	2.5	1	0	0	0	2
32	VOLVO AB	33.8	1	0	2	1	1	0	0	1	1
33	WITZENMANN GMBH METALLSCHLAUCH-F	32	0	0	0	3	3	1	1	3	2
34	MAN AG	31.5	0	0	0	0	5	3	4	0	2
35	DONALDSON CO. INC.	29.5	1	0	0	3	0	0	2.5	2	3
36	E.ON AG	29	2	1	1	0	2	0	0	0	1
37	FUJI HEAVY INDUSTRIES CO LTD	23.5	2.5	2.5	3	0	1	1	1	0	0
38	JOHNSON MATTHEY PLC	23	1	0	1	0	0	0	2	0	1
39	ABB ASEA BROWN BOVERI	23	1	1	4	2	1	0	0	1	1
40	PORSCHE AG	22.1	0	0	0	0	1	0	0	1	3
41	EBERSPACHER, J.	21.5	0	0	0	0	1	2	1	2	5
42	TENNECO AUTOMOTIVE, INC.	21.3	1	0	0	0	1	4	2	2	1
43	CALSONIC KANSEI CORP	20.5	0	0	0	0	0	0	1.5	1	0
44	DELPHI AUTOMOTIVE SYSTEMS	20.5	0	0	0	0	0	0	0	0	0
45	INSTITUT FRANCAIS DU PETROLE	20.3	0	1	0	0	0	0.3	1	0	0
46	HERAEUS HOLDING COMPANY GMBH	20	0	0	0	0	0	0	1	0	0
47	SUZUKI MOTOR CORP	19.5	0	0	1	0	0	0	0	2	1
48	UNITED TECHNOLOGIES CORP	19	0	1	0	0	1	0	2	0	4
49	BRUNSWICK CORP	19	1	1	2	1	0	2	4	2	1
50	ZEUNA-SRRKER GMBH & CO. KG	18	0.5	0	0	1	1	1	0	1	4
51	HONEYWELL INC	18	2	4	4	0	2	1	0	0	1
52	DEUTZ AG	17.5	0	1	1	0	1	1	0	2	3
53	FEV MOTORENTECHNIK GMBH & CO. KG	17	0	0	0	1	5	1	0	1	0
54	KIORITZ CORPORATION	17	2	1	0	0	0	1	2	0	0
55	SCHWABISCHE HUTTENWERKE GMBH	15.5	0	0	0	0	0	1	1	2	1
56	MATSUSHITA ELECTRIC INDUSTRIAL CO L	15	1	0	0	1	0	1	0	1	2
57	SCAMBIA INDUSTRIAL DEVELOPMENTS A	15	0	0	0	0	0	0	0	0	3
58	SUMITOMO ELECTRIC INDUSTRIES LTD	14.5	0	0	0	0	0	0	0	0	3
59	NORTHROP GRUMMAN CORPORATION	14	0	1	0	0	1	0	1	1	0
60	MITSUBISHI HEAVY INDUSTRIES INC	14	0	0	0	0	0	0	1	0	2.5
61	UNISIA JECS CORP.	14	0	0	0	0	0	0	0	0	0
62	OUTBOARD MARINE CORPORATION	13	0	0	0	0	0	0	1	0	1
63	USUI KOKUSAI SANGYO KK	13	0	0	0	0	0	0	1	2	7
64	KAWASAKI HEAVY INDUSTRIES LTD	13	0	2	0	0	1	3	0	4	1
65	ELECTROLUX AB	13	2	0	0	0	0	0	1	0	1
66	GENERAL ELECTRIC CO	12	0	0	0	0	0	0	0	0	0
67	CLEAN DIESEL TECHNOLOGIES INC	12	0	0	0	0	0	0	0	0	0

Rank	Company	All Years	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
68	SOUTHWEST RESEARCH INSTITUTE	12	0	0	0	0	0	0	1	0	0	0	1	1	0	1	0	4	1	1	2
69	TENNESSEE GAS PIPELINE CO.	12	0	0	0	0	0	0	1	2	2	1	2	3	0	1	0	0	0	0	0
70	HYUNDAI CORP	11	0	0	0	0	0	0	0	0	0	0	0	1	0	1	2	1	1	1	4
71	DEERE & COMPANY	11	1	1	0	0	0	1	1	0	0	2	1	2	0	1	0	0	1	0	0
72	NIPPON STEEL CORPORATION	10	0	0	0	0	1.5	0	0	0	2.3	1.5	0.5	0.5	1.3	1	1.3	0	0	0	0
73	ALCAN ALUMINUM LTD	10	0	1	0	0	1	1	5	0	2	0	0	0	0	0	0	0	0	0	0
74	WEBASTO AG FAHRZEUGTECHNIK	10	0	0	0	0	0	1	4	2	3	0	0	0	0	0	0	0	0	0	0
75	ANDREAS STIHL	10	0	0	0	0	0	0	1	1	0	1	0	2	0	0	0	0	3	1	1
76	KOMATSU LIMITED	10	0	0	1	0	0	0	0	1	0	0	0	0	0	0	1	0	3	1.5	2.5
77	SANKEI GIKEN KOGYO KK	9.8	0	0	0	2	1	1.5	0	1	0	0	1	2	0	0	0	0	0	0	1.3
78	J EBERSPACHER GMBH & CO	9.5	0	0	0	0	0	0	0	0	0	0	0	0	2	2	1	1	1	2.5	0
79	ROECHLING INDUSTRIE VERWALTUNG G	9	0	1	0	0	0	0	1	0	0	0	0	3	1	0	0	0	1	0	2
80	NGK SPARK PLUG COMPANY LIMITED	9	0	0	0	0	1	1	0	0	1	1	0	1	0	0	0	1	1	0	2
81	MOTOROLA INC	8.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	2.5	1	0
82	THYSSEN KRUPP	8	0	0	0	1	0	1	2	1	0	0	1	1	0	0	0	0	0	1	0
83	RHI AG	8	0	0	0	0	3	1	0	0	0	3	1	0	0	0	0	0	0	0	0
84	CHEVRONTXACO CORP	8	4	0	0	2	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
85	MANN & HUMMEL	8	0	0	0	0	0	0	0	1	1	1	0	0	1	0	0	0	1	1	2
86	TI AUTOMOTIVE	8	0	0	0	1	0	0	0	0	0	0	1	0	1	0	0	0	0	2	3
87	J EBERSPACHER GMBH & CO	8	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	5
88	EUROPEAN AERONAUTIC DEFENCE AND	7	0	0	0	0	0	1	0	0	0	0	0	1	1	1	0	1	1	1	0
89	EATON CORP	7	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	2	2	1
90	US NAVY	7	0	0	0	0	0	0	0	0	0	1	0	0	0	2	0	2	0	2	0
91	ZEUNA-STARKER GMBH & CO KG	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	3
92	NCT GROUP INC.	7	0	1	0	1	0	0	0	0	0	1	1	0	0	1	2	0	0	0	0
