OFFICE OF TECHNOLOGY POLICY

The U.S. Competitive Position in Advanced Automotive Technologies

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INTRODUCTION

The automotive industry continues to be one of the most important components of the U.S. and world economies. Transportation-related goods and services contributed $1,050 billion to a $9.87 trillion U.S. gross national product in 2000.

It is an industry on the verge of a major technology-led transformation that is leading to more energy efficient and cleaner vehicles. As a result, conventional gasoline internal combustion engine (ICE) vehicles are no longer the only competitive option for consumers and businesses but will increasingly have to compete with hybrid electric, clean diesel, and fuel cell vehicles over the next fifteen years. ICE vehicles, themselves, are transforming as new advanced combustion regimes and electronic component technologies not thought possible even a decade ago become achievable.

The Technology Administration's Office of Technology Policy in cooperation with the U.S. Department of Energy's Office of FreedomCAR and Vehicle Technologies asked CHI Research, Inc. to assess the competitive position of the United States in selected advanced automotive technologies of near-, mid- and long-term interest, and shed light on growing areas of inventive activity based on patenting activity. CHI Research, Inc. assessed the U.S. competitive position in advanced automotive technologies relevant to ongoing research supporting the goals of the FreedomCAR Partnership, and earlier research under the Partnership for a New Generation of Vehicles (PNGV). The work is based on innovations patented in the U.S. Patent and Trademark Office and European Patent Office (EP) systems. CHI Research, Inc. presents and analyzes the patent data for each category. It then compares regional and company patenting trends and patent citation indicators. The findings are quantitative and objective because they are based entirely on patenting activity and patent citation analysis. Eleven advanced automotive technology categories are covered:

- 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 categories are defined in more detail later in the report when the detailed findings are presented for each category. In addition, the report looks at two subsets

within the major categories: lithium polymer/lithium sulfur batteries within advanced batteries, and carbon composites within lightweight materials.[1]

Significant Findings:

- Inventive activity in most of the technologies is growing at a rapid pace. 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.[2]

- 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 in which activity is fairly evenly divided among the United States, Japan and Europe.

- Interest in direct injection, which had been declining for a long time, has definitely picked up again. Europe ranks well ahead of the United States and Japan in direct injection (largely diesel) engine technology.

- Two categories, lightweight materials and hydrogen ICE, are declining. It is important to note, however, that the lightweight materials 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, some parts such as carbon composites are.

- In terms of inventive activity, the United States is a clear leader in automotive fuel cells, on-board hydrogen storage, lightweight materials, new combustion regimes and hydrogen ICE.

- Japan ranks ahead of the United States in four categories: advanced batteries, HEV, ultracapacitors and new combustion regimes. If current trends continue, in several years Japan will overtake the United States in the non-ultracapacitor areas of power electronics.

- While the United States leads Japan in new combustion regimes inventive activity, Japanese patents in this category are far more highly cited than those of the United States and have much faster cycle times (innovation speed).

- Company-level data shows that the large vehicle companies are the active players in certain categories. In other categories, the vehicle companies are far less important than other companies.

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

[2] The analysis looked at U.S. 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."

PATENT ANALYSIS PROCEDURE

Identify the Patents in Each Category

For each category the first task was to find the relevant U.S. 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. 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 in some categories.

We identified patents in each 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 in this research. 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 with 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.

The Appendix 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 ($term_1$ OR $term_2$ OR ... OR $term_n$).

No filter is perfect; in the real world 95 percent accuracy is an excellent result. When we examined patent-level detailed data for most of these categories, we did 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

We decided early on to include both U.S. and European Patent Office (EP) patents, knowing that in many cases we would identify multiple patent documents for the same invention. In order to avoid double counting, we adopted the use of patent families. When U.S. and EP patent applications are filed for the same invention, the published documents, whether published EP applications or granted U.S. or EP patents, are said to be patent "equivalents," or members of the same patent family.[3] Thus, to avoid double counting of U.S. and EP equivalents, we counted patent families, not individual patents. We computed the following indicators 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 looked at activity trends both overall and broken out by region and by company.

Patent analysis is more 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 references are to earlier patents as well as to earlier published papers and other non-patent references. They 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 – The 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 an inventor obtains a patent for an improved motor controller, the patent must cite all former motor controller patents whose ideas the inventor claims 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, as listed in the validation discussion, key inventions tend to accumulate many forward citations because they spur inventions as companies try to improve upon or build 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.

[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.

Since CHI Research, Inc. has all U.S. 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 used the Citation Index, which is 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 percent 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 U.S. 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 U.S. and EP patents using different norms, one for the U.S. patents and one for the EP patents. Then the combined Citation Index is computed as a weighted average. Since we use both U.S. 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 other non-patent references, as well as prior patents. Generally, patents that cite many non-patent references, somewhat more than half of which are to journal scientific articles, are said to be science linked. This indicator 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, 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 gives us 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

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

[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)

that a patent or company or region with a speed index of 1.25 has a cycle time 25% faster than expected.

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 it 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 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 then 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 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 families
- grouping of bar charts comparing patent citation indicators by region and by top-10 company
- 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 so that the reader may peruse the titles and thereby start off with some confidence in the efficacy of the patent search filters.

Patents are partitioned into regions, based on the home address of the first inventor listed on each patent. The regions are the United States, 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 indictors 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 Corporation), 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

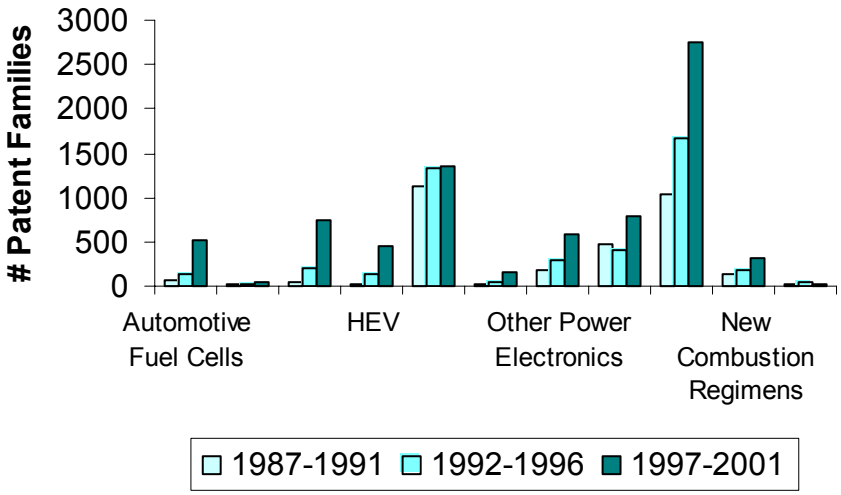
most of the categories, three years appears to be sufficiently long. If a company has not received any patents in the last three years it is probably no longer working in the area.

FINDINGS

Patenting Activity is Growing Rapidly in All But One Category

In this report, we examined data for each of the categories independently. However, it is important to have a perspective of their relative size. **Figure 1** compares each of the categories' patent family activity in three 5-year periods. (The categories are in arranged in the order in which they are listed in the report.)

Figure 1: Comparison of Patent Family Activity



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 also is not growing.

More Patent Families Resulted From Adding EP Documents

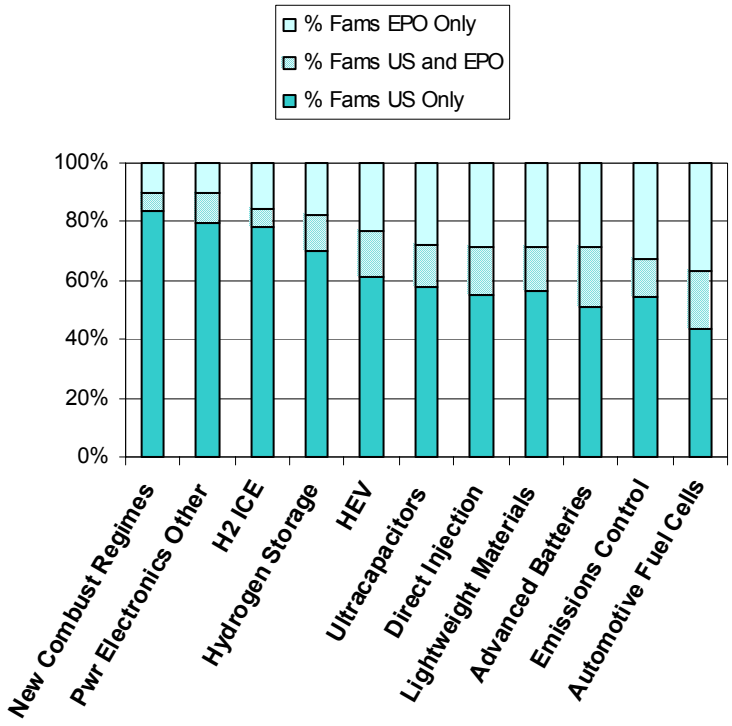
The rationale for combining U.S. and EP patent data, instead of U.S. data alone, is to get as broad a coverage of each technology as possible. In particular, when we include published EP applications, we improve coverage of new inventions for which U.S. patents have yet to be issued. While it is true that about half of U.S. patents are of foreign origin, we believe the inclusion of EP documents creates a more international perspective than could be obtained from U.S. documents alone.[7]

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 U.S. and EP documents would already be there, even if the EP documents

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

were not included, the percentage of families that are based on U.S. patents is made up of the other two bands combined.

Figure 2: Relative Amount of Total Patent Families by Category



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

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 eleven categories here, so, for example, Fuel Cell Systems is a 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.

Figure 3: Extent of Overlap of U.S. Patents Among Categories

Category	Automotive Fuel Cell Systems	HEV	Lightweight Materials	Power Electronics	Direct Injection	Emission Control/ New Combustion 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	1627	196	4
Emission Control / New Combustion 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

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 labeled the category "Automotive Fuel Cells" to differentiate it 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.[8]

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 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** lists 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, the Department of Energy, General Motors, International Fuel Cells, and the University of California.

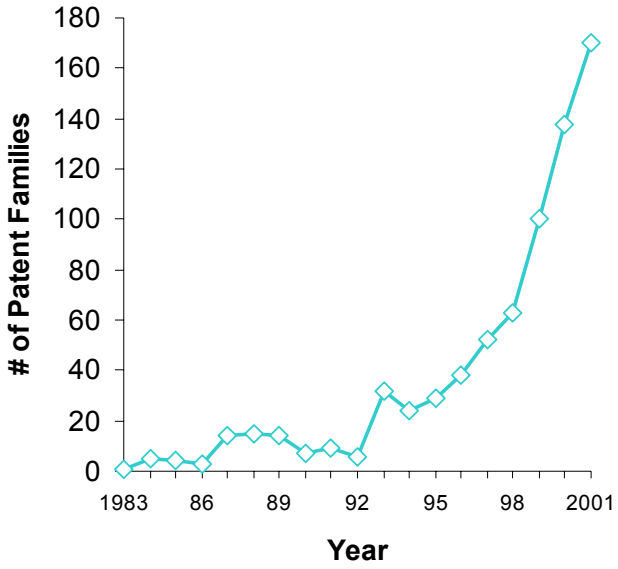
Figure 4: Top-Cited Automotive Fuel Cell Category Patents

Patent	Family Number	Issue Date	Cites Rec	Assignee Name	Title
4876115	10035	10/24/1989	76	USA ENERGY DEPT	ELECTRODE ASSEMBLY FOR USE IN A SOLID POLYMER ELECTROLYTE FUEL CELL
5248566	10064	9/28/1993	56	USA ENERGY DEPT	Fuel cell system for transportation applications
4769297	10028	9/6/1988	55	INTERNATIONAL FUEL CELLS CORP.	Solid polymer electrolyte fuel cell stack water management system
5234777	9	8/10/1993	48	UNIV CALIFORNIA, REGENTS	Membrane catalyst layer for fuel cells
5108849	10048	4/28/1992	45	CANADA NAT'L DEFENCE MINISTER	Fuel cell fluid flow field plate
5211984	10055	5/18/1993	44	UNIV CALIFORNIA, REGENTS	Membrane catalyst layer for fuel cells
5252410	10065	10/12/1993	39	BALLARD POWER SYSTEMS INC.	Lightweight fuel cell membrane electrode assembly with integral reactant flow passages
5084144	10045	1/28/1992	38	PHYSICAL SCIENCES INC.	High utilization supported catalytic metal-containing gas-diffusion electrode, process for making it, and cells utilizing it
4647516	10015	3/3/1987	37	MITSUBISHI DENKI KK	Internal Reforming Type Fuel Cell
4988583	70	1/29/1991	37	CANADA NAT'L DEFENCE MINISTER	Novel fuel cell fluid flow field plate

[8] 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.

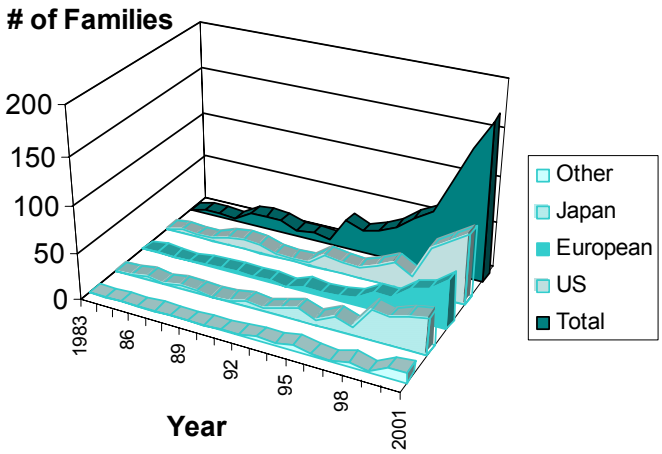
Activity - **Figure 5** shows the marked growth in patenting activity started in 1994 and has increased rapidly ever since, most dramatically in the last three years.

Figure 5: Growth in Fuel Cell Patenting Activity



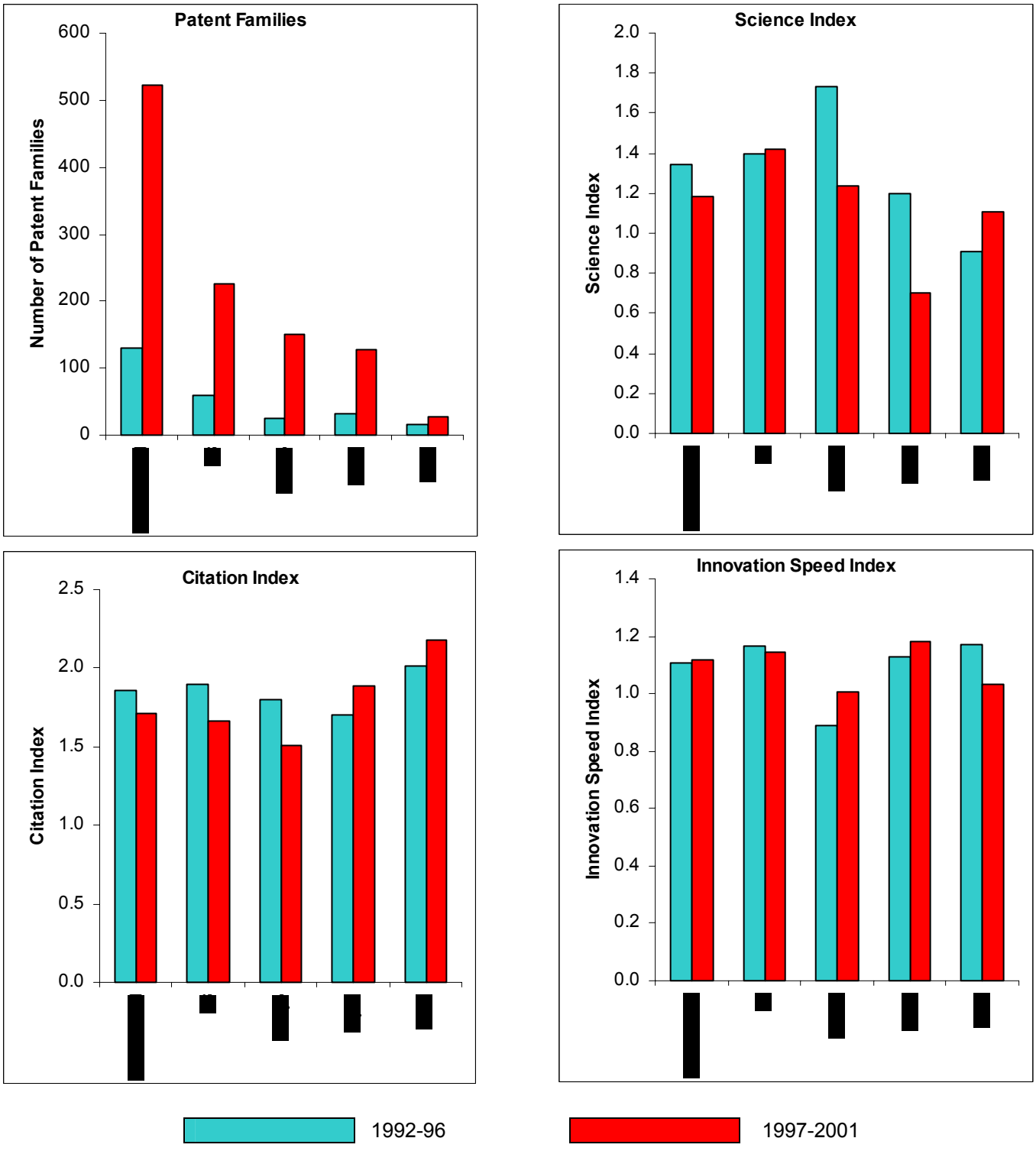
Trends by region - **Figure 6** reveals that the growth in fuel cell patenting has been taking place across all the regions, with the United States only slightly more active than Europe or Japan. Japanese growth in the last several years is relatively slower than in the other regions. There are no relevant patents from Korea.[9]

Figure 6: Growth in Fuel Cell Patenting Activity by Region



[9] 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.