93	LOCKHEED MARTIN CORP.	7	2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	2
94	ORBITAL ENGINE CO. (AUSTRALIA) PTY. L	7	0	0	0	0	0	2	0	0	1	2	0	1	0	0	0	1	0	0	0
95	AEA TECHNOLOGY PLC	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	2
96	EXXON MOBIL CORP.	7	0	0	0	0	0	0	0	2	0	0	1	1	0	0	0	0	1	1	1
97	FLOWMASTER, INC.	7	0	0	0	1	0	0	1	0	0	1	0	1	1	0	0	0	1	1	0
98	UNIVERSITY OF CALIFORNIA	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	3	1
99	BRIGGS & STRATTON CORP	7	0	0	0	0	0	0	0	0	0	0	1	2	0	2	0	2	0	0	0
100	INGERSOLL-RAND COMPANY	6.5	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	2	1	0.5	0
101	FRAUNHOFER GESELLSCHAFT	6.5	0	0	0	0	0	1	0	0	0	0	0	0	0.5	0	0	0	1.5	0	3.5
102	AININ SEIKI COMPANY LIMITED	6.5	1	0	0	0	0	0	0	0	1	0	1	0.5	0	1	0	2	0	0	0
103	INDUSTRIAL TECHNOLOGY RESEARCH IN	6.3	0	0	0	0	0	0	1	0	1	1	0	0	0	0	1	0	2	0.3	0
104	TURBODYNE SYSTEMS INC	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	0
105	UNIVERSITY OF CHICAGO	6	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	0	0	1	1
106	TECUMSEH PRODUCTS COMPANY	6	0	0	2	0	1	0	0	0	0	0	2	0	0	0	0	0	1	0	0
107	TOTAL FINA ELF S.A.	6	0	0	0	0	0	0	0	0	0	1	1	0	0	0	2	0	0	0	2
108	ERHARDT BISHOFF GMBH & CO KG FABRI	6	0	0	0	1	0	1	0	0	0	0	0	1	2	1	0	0	0	0	0
109	MAGMA INTERNATIONAL INC.	6	0	0	0	0	1	0	2	0	1	0	0	0	1	0	0	0	1	0	0
110	HALDOR TOPSOE A/S	6	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	3	0	0
111	FLEXIDER S.P.A.	6	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	2	1
112	NIPPON SHOKUBAI CO., LTD.	6	0	0	0	0	0	1	2	2	0	0	1	0	0	0	0	0	0	0	0
113	PRECISION COMBUSTION INC	6	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1
114	SANGO CO., LTD.	6	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	3	1
115	SANDVIK AB	6	0	0	0	0	0.5	1.5	0	0	0	0	1	0	1	0	1	0	0	1	0
116	ALLEGHENY TECHNOLOGIES INC.	6	0	0	1	0	1	1	0	0	0	0	0	0	2	1	0	0	0	0	0
117	OBERLAND MANGOLD GMBH	6	0	0	0	0	0	0	1	0	1	0	1	0	0	0	0	0	0	2	1
118	SEQUA CORP	6	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	2	1	1	0
119	BP P.L.C.	6	0	0	0	0	0	0	0	1	0	0	0	1	0	0	3	0	1	0	0
120	SWISSAUTO ENGINEERING SA	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	1	1
121	OWEN, WICKERSHAM & ERICKSON	6	3	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
122	SUDDEUTSCHE KUEHLERFABRIK	6	1	0	2	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
123	TRW INCORPORATED	6	0	0	0	1	1	0	0	1	2	0	0	0	1	0	0	0	0	0	0
124	LITEX INC	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	4
125	SENIOR ENGINEERING INVESTMENTS AG	5.5	0	0	0	0	0	0	0	0	1	0	0.5	0	0	0	0	2	1	1	0
126	FEODOR BURGMANN DICHTUNGSWERKE	5.5	0	1	0	1	0	0	1	0	0	0	0	0.5	0	1	0	1	0	0	0
127	IBIDEN CO. LTD.	5.5	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1.5	1	1	0
128	FRIEDRICH BOYSEN GMBH & CO. KG	5.5	0	0	0	0	0	0	0	0	0	2	0	0	0	1.5	1	0	1	0	0
129	VOEST-ALPINE STAHL AG	5	0	0	0	3	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
130	FEDERAL-MOGUL CORP	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	1
131	SULZER AG	5	0	0	0	0	0	0	1	1	0	0	0	0	1	0	1	0	1	0	0
132	RAYTHEON COMPANY	5	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	2	1	0	0
133	UOP INC	5	1	0	0	0	0	0	0	0	0	1	1	0	1	1	0	0	0	0	0
134	UNIFRAX CORP	5	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	1	0	1	1

Figure B10. New Combustion Regimes Patent Families By Co. and Year

Rank	Company	All Years	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
1	TOYOTA MOTOR CORPORATION	40.5	1.5	2.5	2	0.5	3	0	1	0	0	0	0	0	0	1	4	6	6	10	3
2	FORD MOTOR COMPANY	38	2	1	0	0	1	0	2	1	1	3	3	2	4	0	2	1	3	2	10
3	NISSAN MOTOR CO LTD	37.5	1	3	2	1	4	1	2.5	0.5	1	3	1	0	0	1	0	3	3	3.5	7
4	GENERAL MOTORS CORPORATION	25	0	1	1	1	2	1	2	0	3	1	1	1	1	1	2	2	2	1	2
5	ROBERT BOSCH GMBH	16.5	0	1	3	1	0	0	0.5	0	1	1	0	0	0	0	0	0	3	4	2
6	CATERPILLAR INC	16	2	0	0	0	0	0	0	0	0	0	1	0	1	1	3	2	0	5	1
7	INDIVIDUAL PATENTER	15	0	0	0	0	1	0	2	0	2	0	2	1	0	1	2	1	1	1	1
8	DAIMLER CHRYSLER AG	14	0	0	0	0	0	3	0	1	0	0	1	1.5	1	1	0.5	2	1	0	2
9	YAMAHA HATSUDOKI KK	13	0	0	0	0	0	0	0	0	1	1	0	0	0	0	1	1	1	1	0
10	MAZDA MOTOR CORPORATION	13	0	0	0	1	2	0	0	0	1	1	0	0	4	0	1	1	1	1	0
11	HONDA GIKEN KOGYO KK	11.5	0	1	0	0	1	0	0	0.5	1	0	3	1	0	2	1	0	0	0	1
12	CUMMINS, INC.	11	0	0	1	1	0	1	0	0	0	0	0	1	1	1	1	0	0	2	2
13	HITACHI LTD	9.5	0	0	0	0	0	0	0	0	0	2	0	0	1	1	1	1	0	0	0
14	MITSUBISHI ELECTRIC CORP	8	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	6
15	MITSUBISHI MOTORS CORP	8	0	0	0	1	0	0	0	0	0	1	3	0	0	1	0	1	0	1	0
16	SIEMENS AG	7.5	0	0	0	0	0	0	0	1	4	0	0	0	0	0	0	0	0	1.5	1
17	BORG-WARNER INC	7	0	1	0	0	0	0	0	0	0	1	1	2	0	0	0	0	0	1	1
18	UNISIA JECS CORP.	7	0	0	0	0	0	0	0.5	0.5	0	0	0	0	0	2	1	1	0	2	0
19	KOMATSU LIMITED	6	0	2	0	0	0	0	0	0	0	0	1	0	0	0	1	0	1	1	0
20	EATON CORP	6	0	0	0	0	1	0	0	0	0	0	2	0	0	1	0	0	1	1	0
21	DENSO CORP.	5.5	0.5	0.5	0	0.5	1	0	0	0	0	1	0	0	0	0	0	0	1	0	1
22	SATURN ELECTRONICS & ENGINEERING I	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	2
23	STANADYNE AUTOMOTIVE CORP.	5	0	1	0	0	0	0	0	0	1	0	0	0	2	1	0	0	0	0	0
24	TOKICO LTD	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	1	0
25	HONEYWELL INC	5	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	1	1
26	ISUZU MOTORS LIMITED	5	0	0	1	0	0	0	0	0	1	1	0	0	0	0	1	0	1	0	0
27	MURRAY UNITED DEV. CORP.	5	0	0	0	0	0	0	0	1	0	2	1	1	0	0	0	0	0	0	0
28	VOLVO AB	4	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	2
29	SOUTHWEST RESEARCH INSTITUTE	4	0	0	1	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0
30	BAYERISCHE MOTOREN WERKE AG	4	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	2	1
31	OWEN, WICKERSHAM & ERICKSON	4	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	UNITED TECHNOLOGIES CORP	4	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	2	0
33	KOYO SEIKO CO. LTD.	4	0	0	0	0	0	0	1	0	1	0	1	0	0	0	1	0	0	0	0
34	VOLKSWAGEN AG	4	0	0	0	1	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0
35	FIAT S.P.A.	4	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2	0	0
36	CLEMSON UNIV.	4	0	0	0	0	0	1	0	0	0	2	1	0	0	0	0	0	0	0	0
37	SPX CORP	4	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0
38	THYSSEN KRUPP	3.5	0	0	0	0	0	0	0	0	0	1	0	0.5	1	0	0	0	1	0	0
39	TOYODA AUTOMATIC LOOM WORKS, LTD.	3	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	2	0
40	DANA CORPORATION	3	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	1
41	SONEX RESEARCH INC.	3	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
42	BP P.L.C.	3	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0
43	ITT INDUSTRIES INC.	3	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	1
44	HYUNDAI CORP	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0
45	SUN POWER, INC.	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1
46	TOYODA MACHINE WORKS LIMITED	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0
47	KONINKLIJKE PHILIPS ELECTRONICS N.V.	3	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0
48	GOODRICH CORP.	3	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	1	0	0
49	GENERAL ELECTRIC CO	2.5	0	0	0	0	0	0	0	1	0	0	0	0.5	0	0	0	1	0	0	0
50	DANAHER CORP	2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
51	AVL LIST GMBH	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
52	HILLENBRAND INDUSTRIES	2	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