Figure 7: Comparison of Automotive Fuel Cell Patent Family Indicators



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 was shown in Figure 6, the United States 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 United States. The United States 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 General Motors. Other top players are Matsushita Electric, 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.

Figure 8: Companies with Most Automotive Fuel Cell Patent Families

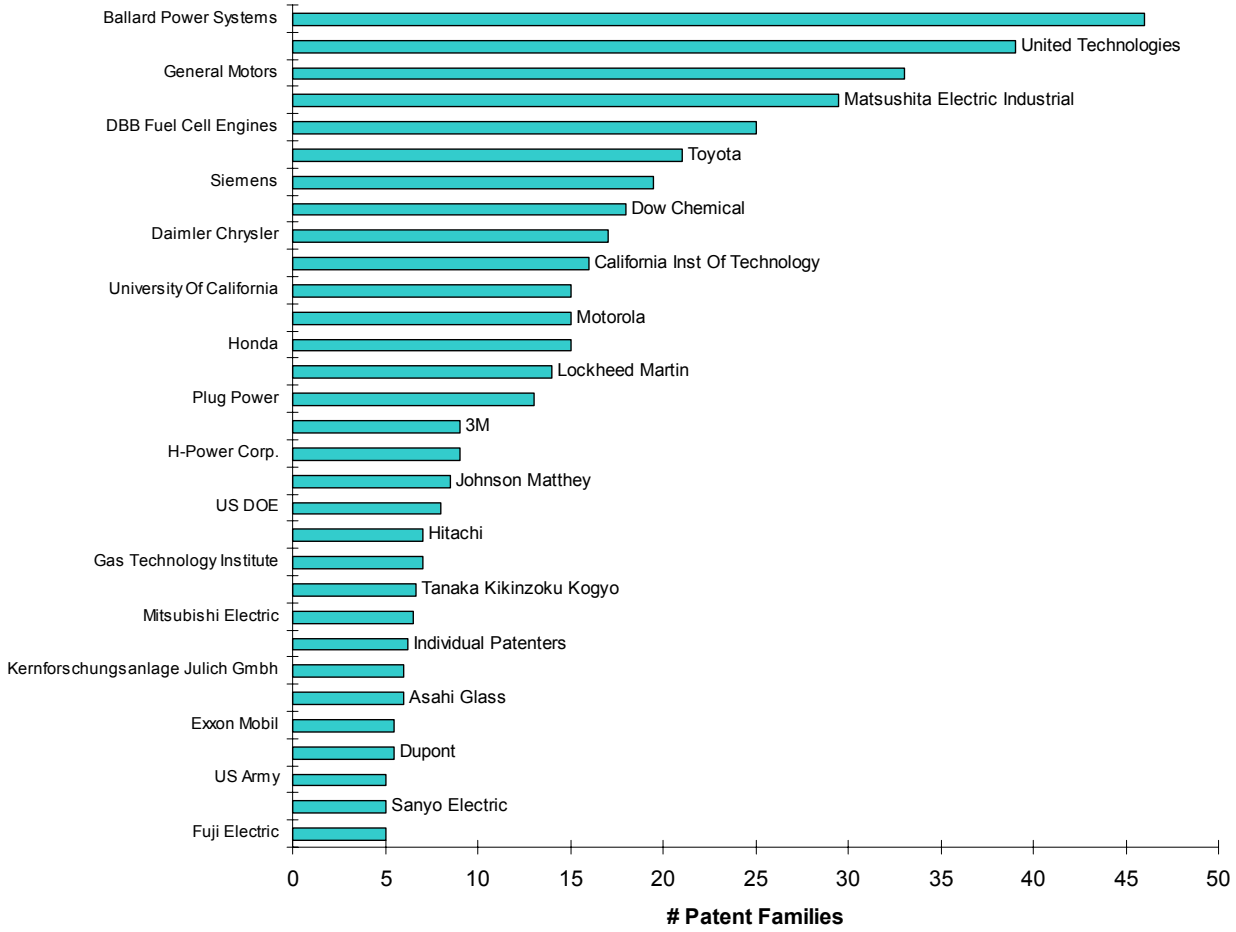
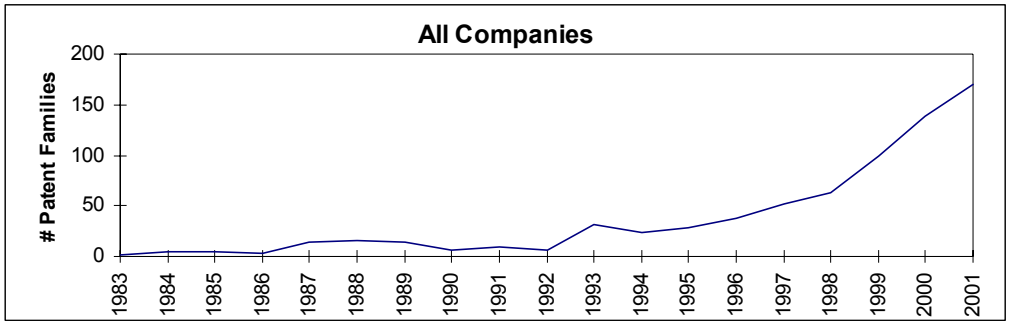
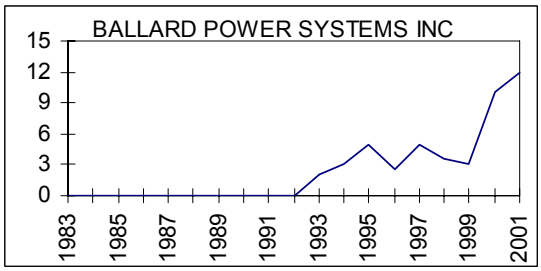
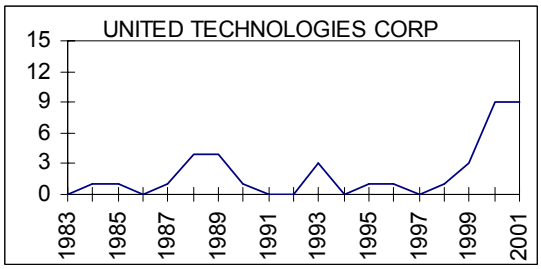
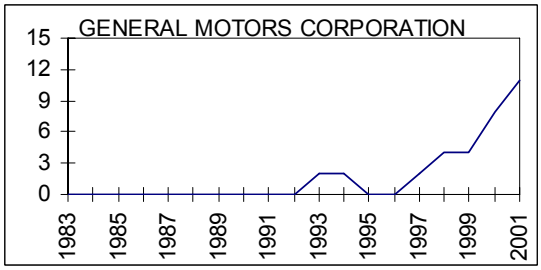


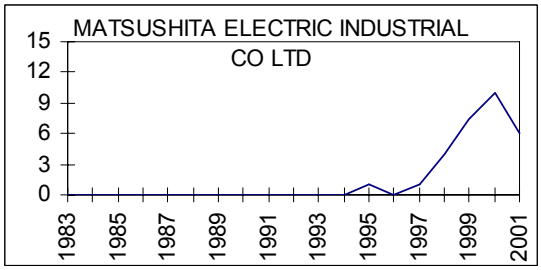
Figure 9: Patent Family Trends Over Time by All Companies, By Company

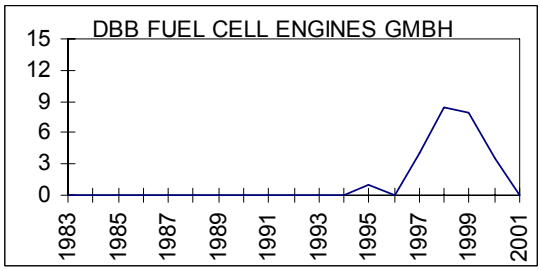


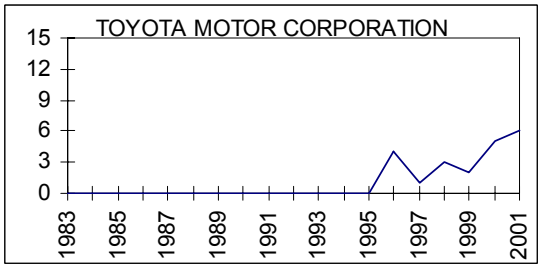


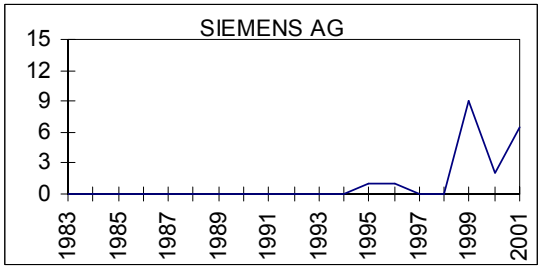


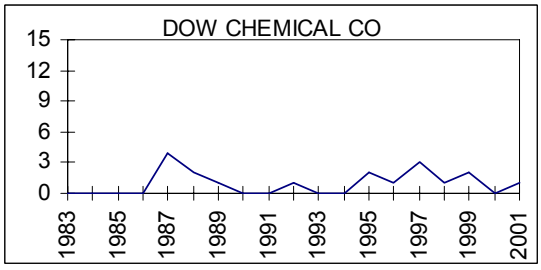


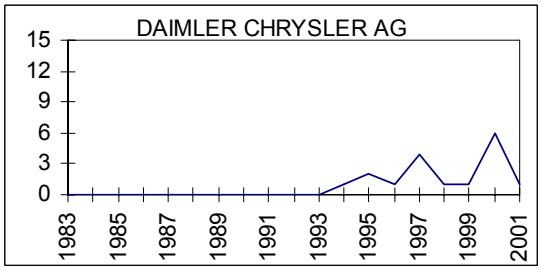


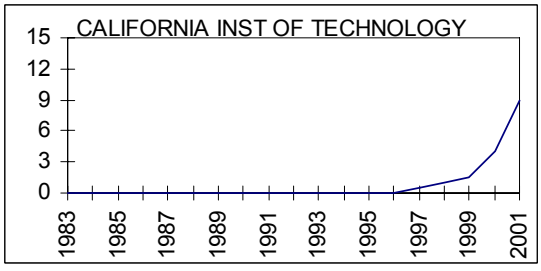






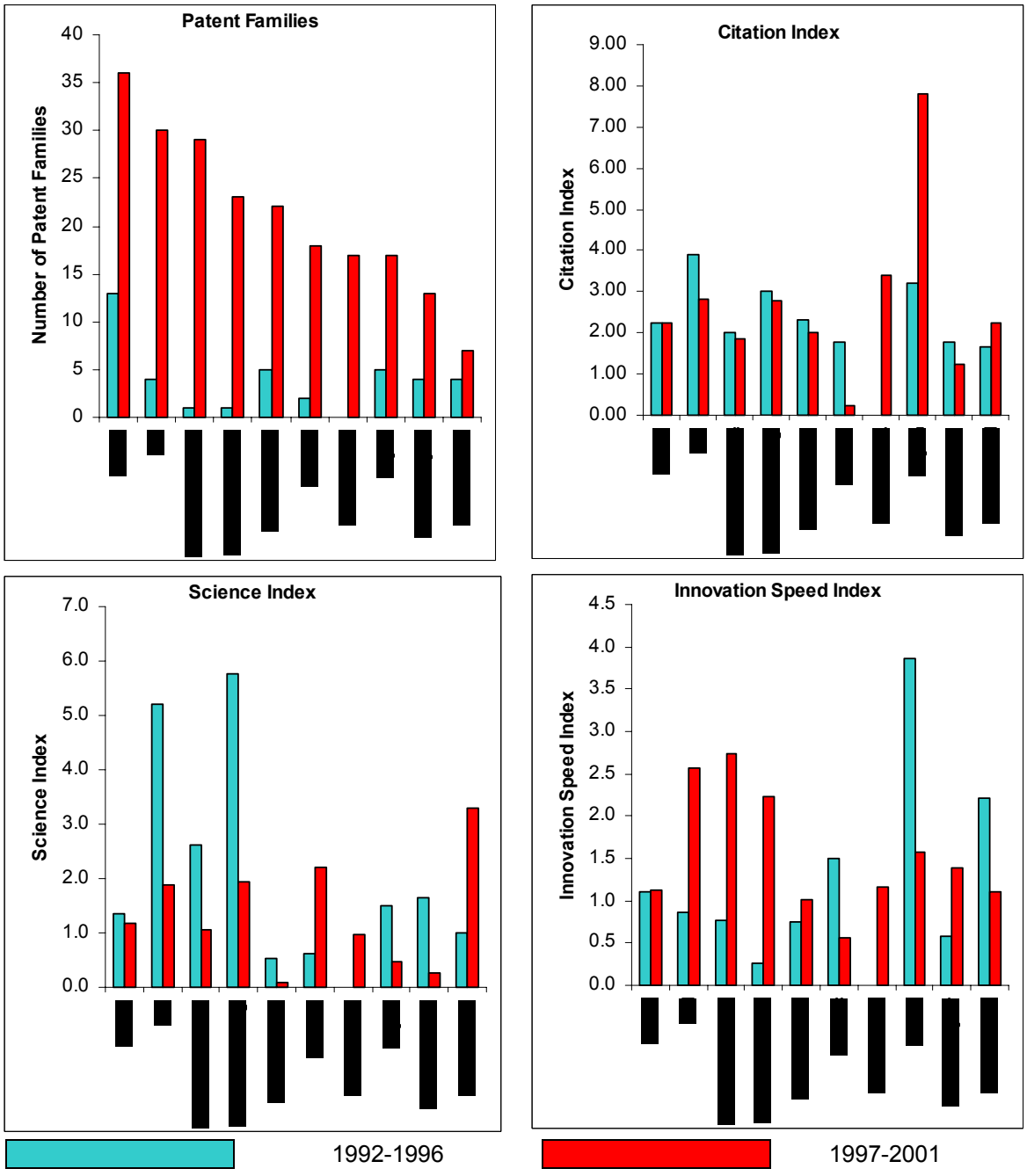






Indicators by company - **Figure 10** compares patent indicators among the top ten Automotive Fuel Cell companies and institutions. In terms of recent activity, the top players are Ballard, General Motors and Matsushita. By a very wide margin, Toyota has the strongest Citation Index, suggesting a markedly 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.

Figure 10: Patent Indicators Among Top 10 Companies & Institutions



Emerging and fading companies - **Figure 11A** 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 change. Strongly "emerging" companies include United Technologies, Matsushita Electric, GM, and Siemens. In **Figure 11B** DBB Fuel Cell Systems is flagged as a fading company, even though the decline is slight.

Figure 11A: Emerging Automotive Fuel Cell Players (Companies With Largest Increase Among Those with 2+ Patents)

Company	1996-1998	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. Magnetmotorischet. 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 Sonnenenrgie Wasser-For Baden	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
Sorapec S.A.	0	2	2	Infinity
Samsung Group	0	2	2	Infinity
Aventis S.A.	1	2.5	1.5	150%

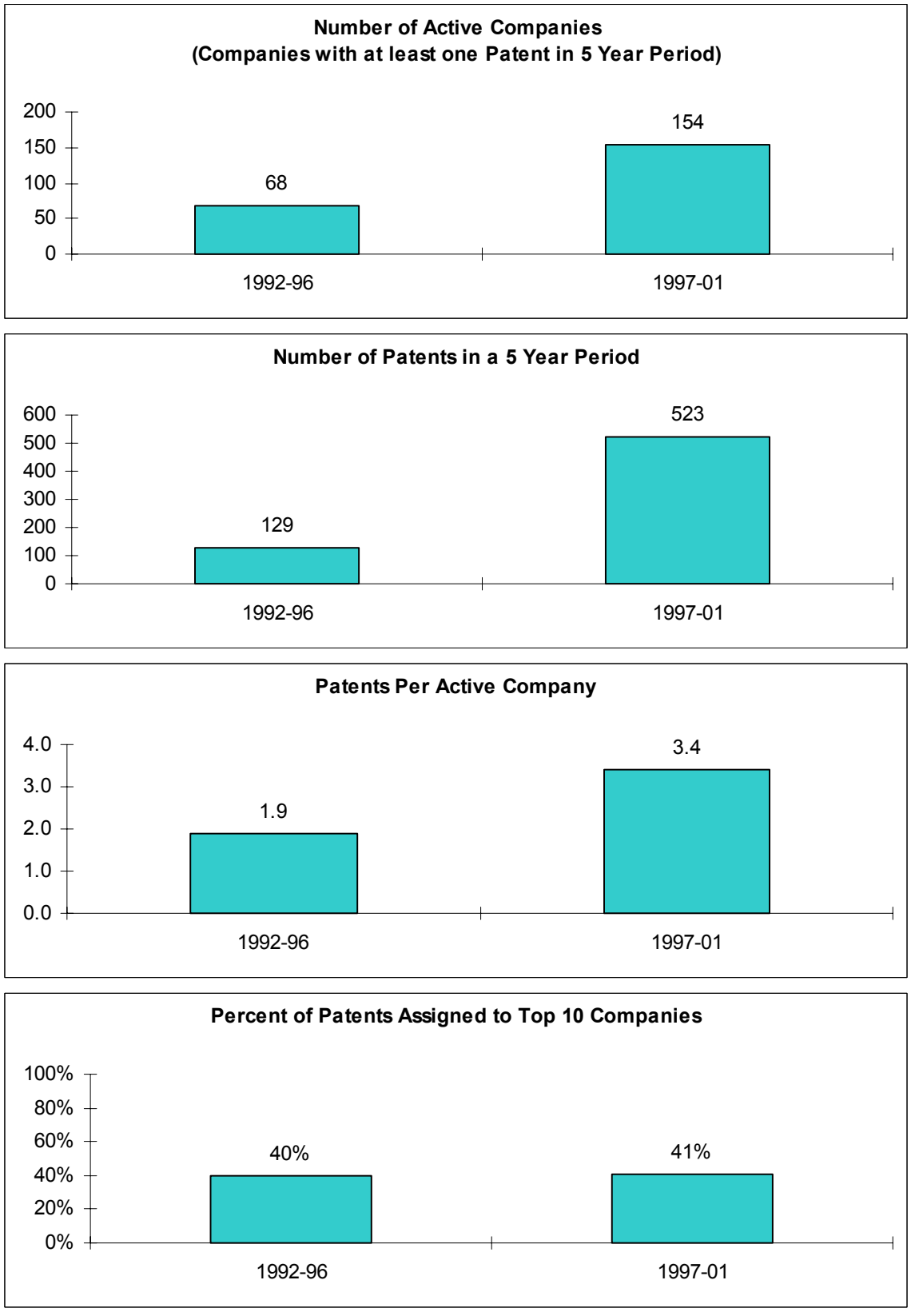
Figure 11B: Fading Automotive Fuel Cell Players
(Companies With Largest Decrease Among Those with 2+ Patents)

Company	1996-1998	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	5	3	2	40%
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%

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 United States 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 U.S., top players are United Technologies and General Motors. In Europe, the top player is a Ballard Power Systems subsidiary, and in Japan it is Toyota. Toyota has some very-high-impact recent patents in this technology.