53	FEV MOTORENTECHNIK GMBH & CO. KG	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
54	PROPANE CARBURETION COMPANY, INC.	2	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
55	TEXTRON INC	2	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56	UNIVERSITY OF BRITISH COLUMBIA	2	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0
57	TENNECO AUTOMOTIVE, INC.	2	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
58	TI AUTOMOTIVE	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
59	SAMSUNG GROUP	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
60	MOTORENFABRIK HATZ GMBH & CO KG	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
61	ANSWER PRODUCTS, INC.	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
62	LAITRAM CORP	2	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
63	COLUMBIA UNIVERSITY	2	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0
64	EMERSON ELECTRIC COMPANY	2	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
65	US NAVY	2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0

Figure B11. Hydrogen ICE Patent Families by Co. and Year

Rank	Company	All Years	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
1	MAZDA MOTOR CORPORATION	4.5	0	0	0.5	0	0	0	0	0	0	0	0	1	3	0	0	0	0	0	0
2	SOUTHWEST RESEARCH INSTITUTE	4	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	1	0	0
3	GERMAN AEROSPACE CENTER	4	0	0	0	1	0	0	1	0	0	1	0	0	1	0	0	0	0	0	0
4	CONSOLIDATION COAL CO.	3	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	CONOCO INC	3	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	UNIVERSITY OF MELBOURNE	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
7	UNIVERSITY OF CENTRAL FLORIDA	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
8	GENERAL MOTORS CORPORATION	2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0
9	HERMAN P ANDERSON TECHNOLOGIES L	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0
10	HYDROGEN BURNER TECHNOLOGY INC	2	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0
11	DENSO CORP.	1.5	0	0	0	0	0	0	1	0	0	0	0	0.5	0	0	0	0	0	0	0
12	FATPOWER INC	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
13	NISSAN MOTOR CO LTD	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	UNI-ENERGY SYSTEMS, INC.	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	UNIQUE ENERGY SYSTEMS, INC.	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	ORBITAL ENGINE CO. (AUSTRALIA) PTY. L	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
17	MASIUK, STEPHEN	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
18	US AIR FORCE	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
19	ROBERT BOSCH GMBH	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	ALTERNATE FUELS, INC.	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
21	NASA/US NATL AERONAUTIC & SPACE AD	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	BP P.L.C.	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
23	FORD MOTOR COMPANY	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	DAIMLER CHRYSLER AG	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
25	ALIRA INC.	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
26	PUGACHEV, ALEXANDR VASILIEVICH	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
27	TRANSGLOBAL TECHNOLOGIES, LTD.	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
28	MAN AG	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
29	UNIVERSITY OF MIAMI	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
30	HONDA GIKEN KOGYO KK	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
31	BAYERISCHE MOTOREN WERKE AG	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
32	KATSUJI BABA	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	GLOBAL TECH ENVIRONMENTAL PRODUC	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
34	BATTELLE MEMORIAL INSTITUTE	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
35	HYDROGEN CONSULTANTS, INC.	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
36	TOYODA AUTOMATIC LOOM WORKS, LTD.	0.5	0	0	0	0	0	0	0	0	0	0.5	0	0	0	0	0	0	0	0	0
37	SEKISUI CHEMICAL CO LTD	0.5	0	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38	TOYOTA MOTOR CORPORATION	0.5	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0	0	0	0	0	0
39	SAES GETTERS SPA	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0
40	LOCKHEED MARTIN CORP.	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0
41	NIPPON STEEL CORPORATION	0.5	0	0	0	0	0	0	0	0	0	0.5	0	0	0	0	0	0	0	0	0
42	INDIVIDUAL PATENTER	6	0	0	0	0	0	1	0	1	2	0	0	0	0	0	1	1	0	0	0
	No Assignees	44	9	6	0	2	0	0	1	0	0	5	2	3	4	4	0	3	1	1	3
	All Companies Combined	107	10	10	6	4	2	3	4	1	2	10	5	9	9	6	6	7	2	5	6

Appendix C
Patent Family Indicators

Figure C1. Patent Family Indicators by Category and Region

Category	Region	# Families		# Patent Documents		Citation Index		TCT		Innovation		Avg NPR		Science Index	
		1992-96	1997-01	1992-96	1997-01	1992-96	1997-01	1992-96	1997-01	1992-96	1997-01	1992-96	1997-01	1992-96	1997-01
Advanced Batteries	All	223	711	328	828	1.5	1.0	5.1	4.0	1.3	1.4	1.7	1.9	1.1	1.2
Advanced Batteries	EU	26	83	39	102	1.2	0.5	5.1	4.7	1.1	1.0	1.4	2.2	0.9	1.4
Advanced Batteries	JP	94	362	165	425	1.7	1.2	4.9	3.1	1.3	1.7	1.9	1.4	1.2	0.9
Advanced Batteries	KR	#N/A	37	#N/A	38	#N/A	0.5	#N/A	4.8	#N/A	1.4	#N/A	0.6	#N/A	0.4
Advanced Batteries	Other	26	40	35	46	1.3	0.6	3.8	4.5	1.9	1.4	2.4	1.5	1.4	0.9
Advanced Batteries	US	81	207	94	239	1.5	1.0	5.8	4.9	1.3	1.3	1.0	3.1	0.8	1.9
Automotive Fuel Cells	All	129	522	169	627	1.9	1.7	6.0	4.9	1.1	1.1	2.0	1.8	1.3	1.2
Automotive Fuel Cells	EU	24	151	31	185	1.8	1.5	6.2	4.4	0.9	1.0	2.6	1.8	1.7	1.2
Automotive Fuel Cells	JP	32	127	50	146	1.7	1.9	5.9	4.4	1.1	1.2	1.9	1.1	1.2	0.7
Automotive Fuel Cells	Other	15	27	19	32	2.0	2.2	5.3	5.0	1.2	1.0	1.3	1.5	0.9	1.1
Automotive Fuel Cells	US	60	226	71	273	1.9	1.7	6.2	5.4	1.2	1.1	1.9	2.2	1.4	1.4
Combustion	All	175	315	190	334	0.99	1.42	10.5	9.0	1.0	1.1	0.5	0.7	1.3	1.2
Combustion	EU	38	59	45	62	0.95	0.95	8.5	8.4	1.0	1.0	0.6	0.3	1.3	0.6
Combustion	JP	41	108	47	120	0.96	1.87	5.6	4.7	1.9	2.0	0.4	0.4	1.1	0.8
Combustion	KR	1	6	1	6	0.66	0.61	11.3	10.4	1.0	1.3	0.0	0.0	0.0	0.0
Combustion	Other	4	5	5	5	1.40	0.62	8.5	16.3	0.9	0.8	0.0	0.6	0.0	1.2
Combustion	US	97	143	100	147	1.00	1.21	13.5	12.4	0.9	0.9	0.7	1.1	1.8	1.9
Diesel	All	411	787	505	908	1.09	1.25	7.2	6.6	1.0	1.1	0.7	0.6	1.4	1.0
Diesel	EU	172	353	219	412	0.78	0.92	5.4	5.7	1.1	1.1	0.6	0.4	1.1	0.8
Diesel	JP	85	225	109	271	1.42	1.64	6.4	5.3	1.1	1.3	0.7	0.6	1.2	1.0
Diesel	KR	2	8	3	8	0.40	0.11	8.5	6.8	1.7	1.2	0.0	0.4	0.0	0.3
Diesel	Other	20	13	23	16	1.54	0.42	6.6	8.9	0.9	0.9	0.4	0.5	0.9	0.8
Diesel	US	134	207	153	223	1.12	1.35	10.4	9.6	0.8	0.9	1.0	0.7	2.2	1.3
Emissions	All	1658	2756	2017	3151	1.08	1.12	7.0	5.8	1.0	1.0	0.6	0.9	1.0	1.1
Emissions	EU	494	991	612	1113	0.71	0.81	5.4	5.0	1.0	1.0	0.5	0.6	0.8	0.9
Emissions	JP	535	844	679	1012	1.38	1.31	5.6	4.7	1.3	1.3	0.6	0.6	1.1	0.8
Emissions	KR	6	18	6	18	0.82	0.44	6.9	8.5	1.5	0.8	0.3	0.2	0.6	0.2
Emissions	Other	39	87	45	100	0.87	0.82	11.7	9.8	0.6	0.7	0.8	0.3	1.4	0.6
Emissions	US	614	865	707	961	1.02	1.13	9.4	7.5	0.9	1.0	0.7	1.5	1.1	1.8