Figure 12: Comparison of Life Cycle Statistics



Automotive Fuel Cells Subcategory: High-Temperature Membranes

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 in a stand-alone category. Department of Energy in-house experts confirm that it is not surprising that there are not many high temperature membrane patents yet. This area is likely to begin expanding in the next few years.

Hydrogen Storage

This category covers technology applicable to on-board hydrogen storage for fuel cells. For the most part, 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 belong to Koppers Company, Standard Oil of Ohio (BP), Daimler Benz, and Energy Conversion Devices (ECD). Only about ten of the patents come anywhere near being highly cited; the most highly cited patents have received only 17 cites each.

Figure 13: Top-Cited Hydrogen Storage Category Patents

Patent	Family Number	Issue Date	Cites Rec	Assignee Name	Title
4859413	10041	8/22/1989	17	STANDARD OIL CO. (OHIO)	COMPOSITIONALLY GRADED AMORPHOUS METAL ALLOYS AND PROCESS FOR THE SYNTHESIS OF SAME
5653951	10062	8/5/1997	17	CATALYTIC MATERIAL LTD	Storage of hydrogen in layered nanostructures
4389326	10006	6/21/1983	14	AGENCE NATIONALE DE VALORISATION, ETS. PUBLIC	Method of storing hydrogen in intimate mixtures of hydrides of magnesium and other metals or alloys
4902579	10042	2/20/1990	14	STANDARD OIL CO. (OHIO)	Amorphous Metal Alloy Compositions for Reversible Hydrogen Storage
4370163	10001	1/25/1983	13	MATSUSHITA ELECTRIC INDUSTRIAL CO. LTD	Hydrogen storage alloy and process for making same
4383606	10003	5/17/1983	13	JOHNSON MATTHEY INC.	Hydrogen storage system
4412982	10010	11/1/1983	12	KOPPERS COMPANY, INC.	Zirconium-titanium-manganese-iron alloy characterized by ZrMn+HD 2 +B stoichiometry
5135589	10050	8/4/1992	12	N/A	Metastable hydrogen storage alloy material
4489564	10017	12/25/1984	11	THYSSEN INDUSTRIE AG	Hydride storage for hydrogen
4396114	10007	8/2/1983	10	MPD TECHNOLOGY CORPORATION	Flexible means for storing and recovering hydrogen

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 the United States has had the most activity, activity in Japan is now nearly up to U.S. levels in Japan, and European activity has faded out altogether.[10]

Figure 14: Hydrogen Storage Patenting Activity

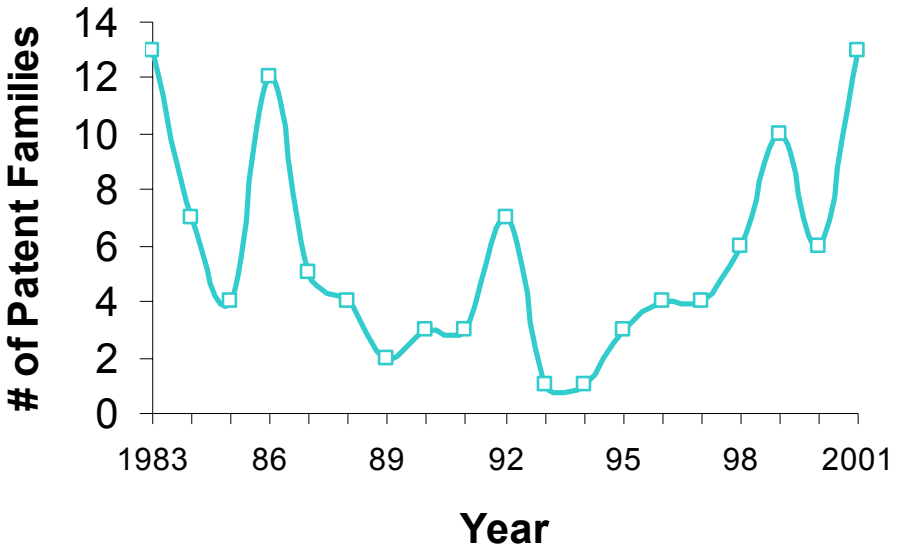
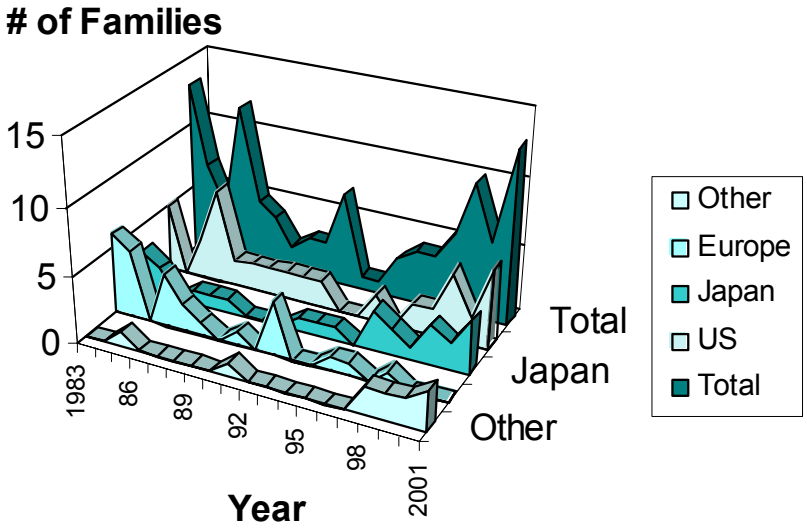


Figure 15: Trends by Region



[10] The Other region is mostly made up of Canadian-invented patents.

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 U.S. patents in the category are highly cited and have faster innovation speeds than the other regions.

Figure 16: Regional Values

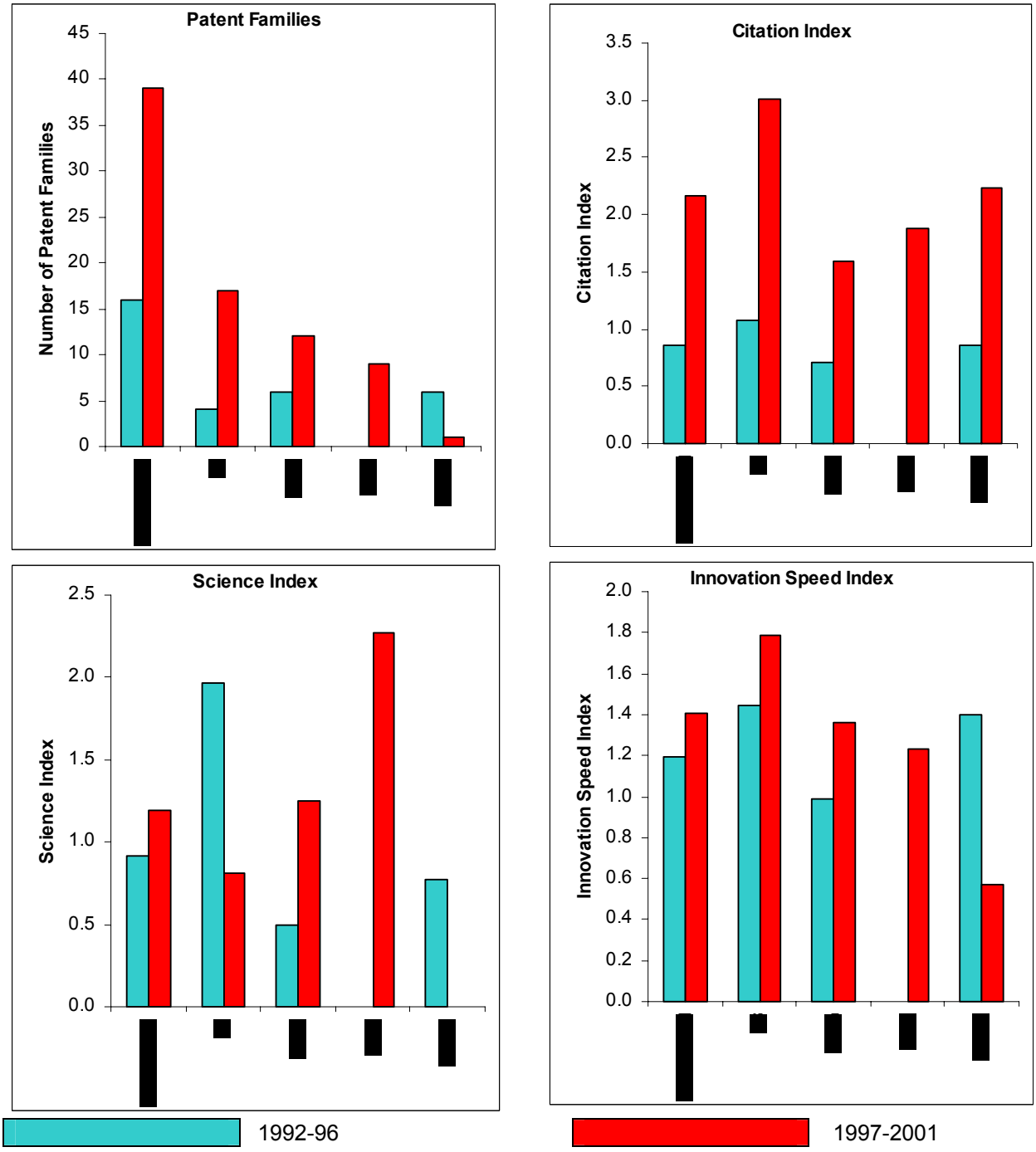
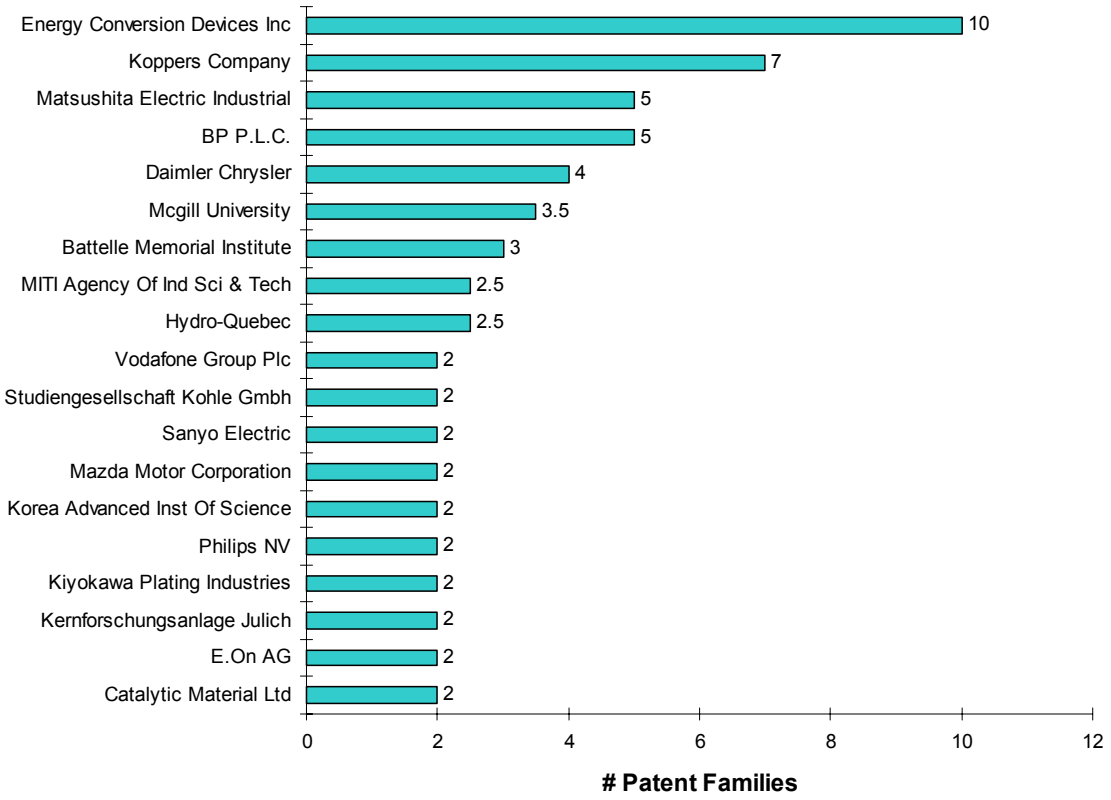


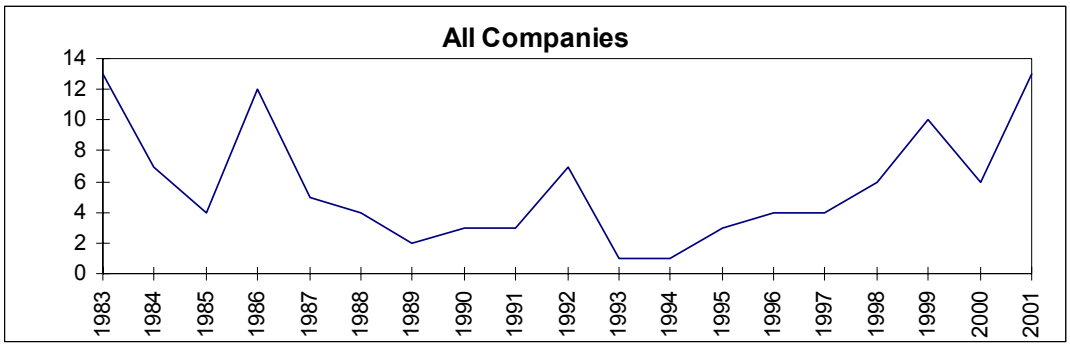
Figure 17: Companies with the Most Patent Families

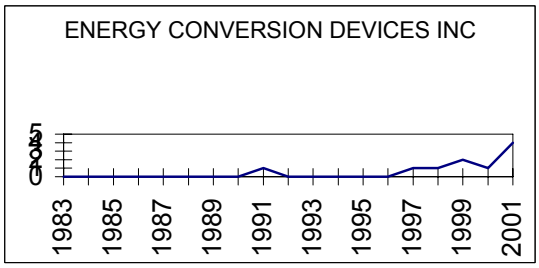


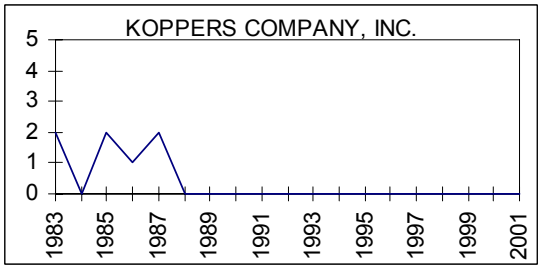
Most active companies - The companies with the most patent families are ranked in **Figure 17.** Energy Conversion Devices is first and Koppers Company second. When we look at **Figure 18**, which compares the trends for the top ten of these companies, we observe that Koppers, BP and DaimlerChrysler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

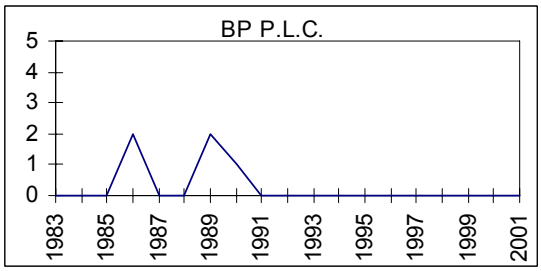
Indicators by company - Figure 19 compares patent citation indicators for ECD and Matsushita (there are too few patents for any other company), but there is really nothing to compare, because the indicators shown are in different time periods.