Hybrid Electric Vehicles	All	128	440	160	512	2.41	2.26	6.2	4.5	1.2	1.5	0.7	0.4	1.1	0.7
Hybrid Electric Vehicles	EU	23	65	30	66	1.46	1.36	5.1	4.6	0.9	1.2	0.4	0.4	0.7	0.8
Hybrid Electric Vehicles	JP	64	268	88	326	2.36	2.55	5.0	3.6	1.5	1.7	0.5	0.3	0.7	0.5
Hybrid Electric Vehicles	Other	3	8	3	9	1.01	3.27	6.5	6.1	1.1	1.2	1.0	1.6	1.4	2.7
Hybrid Electric Vehicles	US	38	102	39	114	2.90	2.07	9.7	6.7	1.0	1.1	1.2	0.7	2.1	0.9
Hydrogen Internal Combustion Engines	All	38	26	40	27	1.20	0.66	9.9	10.3	1.1	0.8	1.0	1.8	2.2	2.5
Hydrogen Internal Combustion Engines	EU	4	5	4	5	0.48	0.72	4.4	2.8	1.9	1.8	1.3	0.6	2.0	0.8
Hydrogen Internal Combustion Engines	JP	7	#N/A	8	#N/A	0.62	#N/A	5.9	#N/A	1.9	#N/A	1.1	#N/A	2.8	#N/A
Hydrogen Internal Combustion Engines	Other	3	5	3	5	1.07	1.59	14.1	11.3	0.7	0.9	0.0	0.0	0.0	0.0
Hydrogen Internal Combustion Engines	US	24	17	25	18	1.46	0.44	11.5	11.5	1.0	0.8	1.0	2.7	2.3	3.5
Hydrogen Storage	All	16	39	20	47	0.9	2.2	6.7	5.5	1.2	1.4	1.5	2.1	0.9	1.2
Hydrogen Storage	EU	6	1	8	2	0.9	2.2	5.2	12.3	1.4	0.6	1.3	0.0	0.8	0.0
Hydrogen Storage	JP	6	12	8	14	0.7	1.6	8.6	6.2	1.0	1.4	0.8	1.9	0.5	1.3
Hydrogen Storage	Other	#N/A	9	#N/A	11	#N/A	1.9	#N/A	5.3	#N/A	1.2	#N/A	3.7	#N/A	2.3
Hydrogen Storage	US	4	17	4	20	1.1	3.0	5.7	4.5	1.4	1.8	3.3	1.6	2.0	0.8
Lightweight Materials	All	1340	1343	1613	1508	0.97	1.04	6.9	7.3	1.1	1.0	1.5	1.6	1.2	1.1
Lightweight Materials	EU	245	365	307	401	0.81	0.88	5.7	6.6	1.2	1.0	1.2	1.1	1.1	1.0
Lightweight Materials	JP	436	375	558	430	0.94	0.93	6.2	6.0	1.1	1.3	1.3	1.4	0.9	0.9
Lightweight Materials	KR	7	8	7	8	0.45	0.21	6.6	9.6	1.3	1.0	1.4	4.0	1.0	2.1
Lightweight Materials	Other	43	55	50	60	0.83	0.87	8.9	6.6	0.8	1.1	1.0	1.7	0.7	1.1
Lightweight Materials	US	626	562	708	636	1.05	1.16	7.8	8.6	1.0	1.0	2.0	2.1	1.5	1.4
Power Electronics Excluding Ultracapacitors	All	301	594	353	639	1.54	1.28	6.7	6.8	1.3	1.2	0.8	0.9	1.0	1.1
Power Electronics Excluding Ultracapacitors	EU	50	105	67	120	1.06	0.71	5.7	5.4	1.2	1.1	0.9	0.9	1.1	1.1
Power Electronics Excluding Ultracapacitors	JP	77	164	86	173	1.45	1.51	5.6	6.0	1.6	1.4	0.4	0.4	0.5	0.5
Power Electronics Excluding Ultracapacitors	KR	5	28	5	29	1.42	0.80	5.4	6.5	1.4	1.2	0.2	0.7	0.2	0.6
Power Electronics Excluding Ultracapacitors	Other	10	14	10	14	0.91	1.50	7.6	7.6	1.3	1.1	0.2	1.0	0.3	0.9
Power Electronics Excluding Ultracapacitors	US	161	290	188	311	1.73	1.29	7.6	7.8	1.2	1.1	0.9	1.3	1.2	1.5
Ultra Capacitors	All	53	158	65	173	1.0	1.0	6.6	4.7	1.0	1.2	1.6	0.9	1.3	0.9
Ultra Capacitors	EU	8	14	11	17	0.8	0.0	3.9	4.7	1.3	0.8	1.7	1.7	1.2	1.8
Ultra Capacitors	JP	31	100	40	108	1.1	1.0	5.4	4.6	1.2	1.2	1.6	0.5	1.3	0.5
Ultra Capacitors	Other	2	11	2	11	0.6	0.7	7.7	1.8	1.0	1.8	0.0	1.3	0.0	1.4
Ultra Capacitors	US	12	37	12	42	1.1	1.1	12.9	5.7	0.6	1.2	2.0	1.4	1.6	1.2

Figure C2. Patent Family Indicators by Category and Company

Category	Company	# Families		# Patent Documents		Citation Index		TCT		Innovation Speed Index		Avg NPR		Science Index	
		1992-96	1997-2001	1992-96	1997-2001	1992-96	1997-2001	1992-96	1997-2001	1992-96	1997-2001	1992-96	1997-2001	1992-96	1997-2001
Advanced Batteries	Matsushita Electric	16	57	16	57	1.98	1.60	5.7	3.1	1.2	1.4	1.4	1.5	1.0	1.0
Advanced Batteries	Valence Technology	2	29	2	29	2.38	0.80	4.4	6.7	1.9	1.2	2.0	4.8	2.0	3.1
Advanced Batteries	NGK Insulators	0	26	0	26	0.00	1.60	0.0	2.2	0.0	1.3	0.0	2.0	0.0	1.5
Advanced Batteries	Mitsubishi Electric	0	24	0	24	0.00	2.53	0.0	1.4	0.0	3.3	0.0	0.1	0.0	0.1
Advanced Batteries	Samsung	0	22	0	22	0.00	0.47	0.0	5.5	0.0	1.3	0.0	0.4	0.0	0.2