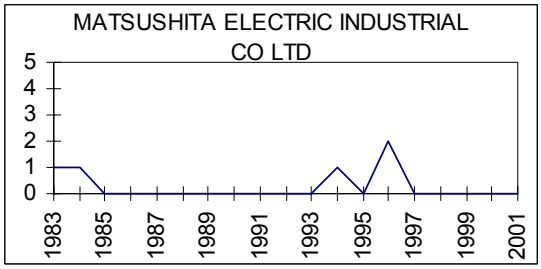
Figure 18: Trends for Top Ten Companies

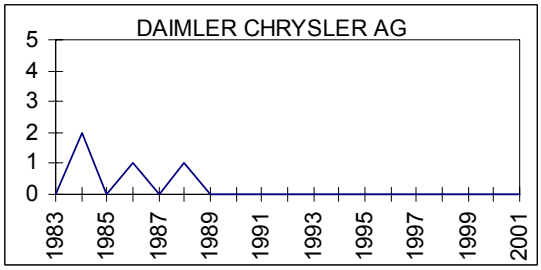


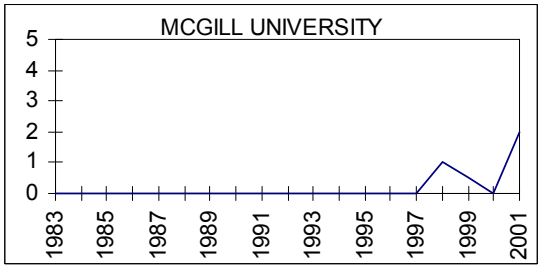


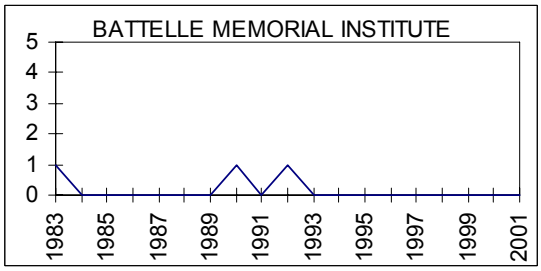


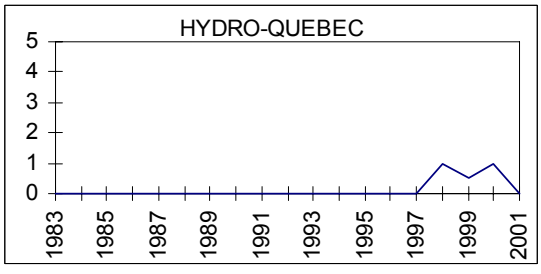


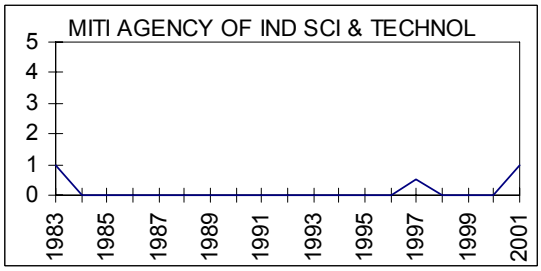












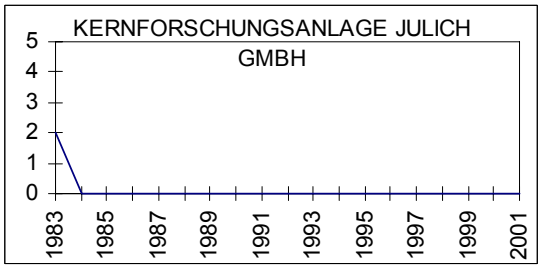
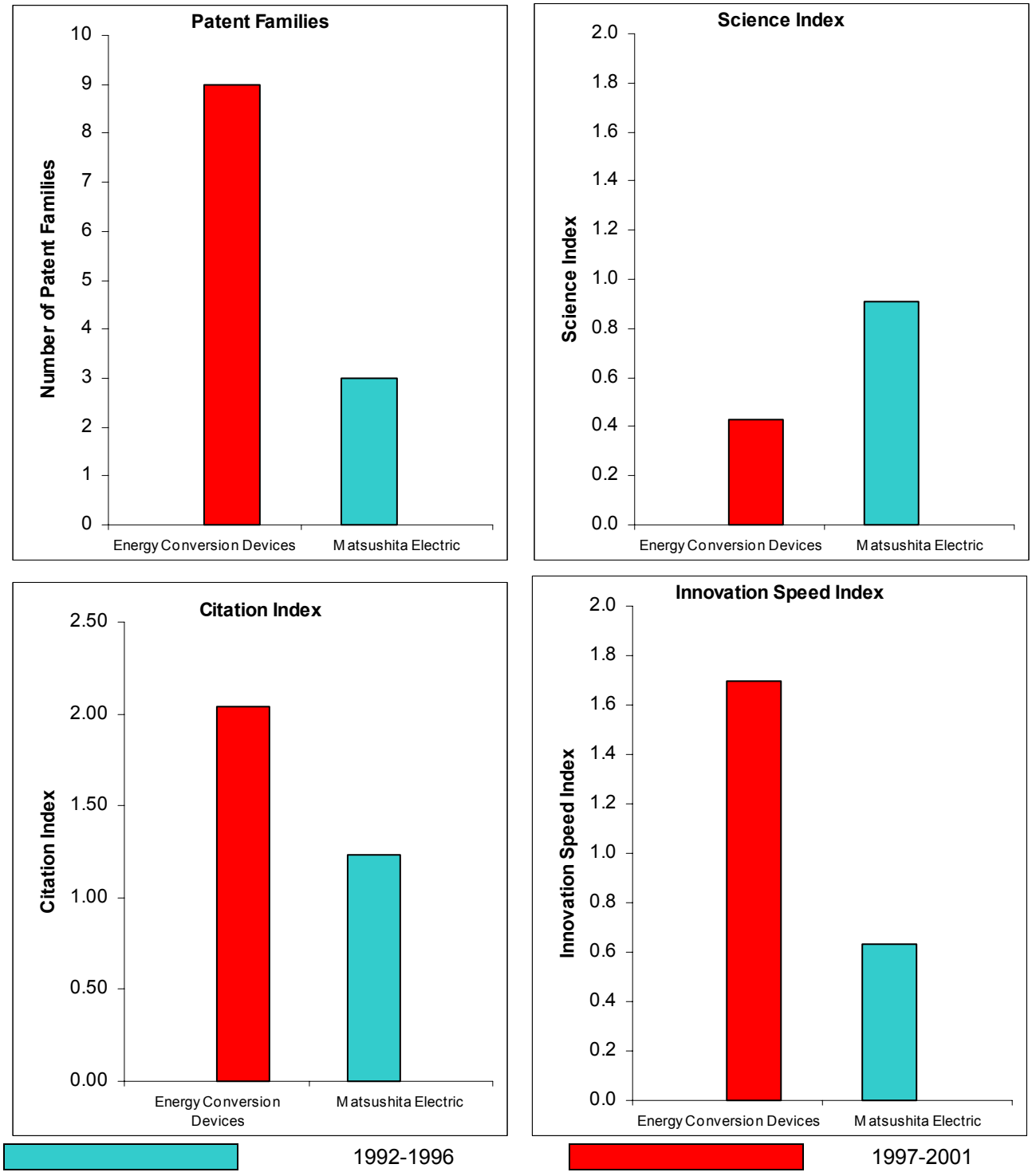


Figure 19: Patent citation indicators for ECD and Matsushita



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.

Figure 20: Emerging and Fading Companies
(Companies With Largest Increase and Decrease Among Those with 2+ Patents)

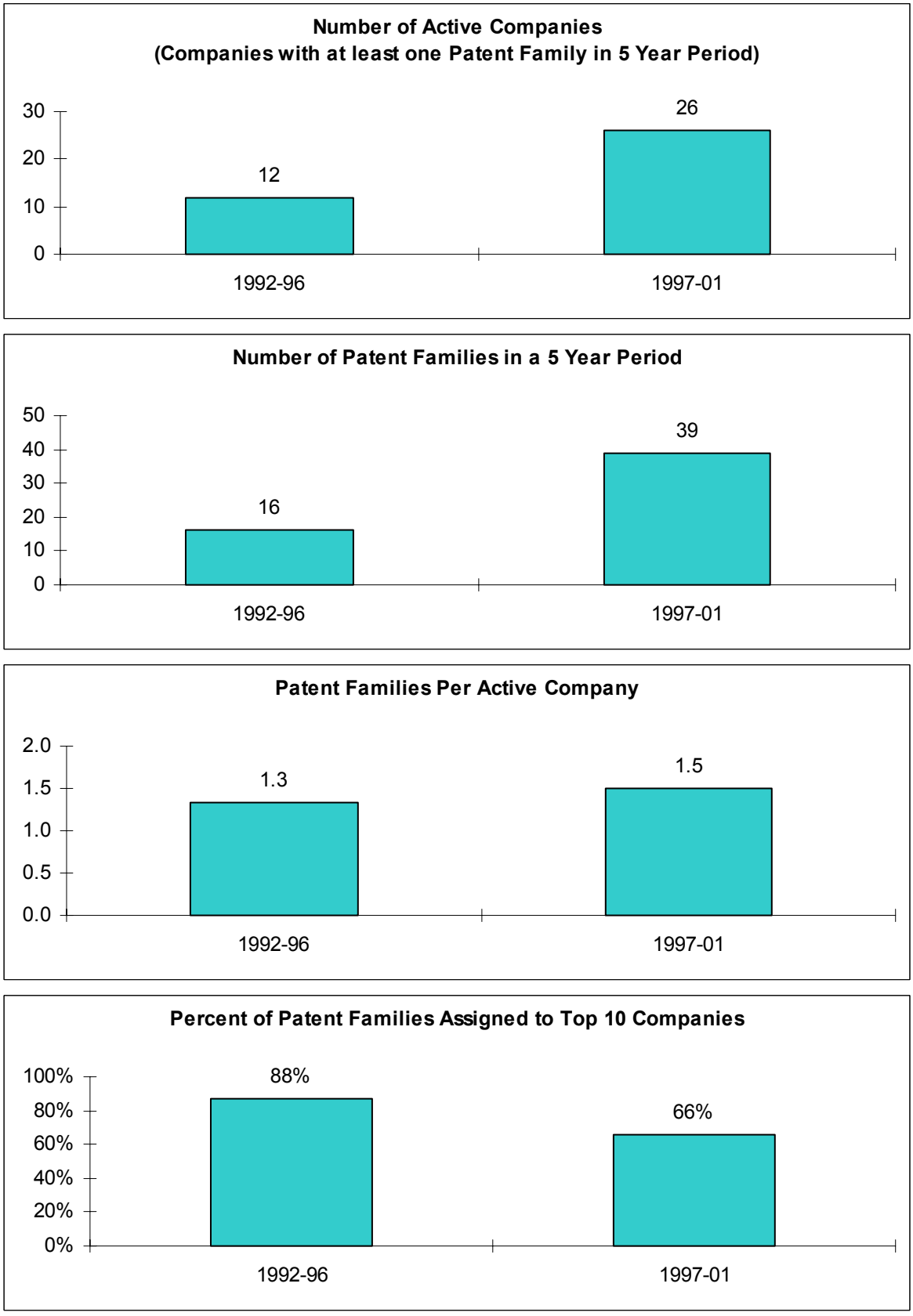
Emerging Companies	1996-1998	1999-2001	Increase	% Increase
Energy Conversion Devices Inc	2	7	5	250%
Kiyokawa Plating Industries Co Ltd	0	2	2	Infinity
Mcgill University	1	2.5	1.5	150%

Fading Companies	1996-1998	1999-2001	Decrease	%Decrease
Matsushita Electric Industrial Co Ltd	2	0	2	100%
Catalytic Material Ltd	2	0	2	100%

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 United States 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 is where the action appears to be located.

Figure 21: Life Cycle Statistics



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 nickel cadmium (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 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 1,004 patent families in this category, of which 290 come from the inclusion of EP documents, a significant 41 percent increase over the U.S.-only count.

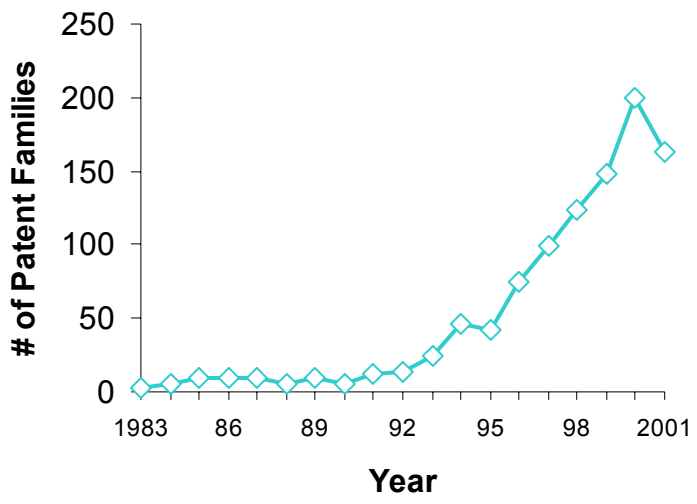
Top-cited representative patents - **Figure 22** lists the top-cited patents, led off by a Bell Communications Research (Bellcore) patent that has received 70 cites. Bellcore and Matsushita Electric both appear several times in this list.

Figure 22: Top-Cited Advanced Battery Patents

Patent	Family Number	Issue Date	Cites Rec	First Assignee	TItle
5296318	10059	3/22/94	70	BELL COMMUNICATIONS RESEARCH, INC.	Rechargeable lithium intercalation battery with hybrid polymeric electrolyte
5350645	10074	9/27/94	39	MICRON COMMUNICATIONS INC.	Polymer-lithium batteries and improved methods for manufacturing batteries
4423125	10005	12/27/83	38	LUCENT REASSIGNED FROM AT&T	Ambient temperature rechargeable battery
5187033	10041	2/16/93	38	MATSUSHITA ELECTRIC INDUSTRIAL CO. LTD	Lithium secondary battery
4616170	7	10/7/86	34	URSTOGER; RUPERT	ARRANGEMENT AND METHOD FOR OPERATING AN ELECTROCHEMICAL STORAGE DEVICE
5456000	10097	10/10/95	34	BELL COMMUNICATIONS RESEARCH, INC.	Method of making an electrolyte activatable lithium-ion rechargeable battery cell
5429890	10092	7/4/95	33	VALENCE TECHNOLOGY, INC.	Cathode-active material blends of Li+HD x+B Mn+HD 2+B O+HD 4
4550064	10010	10/29/85	30	CALIFORNIA INST. OF TECHNOLOGY	HIGH CYCLE LIFE SECONDARY LITHIUM BATTERY
5211933	10046	5/18/93	30	BELL COMMUNICATIONS RESEARCH, INC.	Method for preparation of LiCoO+HD 2 +B intercalation compound for use in secondary lithium batteries
EP0573266	68	12/8/99	29	TOSHIBA KK	Lithium secondary battery and method of manufacturing carbonaceous material for negative electrode of the battery

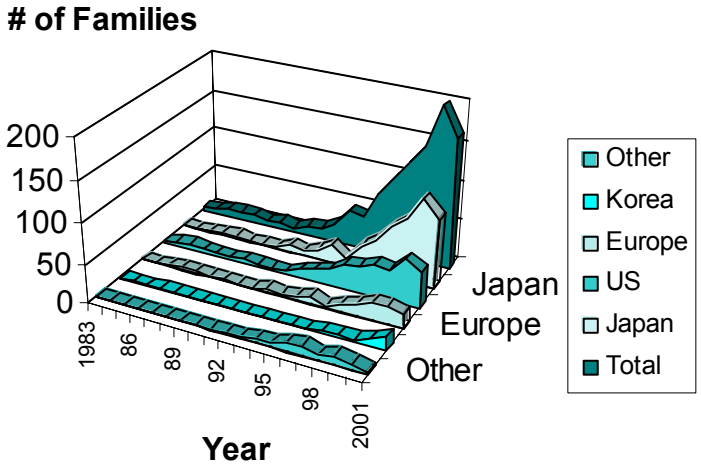
Activity - **Figure 23** clearly shows very strong growth in this area from 1996 onwards. The drop in the last year is unexplained.

Figure 23: Patent Activity



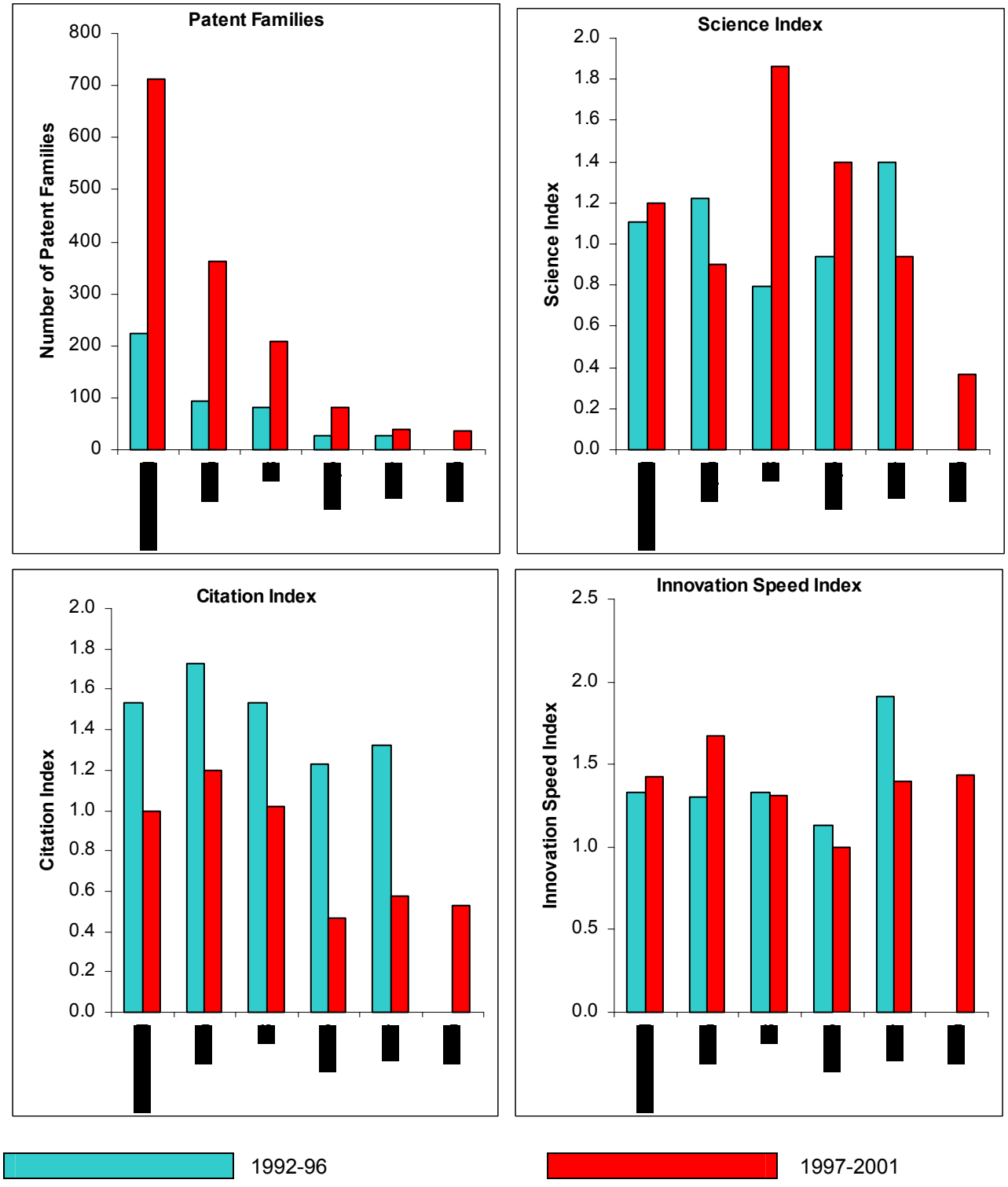
Trends by region - **Figure 24** compares regional trends for Advanced Batteries. Clearly Japan is the dominant region, with the United States second and Europe third. The drop in patenting from 2000 to 2001 shows up in the trends for all regions except Korea.

Figure 24: Regional Trends for Advanced Batteries



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

Figure 25: Regional Indicator Values



Most active companies - The companies with the most patent families in the category are ranked in descending order in **Figure 26.** Matsushita Electric Industrial is first by a wide margin with 76 families. Valence Technology with 30.5 and Science Applications International with 26 follow.[11] It is observed that seven of the top ten players are Japanese companies.

Figure 26: Companies with Most Patent Families

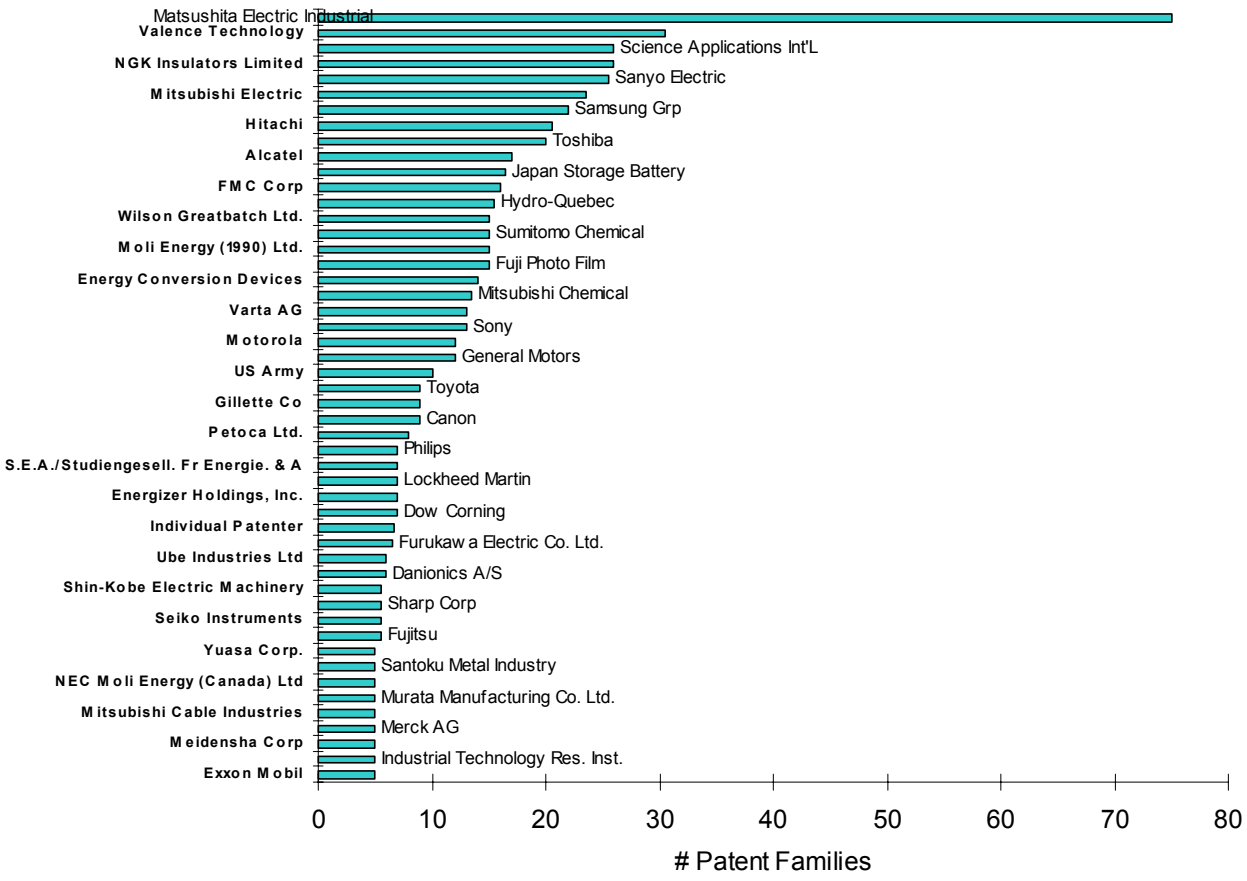
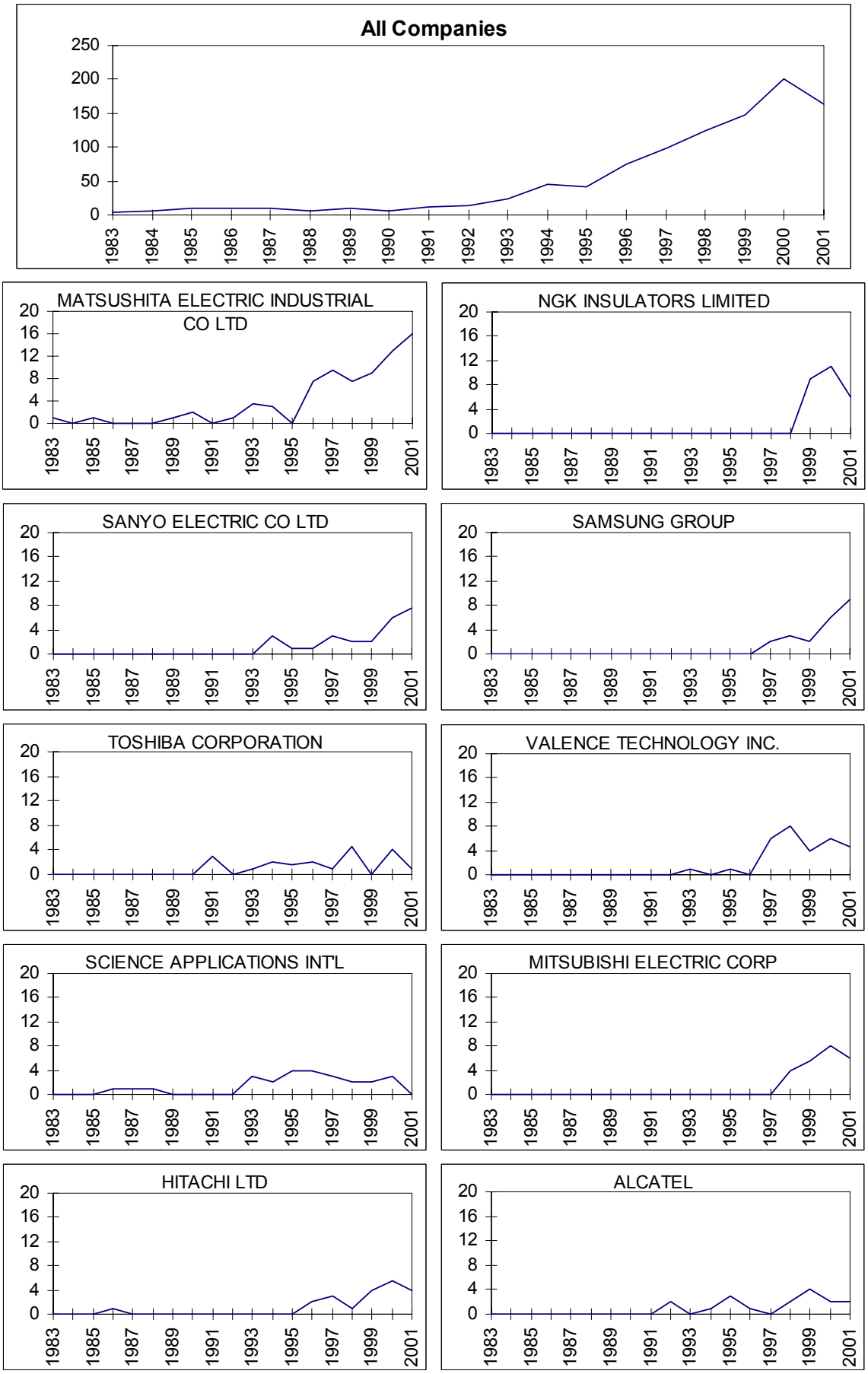


Figure 27 compares patent family trends for the top ten companies. Clearly, Matsushita is coming on strong in this area, as are a number of others such as Sanyo, Samsung, and NGK. This is definitely a growth area, and the growth is coming out of Japan.

Indicators by company - While Matsushita Electric holds by far the most patents, it is not the strongest player in terms of other indicators, 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).

[11] 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).

Figure 27: Patent Family Trends for Top Ten Companies



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 United Kingdom's Wilson 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.

Figure 26: Emerging and Fading Players
(Companies With Largest Increase and Decrease Among Those with 2+ Patents)

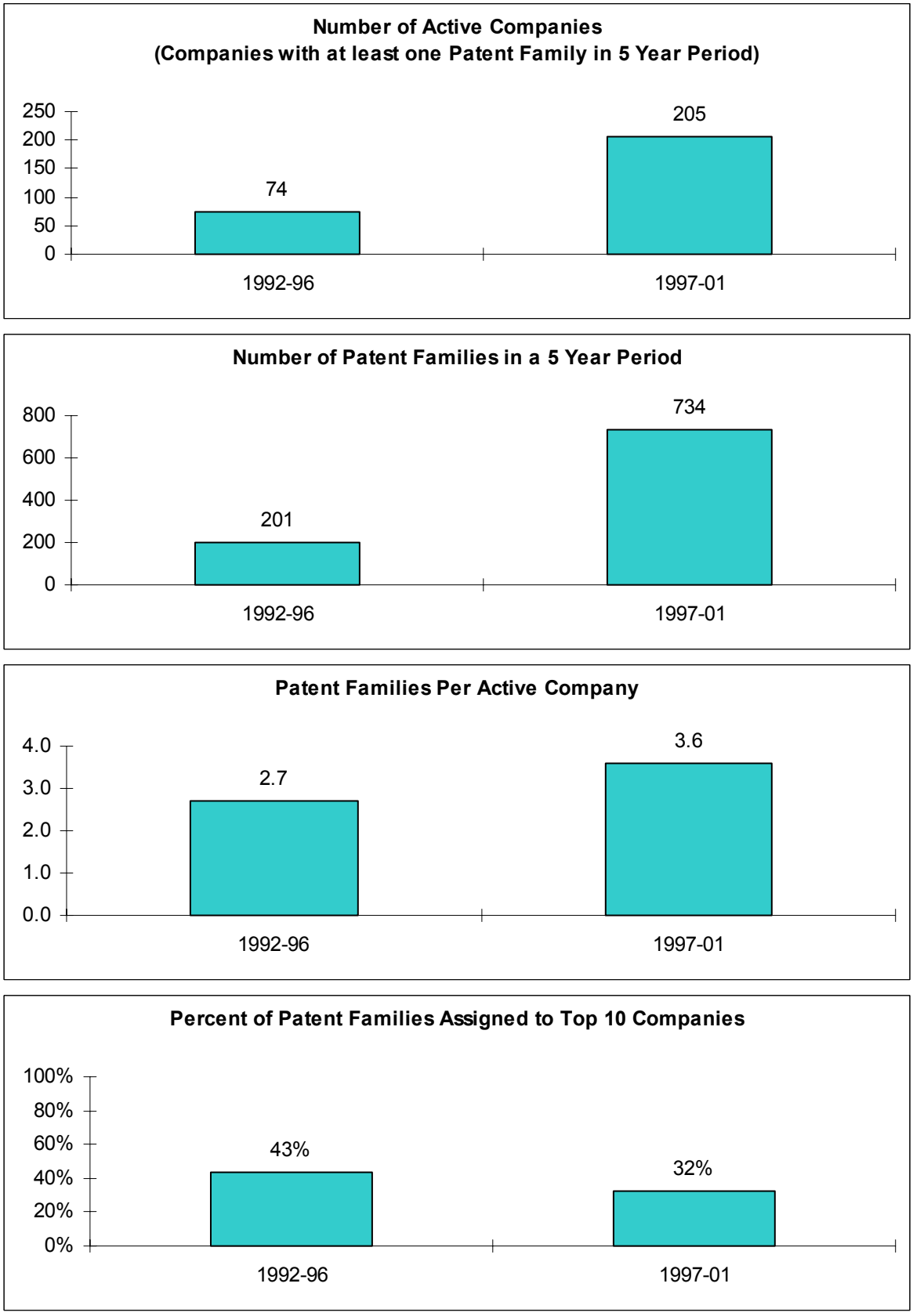
Emerging Companies	1996-1998	1999-2001	Increase	% Increase
NGK Insulators Limited	0	26	26	Infinity
Mitsubishi Electric Corp	4	19.5	15.5	388%
Matsushita Electric Industrial Co Ltd	24.5	38	13.5	55%
Wilson Greatbatch Ltd.	1	14	13	1300%
Samsung Group	5	17	12	240%
Mitsubishi Chemical Corp.	0.5	10.5	10	2000%
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
Polyplus 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

Fading Companies	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%

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.

Figure 30: Life Cycle Statistics



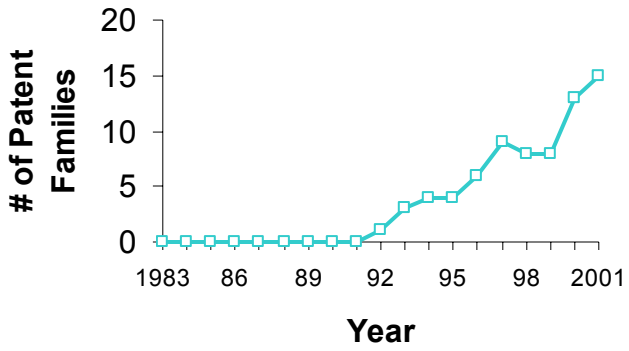
Overall Finding - The United States ranks behind Japan in Advanced Batteries, and Europe ranks well behind the United States. Matsushita Electric Industrial is the leading company, and many of the other top players are also Japanese.

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.

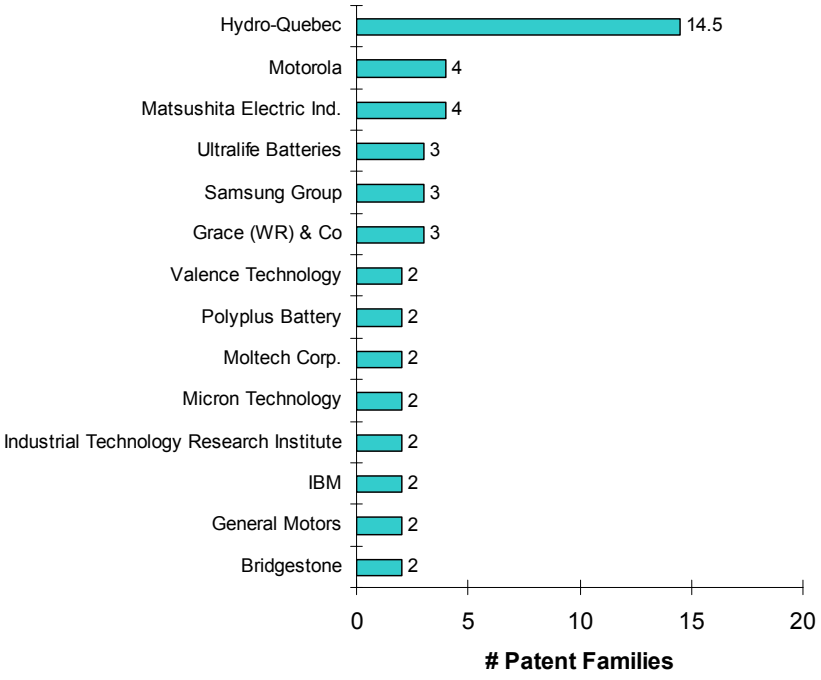
Activity - **Figure 31** shows how activity in this area has grown steadily since the first patent appears in 1992 to 15 patent families in 2001.

Figure 31: Patent Activity



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.

Figure 32: Companies with the Most Patent Families



Hybrid Electric Vehicles (HEV)

The concept of HEVs went through a period of very high interest and research but recently emphasis has shifted toward fuel cells. However, patenting activity in HEVs continues to grow. There now are HEVs on the road, and HEVs still may prove to be the viable solution, either alone or in combination with fuel cells, to the need for more energy efficient vehicles.

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.

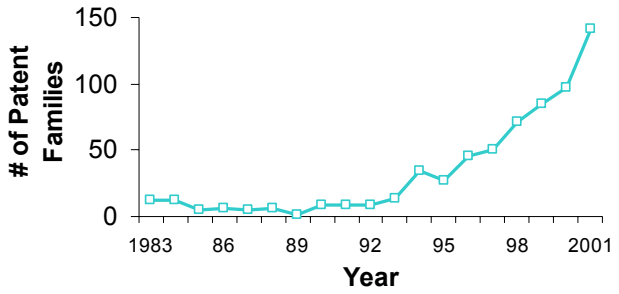
Top-cited representative patents - 636 HEV patent families were identified, of which 149 resulted from inclusion of EP data. **Figure 33** is a list of the top-cited HEV patents. It comes as no surprise that many of the big automobile companies have multiple patents in the list, including Volkswagen, General Motors, Ford, 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.