Advanced Batteries	Sanyo Electric	5	21	5	21	0.97	0.47	6.3	3.2	0.9	1.6	1.8	1.2	1.1	0.8
Advanced Batteries	Hitachi	2	18	2	18	0.55	0.70	5.4	3.3	1.1	1.2	2.0	1.4	1.2	1.0
Advanced Batteries	Toshiba	7	11	7	11	2.35	1.64	5.4	5.3	1.2	1.2	1.9	1.6	1.0	1.1
Advanced Batteries	Alcatel	7	10	7	10	0.73	1.65	3.5	5.6	1.5	0.7	1.3	1.8	0.8	1.1
Advanced Batteries	Science Applications	13	10	13	10	3.06	0.44	4.0	2.4	2.0	2.4	1.2	0.7	0.9	0.4
Automotive Fuel Cells	Baifard	13	36	13	36	2.24	2.23	5.8	4.2	1.1	1.1	1.9	1.6	1.4	1.2
Automotive Fuel Cells	GM	4	30	4	30	3.80	2.81	9.0	1.5	0.9	2.6	7.3	2.5	5.2	1.9
Automotive Fuel Cells	Matsushita Electric	1	29	1	29	2.00	1.85	4.4	1.3	0.8	2.7	5.0	1.5	2.6	1.1
Automotive Fuel Cells	DBB Fuel Cell Engines	1	23	1	24	3.00	2.76	12.7	1.7	0.3	2.2	8.0	2.3	5.8	1.9
Automotive Fuel Cells	United Technologies	5	22	5	22	2.34	2.00	11.3	6.9	0.8	1.0	0.8	0.1	0.5	0.1
Automotive Fuel Cells	Siemens	2	18	2	18	1.77	0.24	4.0	5.0	1.5	0.6	1.0	3.0	0.6	2.2
Automotive Fuel Cells	Cal. Inst. Tech.	0	17	0	17	0.00	3.38	0.0	6.2	0.0	1.2	0.0	1.6	0.0	1.0
Automotive Fuel Cells	Toyota	5	17	5	17	3.22	7.80	0.8	2.6	3.9	1.6	3.2	0.7	1.5	0.5
Automotive Fuel Cells	Daimler Chrysler	4	13	4	13	1.76	1.24	6.1	2.9	0.6	1.4	2.3	0.3	1.6	0.3
Automotive Fuel Cells	Dow Chemical	4	7	4	7	1.65	2.22	2.6	6.7	2.2	1.1	1.5	5.4	1.0	3.3
Hydrogen Storage	Energy Conversion Devic	0	9	0	9	0.00	2.04	0.0	4.7	0.0	1.7	0.0	0.8	0.0	0.4
Hydrogen Storage	Matsushita Electric	3	0	3	0	1.23	0.00	9.2	0.0	0.6	0.9	1.7	0.0	0.9	0.0
Ultracapitors	Asahi Glass	2	27	2	27	1.81	0.87	5.7	4.6	1.0	1.0	0.5	0.4	0.6	0.5
Ultracapitors	NEC	7	20	7	20	0.45	1.15	8.4	8.9	0.9	1.3	0.3	0.4	0.3	0.3
Ultracapitors	GE	1	11	1	11	3.77	1.16	9.7	5.4	0.9	1.4	3.0	1.0	4.7	1.0
Ultracapitors	Honda	0	10	0	10	0.00	0.48	0.0	6.6	0.0	1.1	0.0	0.1	0.0	0.1
Ultracapitors	Jeol	2	8	2	8	1.14	1.80	6.0	5.8	1.1	1.0	0.0	0.9	0.0	1.0
Ultracapitors	Nissinbo Ind.	2	6	2	6	1.64	0.53	4.1	3.4	0.9	1.1	2.0	0.2	1.4	0.2
Ultracapitors	Matsushita Electric	4	4	4	4	1.86	0.00	4.0	3.3	1.8	0.9	3.8	0.5	3.2	0.9
Ultracapitors	Isuzu	5	0	5	0	0.78	0.00	4.3	0.0	1.7	0.0	0.8	0.0	0.8	0.0
Ultracapitors	Murata Mfg	2	0	2	0	0.72	0.00	3.1	0.0	2.5	0.0	0.0	0.0	0.0	0.0
Combustion	Caterpillar	3	11	3	11	2.09	1.81	4.2	6.9	2.7	1.7	4.0	0.2	11.9	0.4
Combustion	Cummins	3	5	3	5	0.30	2.61	12.5	13.9	0.7	0.6	0.3	0.4	1.2	1.1
Combustion	Daimler Chrysler	5	6	5	6	1.21	0.37	8.5	3.6	1.0	2.4	0.2	0.2	0.6	0.4
Combustion	Ford	12	18	12	18	1.11	1.03	14.9	8.1	0.7	1.1	0.3	0.5	1.1	1.0
Combustion	GM	5	9	5	9	0.67	1.39	2.5	7.0	2.6	1.5	0.2	0.2	0.3	0.5
Combustion	Honda	6	2	6	2	0.96	0.29	3.0	7.7	3.3	1.5	1.0	1.0	2.7	2.0
Combustion	Mazda	5	4	5	4	1.27	1.55	2.9	4.0	4.0	1.3	0.4	1.8	0.8	2.4
Combustion	Nissan	5	17	5	17	1.51	2.53	5.4	3.8	1.1	1.7	0.4	0.8	0.7	1.3
Combustion	Robert Bosch	1	9	1	9	2.56	1.07	10.8	3.7	0.6	2.1	1.0	0.2	4.0	0.4
Combustion	Toyota	1	29	1	29	1.57	1.81	2.8	4.1	3.4	1.7	0.0	0.4	0.0	0.8
Combustion	Yamaha Motors	2	10	2	10	2.32	2.96	3.5	4.7	2.3	2.4	3.0	0.5	3.2	1.9
Diesel	Caterpillar	6	25	6	25	0.82	2.77	6.2	8.6	1.0	1.0	1.2	3.4	2.5	4.3
Diesel	Daimler Chrysler	27	51	27	51	1.48	0.80	5.9	6.9	1.5	1.1	1.0	0.4	2.2	0.7
Diesel	Fiat	7	14	7	14	0.85	2.13	4.3	4.9	2.0	1.0	0.3	0.5	0.6	0.9
Diesel	Ford	3	28	3	28	0.86	2.00	7.2	5.8	1.6	1.3	1.0	0.2	2.8	0.4
Diesel	GM	14	14	14	14	1.23	2.13	8.4	6.6	0.8	1.1	1.0	0.3	3.0	0.5
Diesel	MAN AG	11	23	11	23	0.73	2.39	3.7	4.8	1.2	1.1	0.8	0.5	1.4	1.1
Diesel	Nissan	7	43	7	43	0.54	1.33	6.0	4.7	1.1	1.3	0.1	0.5	0.3	0.7
Diesel	Robert Bosch	40	51	40	51	0.82	1.06	4.4	6.1	1.3	1.2	0.4	0.2	0.7	0.5
Diesel	Toyota	14	40	14	40	2.66	1.51	7.9	3.6	0.6	1.2	0.6	0.9	1.0	1.2