Figure 33: Top Cited HEV Patents

Patent	Family	Issue Date	# Cites	Assignee Name	Title
4533011	10027	8/6/85	80	VOLKSWAGEN WERK AG	HYBRID DRIVE FOR A VEHICLE, IN PARTICULAR AN AUTOMOBILE
5343970	10085	9/6/94	80	N/A	Hybrid electric vehicle
4544868	10028	10/1/85	70	GENERAL MOTORS CORP.	BRUSHLESS DC MOTOR CONTROLLER
5172784	10054	12/22/92	59	N/A	Hybrid electric propulsion system
5318142	10074	6/7/94	54	FORD MOTOR CO.	Hybrid drive system
4588040	10034	5/13/86	42	N/A	HYBRID POWER SYSTEM FOR DRIVING A MOTOR VEHICLE
5327987	10081	7/12/94	40	N/A	High efficiency hybrid car with gasoline engine, and electric battery powered motor
4962969	7	10/16/90	39	FORD MOTOR CO.	ADAPTIVE CONTROLLER FOR REGENERATIVE AND FRICTION BRAKING SYSTEM
4671577	10036	6/9/87	36	UTDC INC.	COMBINED REGENERATIVE AND FRICTION BRAKING SYSTEM FOR A VEHICLE
4470476	10022	9/11/84	34	N/A	Hybrid vehicles

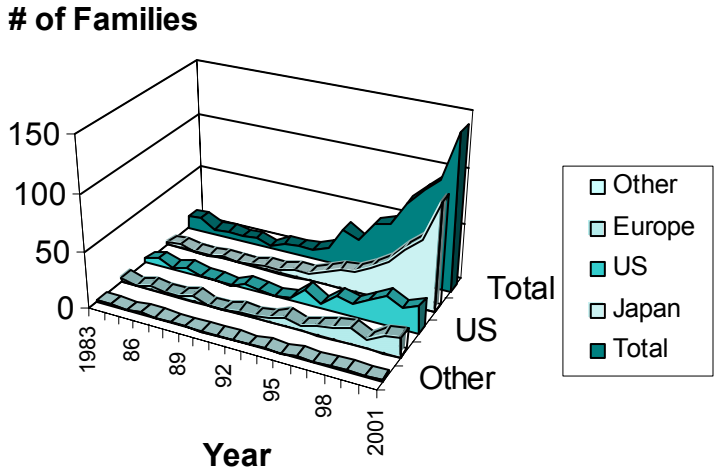
Activity - **Figure 34** shows this area is also one of rapid and substantial growth since the mid 1990s, going from 30 patent families in 1995 to 100 in 2000 and 140 in 2001.

Figure 34: HEV Patent Activity



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

Figure 35: Trends by Regions



Indicators by region - Regional indicators are compared in **Figure 36** (see next page). If we disregard the indicators for the Other region (it has less than ten patent families), then Japanese HEV patents are 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 at number one and then 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.

Figure 37: Most Active Companies

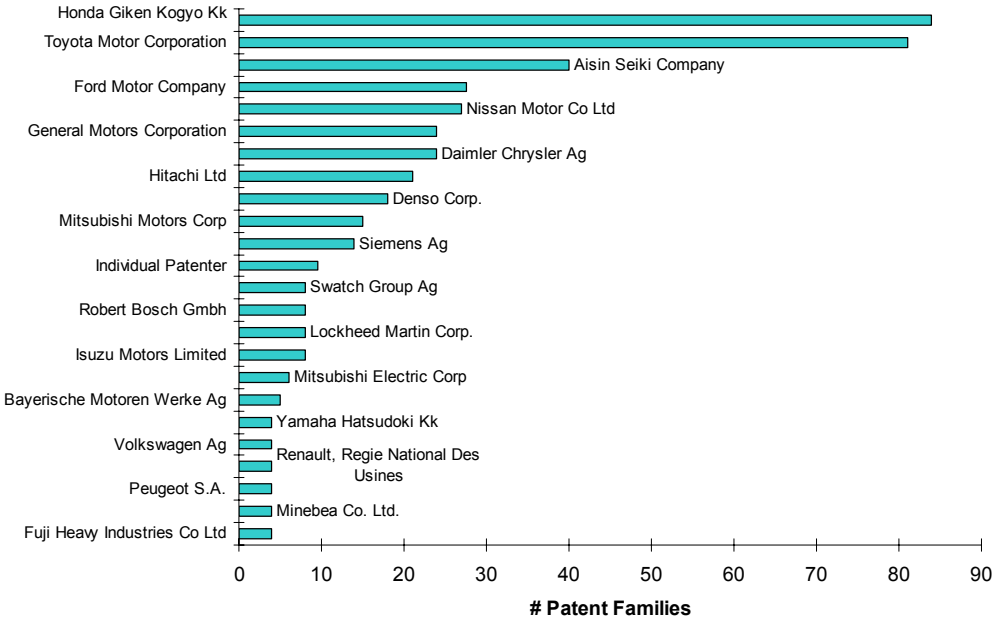
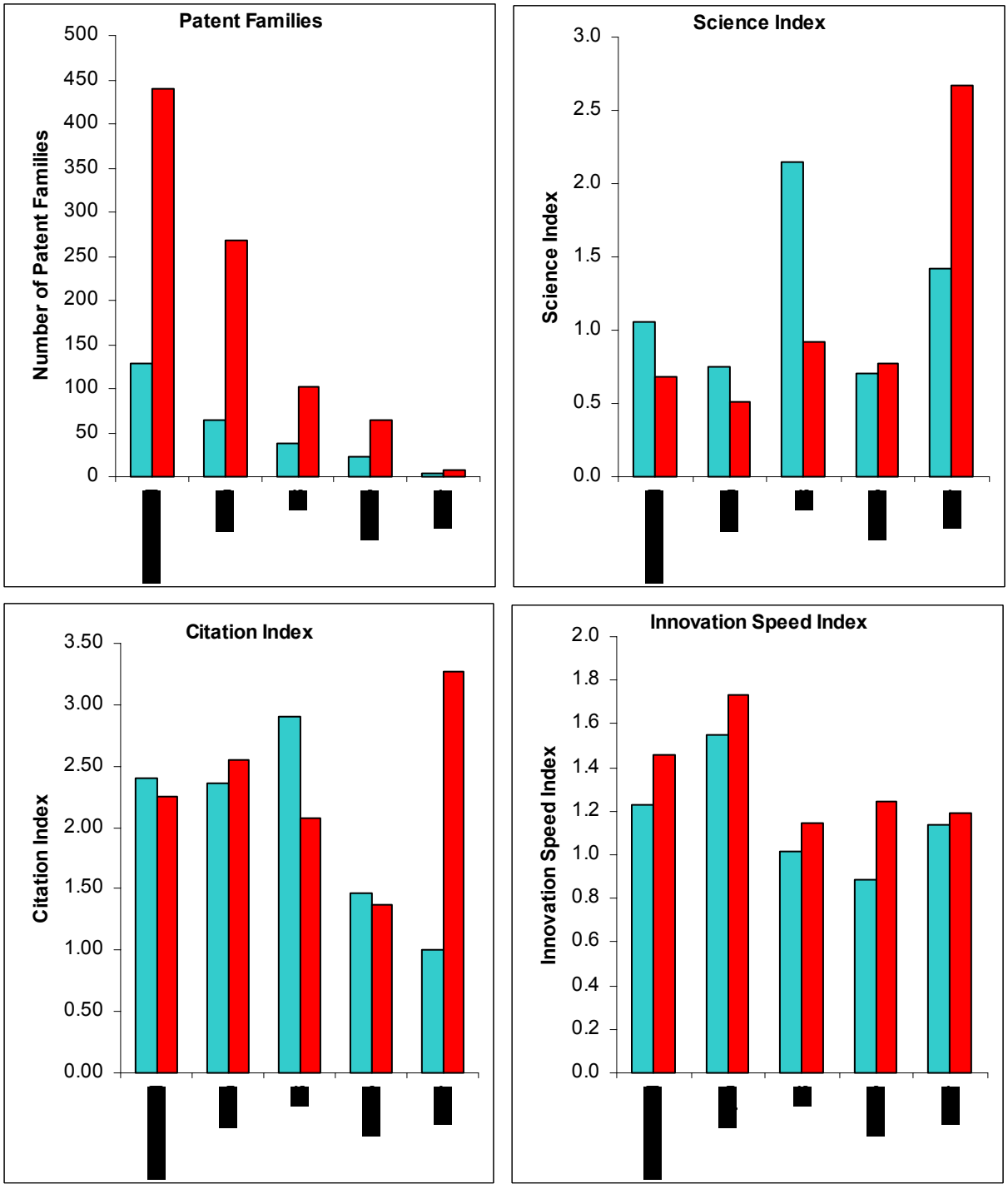
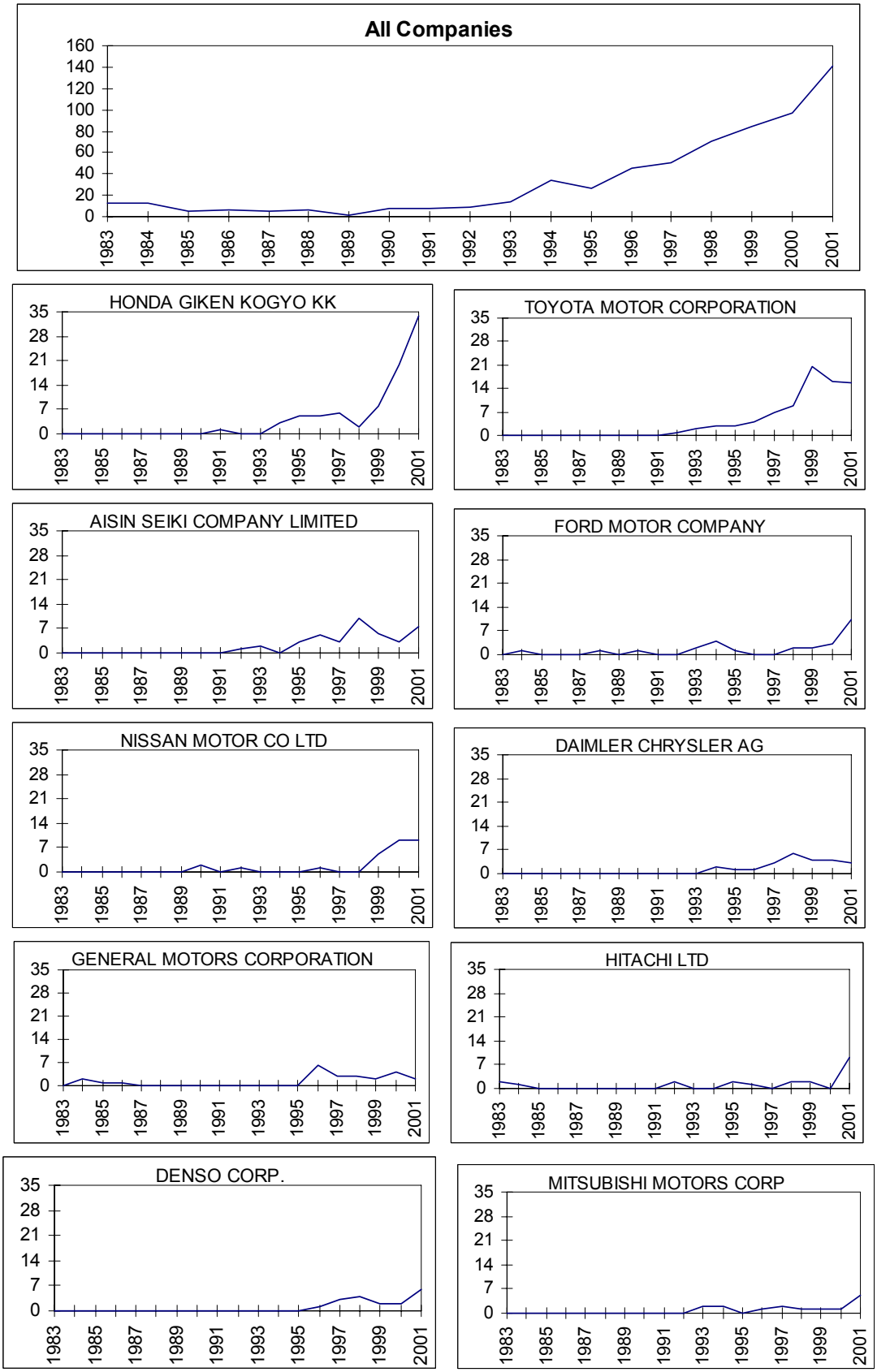


Figure 36: Indicators by Region



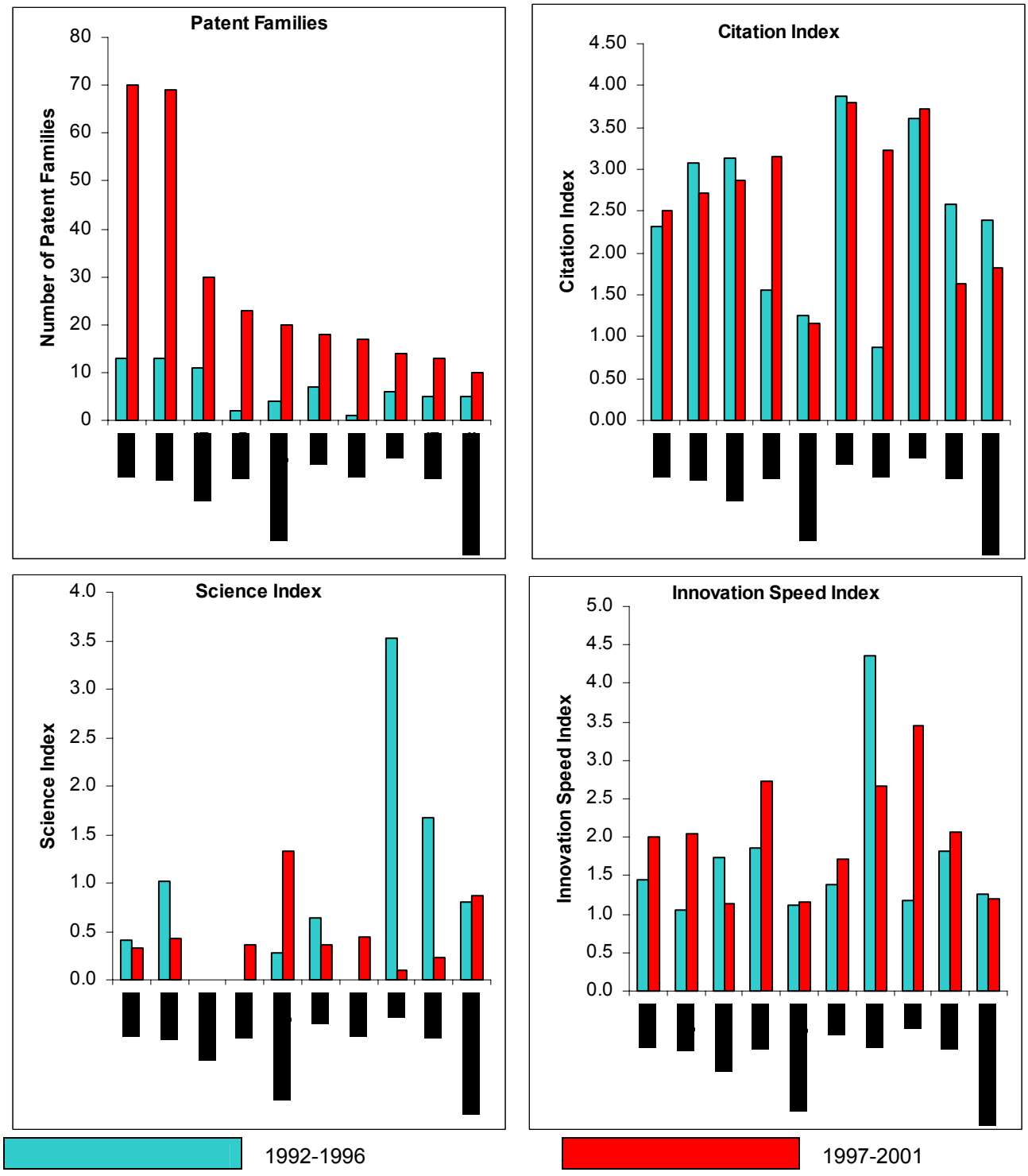
As is shown in **Figure 38,** Honda is the patent invention machine driving the high growth in HEV patenting, with Toyota ranking next but not coming on nearly as strong in recent years.

Figure 38: Highest Growth in HEV Patenting



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 DaimlerChrysler, Hitachi and Mitsubishi Motors are less highly cited. Innovation Speed rankings are General Motors first, Nissan second, Toyota, Honda and Hitachi third and, again, DaimlerChrysler and Mitsubishi Motors rank well below the others.

Figure 39: Patent Indicator Values by Company



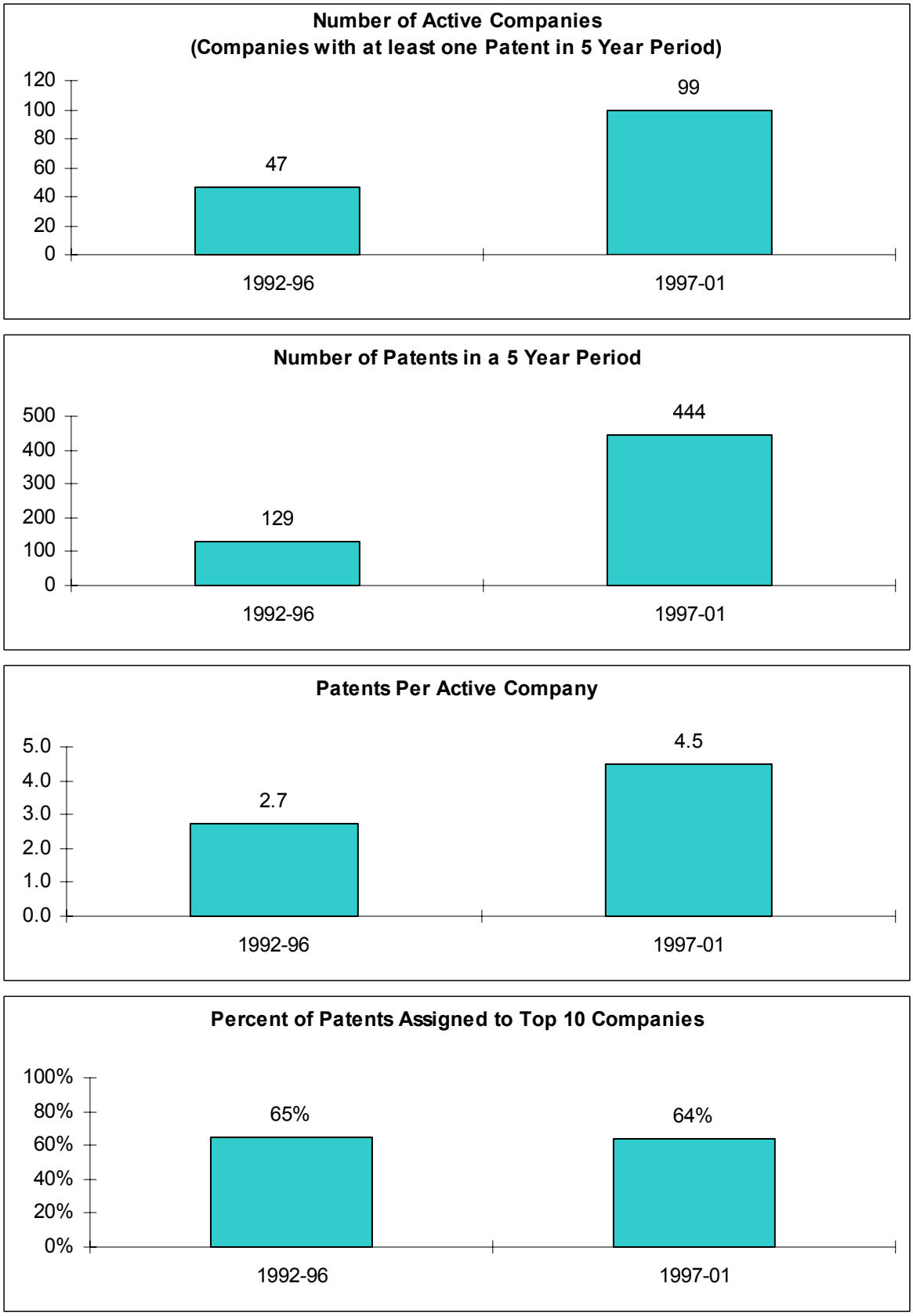
Emerging and fading companies - Among the emerging and fading data in **Figure 40**, the most noticeable fact is that, at least in terms of patenting, General Motors appears to be leaving the field.

Figure 40: Emerging and Fading Companies
(Companies With Largest Increase and Decrease Among Those with 2+ Patents)

Emerging Companies	1996-1998	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	**1996-1998**	**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%

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.

Figure 41: Life Cycle Statistics



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

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, warm-forming, and hydro-forming.

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 1,230 of the families, expanding the U.S.-only set by 40 percent. The identified patent set for this category is the most diverse of any of the categories. The patents are for materials compositions and manufacturing methods, as well as applications.

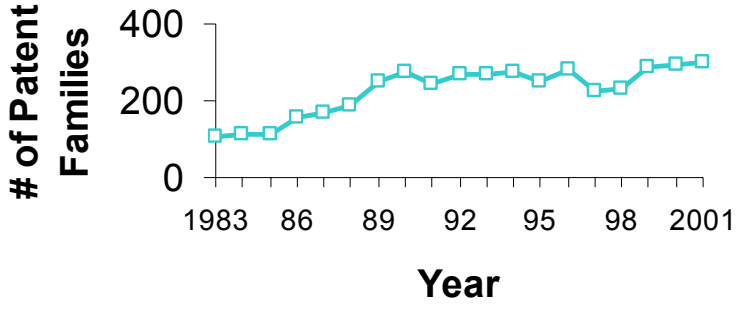
Top-cited representative patents – Among the top-cited patents listed in **Figure 42**, many are for carbon composites, carbon fiber reinforced materials, and their applications. Others are for ceramics, and are largely applicable to automotive applications. The most highly cited patent is for a shaped 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.

Figure 42: Top Cited Lightweight Materials Patents

Patent	Family Number	Issue Date	Cites Rec.	Assignee Name	Title
04588443	10207	5/13/1986	102	AALBORG PORTLAND-CEMENT-FABRIK, A/S	SHAPED ARTICLE AND COMPOSITE MATERIAL AND METHOD FOR PRODUCING SAME
04605440	2050	8/12/1986	87	UNIV CALIFORNIA	BORON-CARBIDE-ALUMINUM AND BORON-CARBIDE -REACTIVE METAL CERMETS
04376803	10005	3/15/1983	86	AEROSPACE CORP., THE	Carbon-reinforced metal-matrix composites
04570316	10194	2/18/1986	81	NIPPON PISTON RING CO., LTD.	METHOD FOR MANUFACTURING A ROTOR FOR A ROTARY FLUID PUMP
04376804	10006	3/15/1983	79	AEROSPACE CORP., THE	Pyrolyzed pitch coatings for carbon fiber
04404262	10039	9/13/1983	73	INTERNATIONAL HARVESTER CO.	Composite metallic and refractory article and method of manufacturing the article
E0340957	12663	3/16/1994	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	1/12/1988	67	UNIV CALIFORNIA, REGENTS	Infiltration processing of boron carbide-, boron-, and boride-reactive metal cermets
04700823	10339	10/20/1987	66	EATON CORP.	Clutch with pyrolytic carbon friction material
E0364963	2376	12/28/1994	60	CHRYSLER MOTORS CORP.	A method of producing a ceramic reinforced composite automotive component.

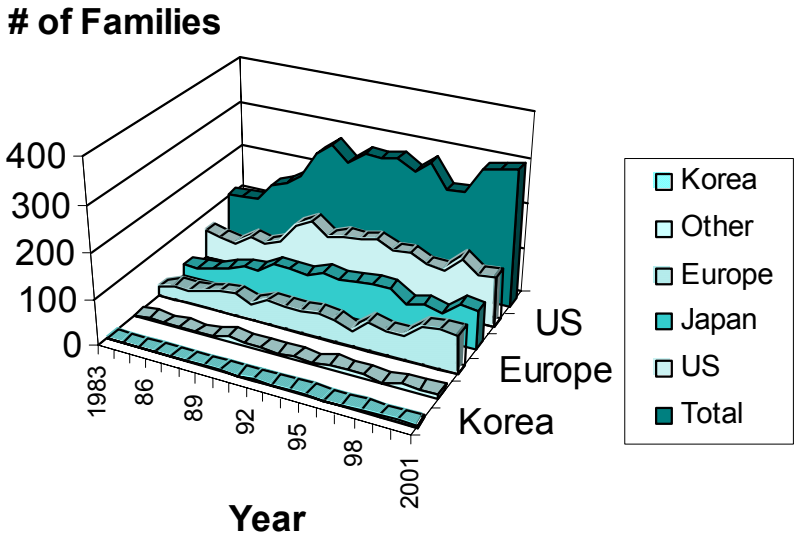
Activity - Unlike every other category in this study, the patent family activity trend for Lightweight Materials, shown in **Figure 43**, has been relatively flat since the mid-1990s. No doubt, this is not the case at some detailed level, where, for example, one would assume that metal matrix and nanotechnology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

Figure 43: Patent Family Activity in Lightweight Materials



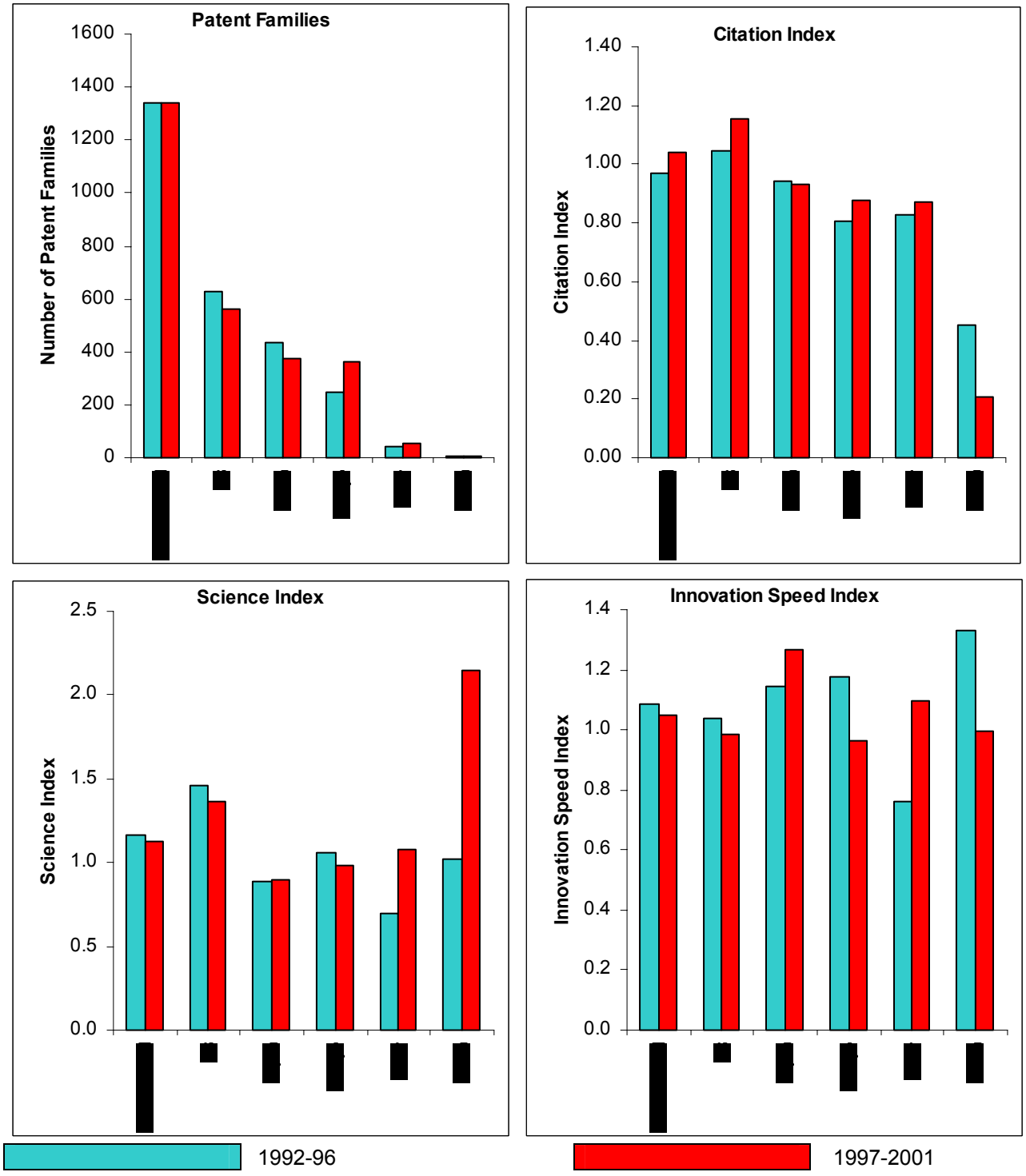
Trends by region - As is shown in **Figure 44**, among all the categories, this is the only one where Europe is growing while the United States and Japan are declining.

Figure 44: Trends by Region



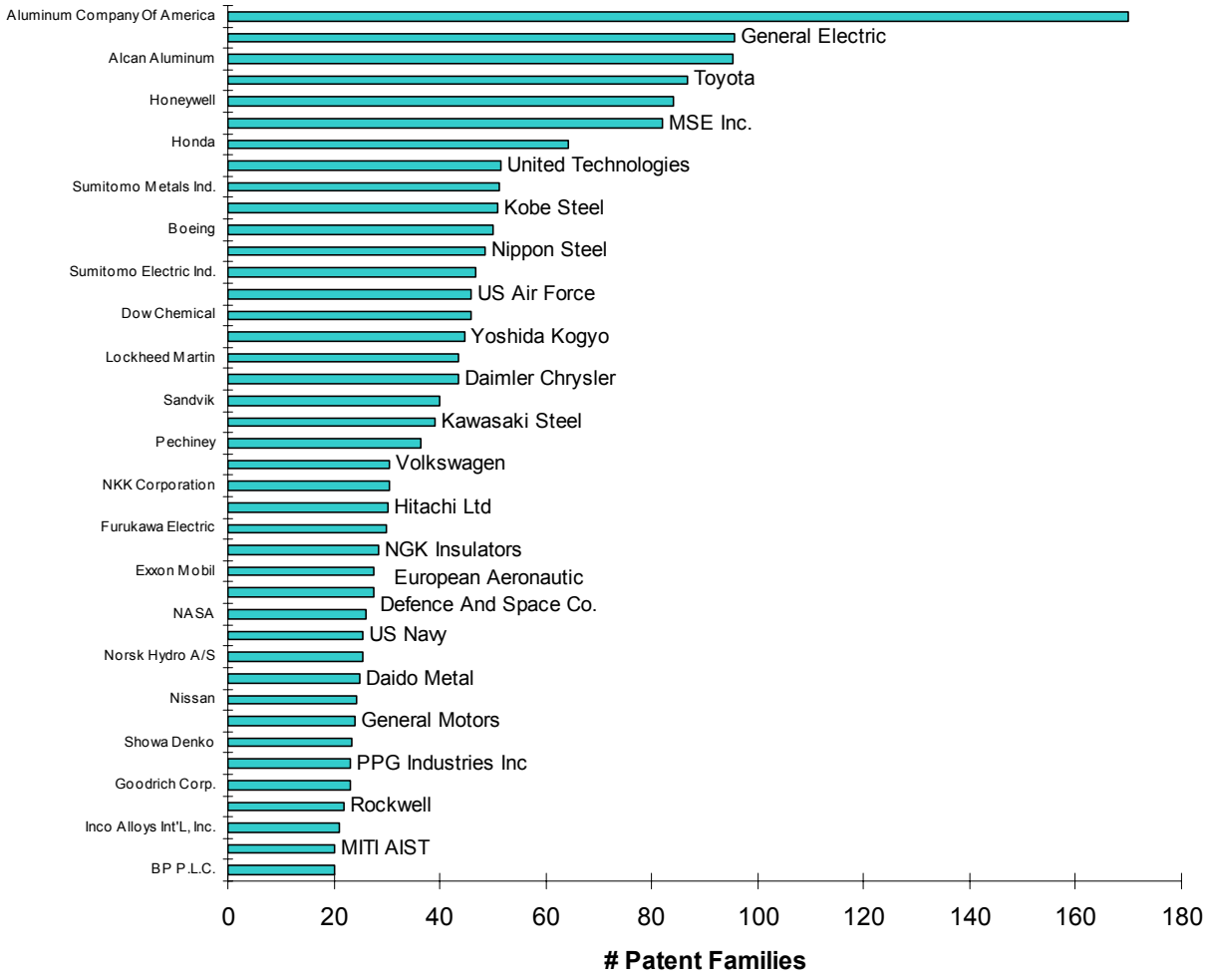
Indicators by region - **Figure 45** compares the regional indicators. Korea's set is so tiny its indicator values are not meaningful. Citation Index values are highest for the U.S. patent families, second highest for Japan's and lower for Europe. The United States has the highest Science Index value,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

Figure 45: Indicators by Region



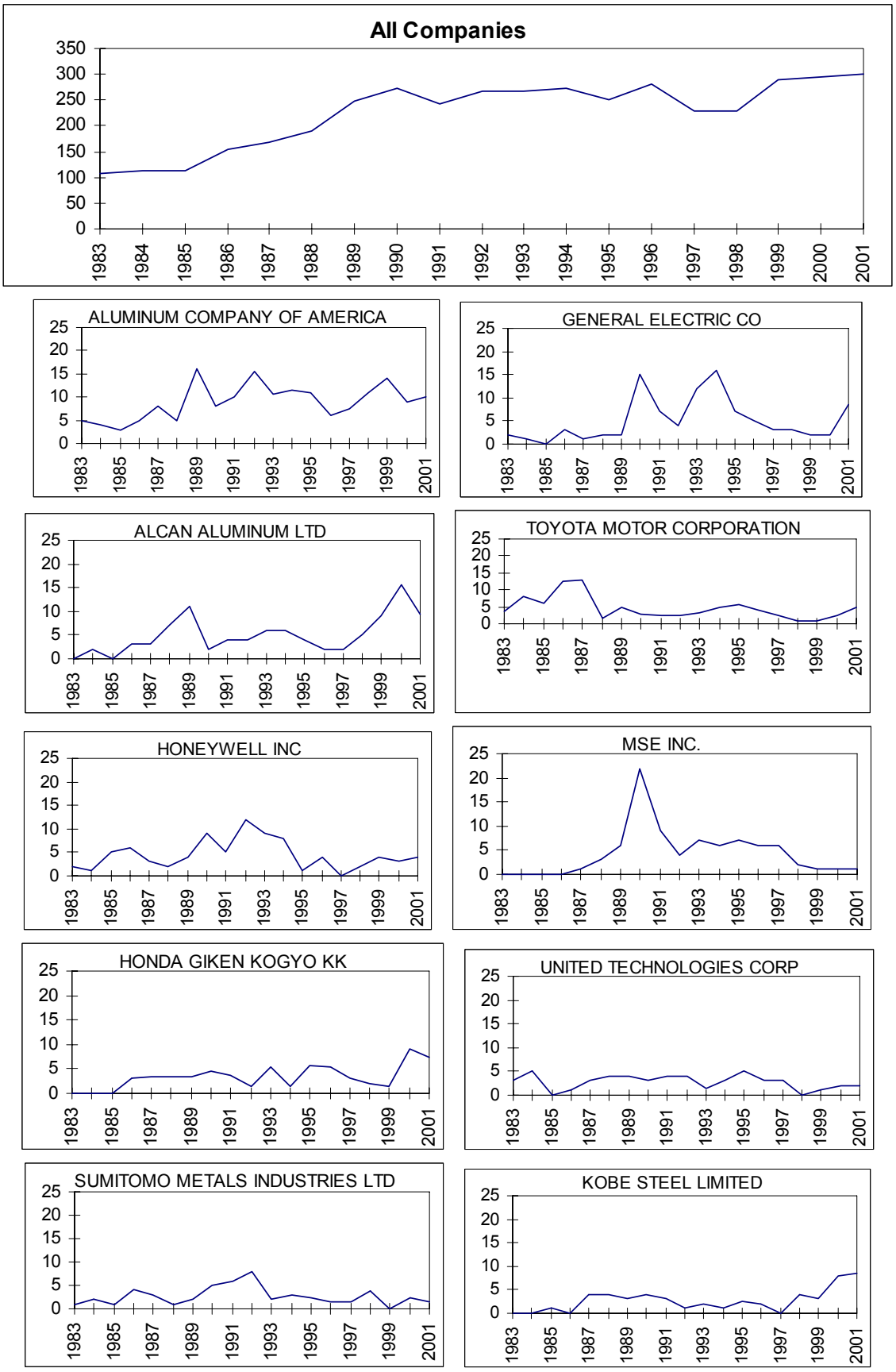
Most active companies - As shown in **Figure 46**, Alcoa has the most Lightweight Materials patent families, nearly twice as many as second place players, General Electric and Alcan. Automotive manufacturers rank fairly far up in the list; Toyota is fourth and Honda seventh.