Diesel	Yamaha Motors	13	41	13	41	1.21	1.75	4.4	5.2	1.7	1.8	0.6	0.4	1.2	0.7
Emissions	Daimler Chrysler	39	115	39	115	1.24	1.87	6.7	4.8	1.0	1.3	0.4	0.3	0.6	0.5
Emissions	Denso	44	41	44	41	1.35	1.04	4.4	4.7	1.6	1.5	0.5	0.5	0.9	0.6
Emissions	Emitec	41	62	41	62	0.47	0.30	3.1	5.2	1.4	0.8	0.7	0.5	1.1	0.8
Emissions	Ford	113	191	113	191	1.39	1.87	5.9	3.8	1.3	1.5	0.4	0.6	0.7	0.8
Emissions	GM	39	53	39	53	0.93	1.00	6.5	6.7	1.2	1.2	0.8	1.4	1.2	1.5
Emissions	Honda	63	168	63	168	1.18	1.13	4.4	4.7	1.9	1.4	0.1	0.5	0.3	0.7
Emissions	Nissan	31	81	31	81	1.15	0.97	5.1	3.6	1.9	1.7	0.2	0.2	0.4	0.3
Emissions	Robert Bosch	32	46	32	46	0.81	1.04	6.7	4.6	1.2	1.2	0.5	0.5	0.7	0.7
Emissions	Siemens	27	109	27	109	1.55	1.17	2.5	5.3	1.6	1.0	1.0	0.7	1.5	1.1
Emissions	Toyota	119	219	119	219	2.25	1.58	4.4	3.5	1.3	1.4	0.8	0.9	1.3	1.2
Hybrid Electric Vehicles	Aisin Seiki	11	30	11	30	3.13	2.87	5.4	6.6	1.7	1.1	0.0	0.0	0.0	0.0
Hybrid Electric Vehicles	Daimler Chrysler	4	20	4	20	1.26	1.16	8.8	7.2	1.1	1.2	0.3	0.8	0.3	1.3
Hybrid Electric Vehicles	Denso	1	17	1	17	0.88	3.23	1.8	2.6	4.4	2.7	0.0	0.3	0.0	0.4
Hybrid Electric Vehicles	Ford	7	18	7	18	3.87	3.81	7.8	4.1	1.4	1.7	0.3	0.2	0.6	0.4
Hybrid Electric Vehicles	GM	6	14	6	14	3.61	3.72	9.1	2.6	1.2	3.4	1.5	0.1	3.5	0.1
Hybrid Electric Vehicles	Hitachi	5	13	5	13	2.59	1.63	4.2	2.7	1.8	2.1	1.2	0.2	1.7	0.2
Hybrid Electric Vehicles	Honda	13	70	13	70	2.31	2.51	5.1	2.6	1.4	2.0	0.3	0.2	0.4	0.3
Hybrid Electric Vehicles	Mitsubishi Motors	5	10	5	10	2.39	1.82	5.6	5.6	1.3	1.2	0.6	0.6	0.8	0.9
Hybrid Electric Vehicles	Nissan	2	23	2	23	1.55	3.16	4.3	2.8	1.9	2.7	0.0	0.3	0.0	0.4
Hybrid Electric Vehicles	Toyota	13	69	13	69	3.07	2.71	7.8	3.1	1.1	2.0	0.8	0.2	1.0	0.4
Hydrogen Internal Combustion Engine	German Aerospace Ctr	2	0	2	0	0.40	0.00	4.4	0.0	3.1	0.0	1.0	0.0	2.7	0.0
Hydrogen Internal Combustion Engine	Mazda	4	0	4	0	0.44	0.00	4.1	0.0	3.3	0.0	0.8	0.0	1.6	0.0
Hydrogen Internal Combustion Engine	SW Res. Inst.	3	1	3	1	1.28	0.51	14.3	6.3	0.8	2.0	0.0	11.0	0.0	16.7
Lightweight Materials	Alcan	22	43	22	43	0.35	0.99	4.2	5.7	1.3	1.1	1.0	2.0	0.8	1.3
Lightweight Materials	Alcoa	57	52	57	52	1.35	1.25	7.7	9.8	1.0	0.8	1.8	1.1	1.3	0.6
Lightweight Materials	GE	44	19	44	19	0.68	0.85	8.9	8.5	0.9	0.9	4.0	0.8	2.6	0.6
Lightweight Materials	Honda	26	28	26	28	0.62	1.20	5.3	5.5	1.3	1.3	1.1	1.2	0.8	0.9
Lightweight Materials	Honeywell	34	13	34	13	0.75	2.85	4.9	6.1	1.9	1.3	2.1	1.5	1.6	1.2
Lightweight Materials	Kobe	10	25	10	25	0.61	0.90	6.3	5.9	1.0	1.3	1.4	1.5	1.0	1.0
Lightweight Materials	NSE	30	11	30	11	0.72	1.51	9.1	9.2	0.9	0.8	2.6	3.7	1.6	1.9
Lightweight Materials	Sumitomo Metals	18	13	18	13	1.12	0.49	7.4	6.5	0.9	1.0	1.1	0.9	0.8	0.6
Lightweight Materials	Toyota	27	14	27	14	1.13	0.65	4.4	3.1	1.1	2.0	1.6	2.6	1.1	1.6
Lightweight Materials	United Technologies	17	8	17	8	0.73	0.21	9.6	11.4	0.9	0.7	2.2	0.6	2.1	0.4
Power Electronics not Ultracapacitor	Aisin Seiki	7	21	7	21	1.28	2.64	4.3	6.8	1.8	1.3	0.0	0.1	0.0	0.2
Power Electronics not Ultracapacitor	Daimler Chrysler	5	10	5	10	1.78	1.17	4.6	6.6	1.5	1.3	0.6	1.2	0.5	1.7
Power Electronics not Ultracapacitor	Emerson	21	24	21	24	2.95	1.74	4.9	8.8	1.3	0.9	0.8	4.0	1.0	4.5
Power Electronics not Ultracapacitor	Ford	9	12	9	12	1.76	1.89	7.4	5.1	1.2	1.6	0.1	1.4	0.2	1.4
Power Electronics not Ultracapacitor	GE	11	9	11	9	2.82	1.88	6.7	5.7	1.5	1.4	0.4	0.2	0.6	0.2
Power Electronics not Ultracapacitor	GM	8	15	8	15	1.25	1.40	5.5	4.7	1.7	1.6	0.0	0.9	0.0	0.9
Power Electronics not Ultracapacitor	Hitachi	6	13	6	13	1.70	1.38	9.4	5.0	1.1	1.9	0.5	0.2	1.0	0.2
Power Electronics not Ultracapacitor	Honda														