Figure 46: Most Active Companies



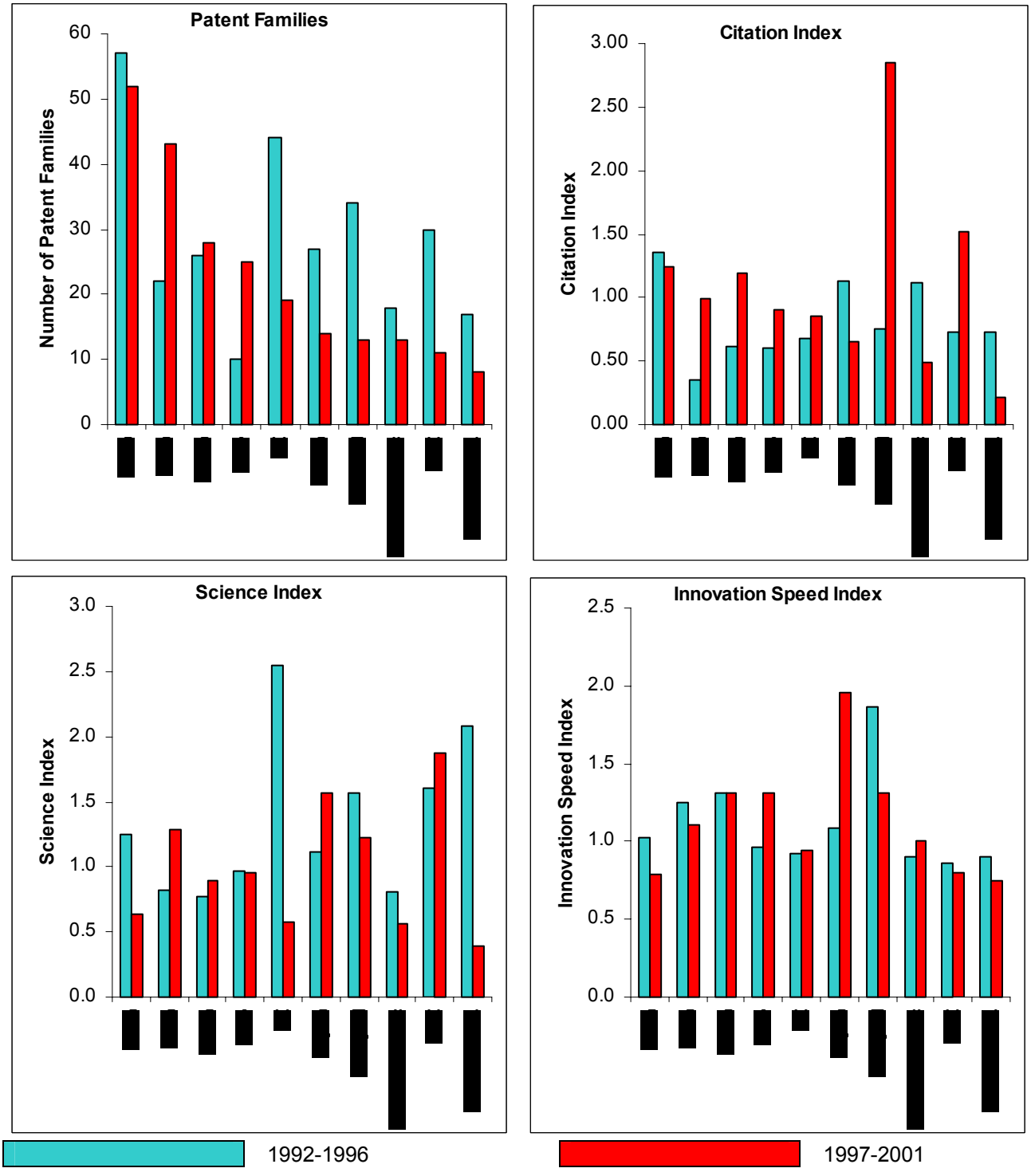
Patent family trends for the top 10 companies are shown in **Figure 47** (see next page). Almost all reflect the overall flat activity picture of this category, or even declining activity, with the possible exception of a few such as Kobe Steel.

Figure 47: Patent Family Trends



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.

Figure 48: Indicators by Company



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 are MSE Inc., Eastman Kodak, and IBM.

Figure 49: Emerging and Fading Companies
(Companies With Largest Increase and Decrease Among Those with 2+ Patents)

Emerging Companies	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%

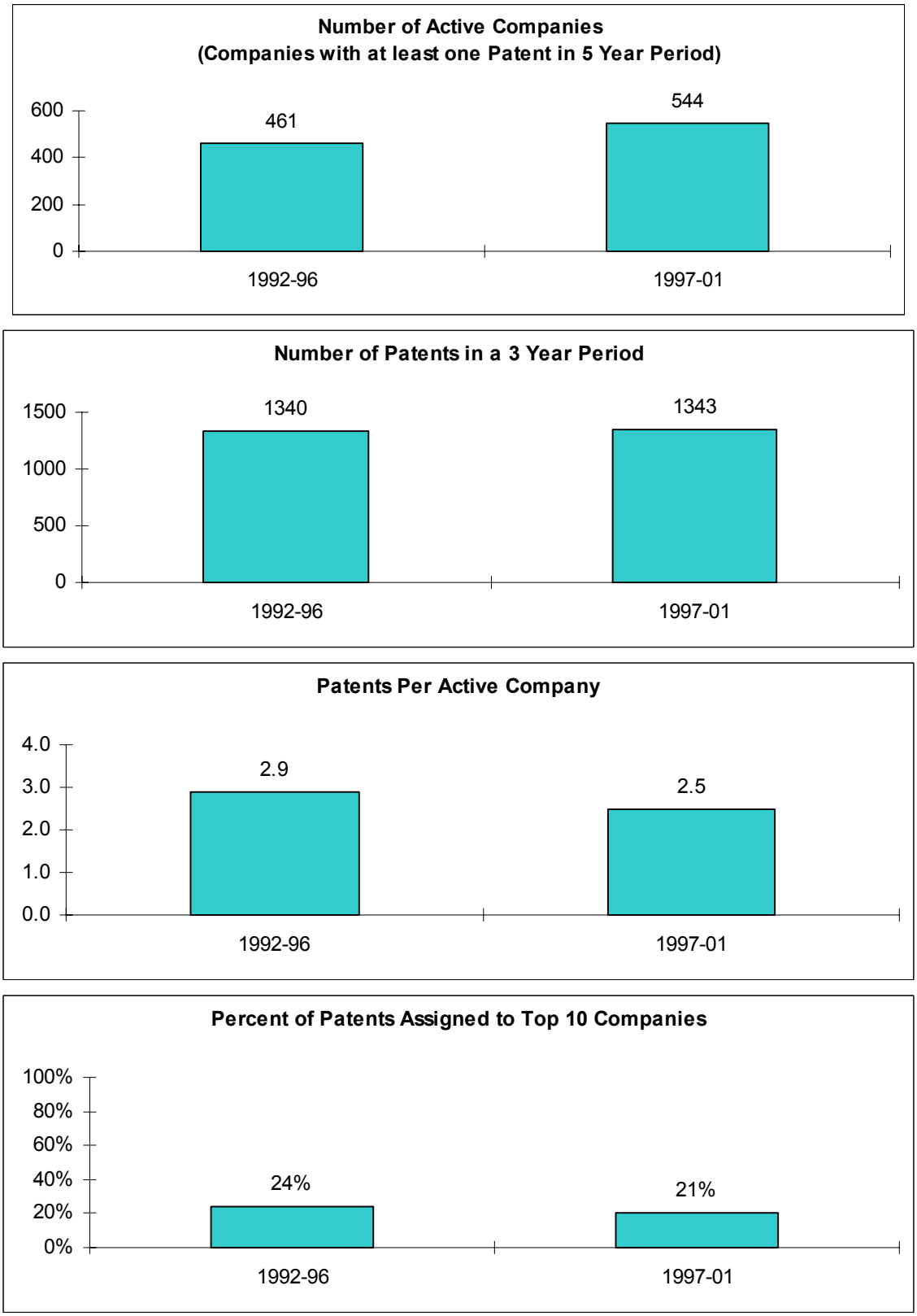
Dowa Mining Co. Ltd.	1	3	2	200%
MAN Ag	0	2	2	Infinity
Mitsui Mining And Smelting Co. Ltd.	0	2	2	Infinity
University Of Connecticut	0	2	2	Infinity
Teleflex Inc.	0	2	2	Infinity
Koyo Seiko Co. Ltd.	0	2	2	Infinity
Materials Innovation Inc	0	2	2	Infinity
Daiki Aluminium Kogyosho	0	2	2	Infinity
Honsel Gmbh & 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
Memry 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%

Fading Companies	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%

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.

Figure 50: Life Cycle Statistics



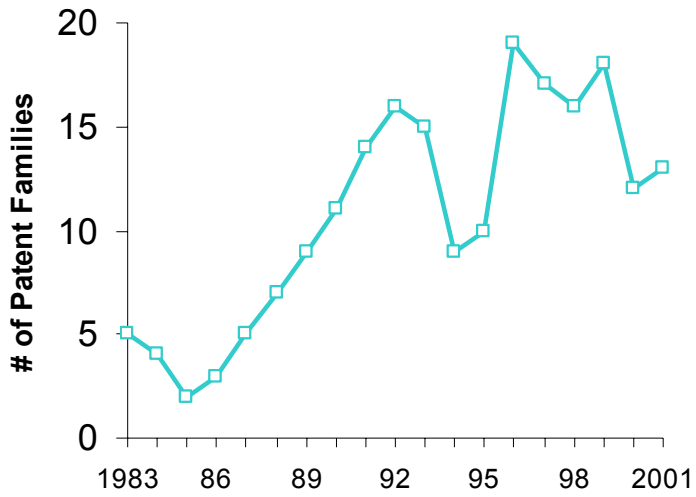
Overall Finding - As it has been defined, the whole of lightweight materials is not growing; offsetting growth in activity in Europe are declines for the United States and Japan. Still, it is mostly U.S. and Japanese companies that top the list of most active players. Only when we look at a sub-area 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 reinforc*.

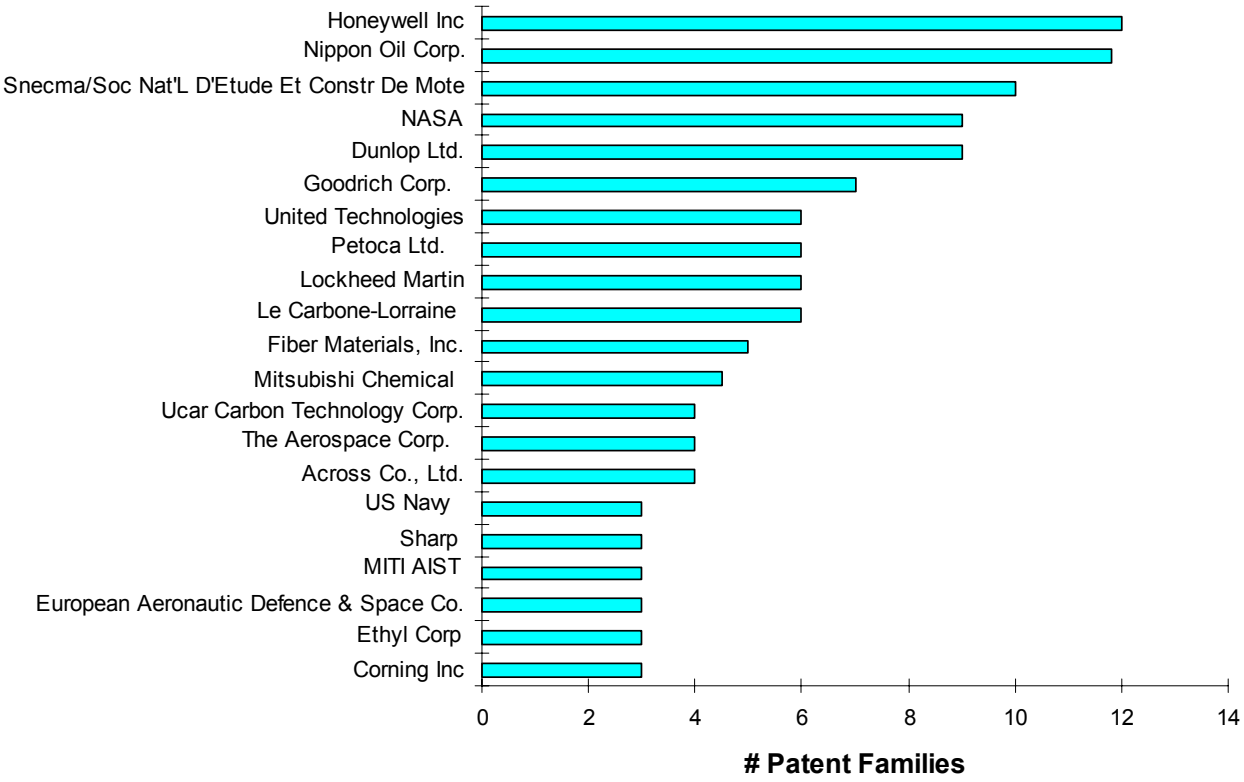
Activity - The upward trend in carbon composite patent families is evident in **Figure 51.** Having said that, it must be recognized that there are only about 15 new patent families per year over the last 5 years. Thus, the resulting set is quite small. While one would think this is a very hot area of 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.

Figure 51: Activity in Carbon Composite Patent Families



Most active companies - The companies the most carbon composite patent families are shown in **Figure 52.** The United States, 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.

Figure 53: Most Active Companies



Ultracapacitors

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

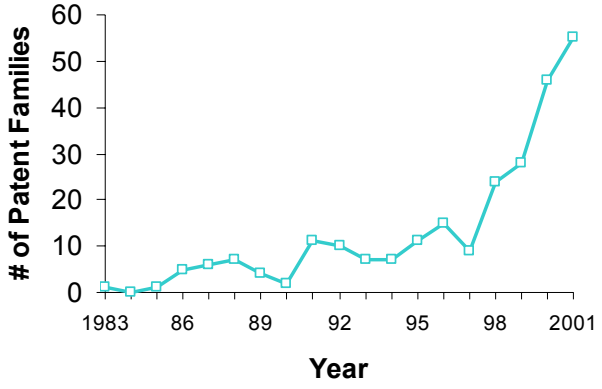
Top-cited representative patents - This category is one of the smaller ones in terms of total patent family counts, and is made up of 249 families (38 result from adding in EP documents). The top-cited Ultracapacitor patents are listed in **Figure 53.** Matsushita Electric Industrial holds the most highly cited patent in the list as well as a number of other patents there.[12] This area is relatively new and small, and the cite counts are also relatively low compared to other categories.

Figure 53: Top-Cited Representative Ultracapacitor Patents

Patent	Family Number	Issue Date	Cites Rec	First Assignee	Title
5150283	10027	9/22/92	38	MATSUSHITA ELECTRIC	Electric double layer capacitor and method for producing the same
5260855	10036	11/9/93	36	N/A	Supercapacitors based on carbon foams
4562511	10002	12/31/85	26	MATSUSHITA ELECTRIC	ELECTRIC DOUBLE LAYER CAPACITOR
5345154	10039	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 mode
4737889	10011	4/12/88	24	MATSUSHITA ELECTRIC	Polarizable electrode body and method for its making
4597028	10003	6/24/86	21	MATSUSHITA ELECTRIC	ELECTRIC DOUBLE LAYER CAPACITOR AND METHOD FOR PRODUCING THE SAME
5621607	44	4/15/97	19	MAXWELL LABORATORIES	High performance double layer capacitors including aluminum carbon composite electrodes
5682288	62	10/28/97	18	JAPAN GORE-TEX, INC.	Electric double-layer capacitor and method for making the same
4810599	17	3/7/89	17	JAPAN SYNTHETIC RUBBER	STRUCTURE SUITABLE FOR SOLID ELECTROCHEMICAL ELEMENTS
5172307	10030	12/15/92	17	NEC CORP.	Activated carbon/polyacene composite and process for producing the same

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.

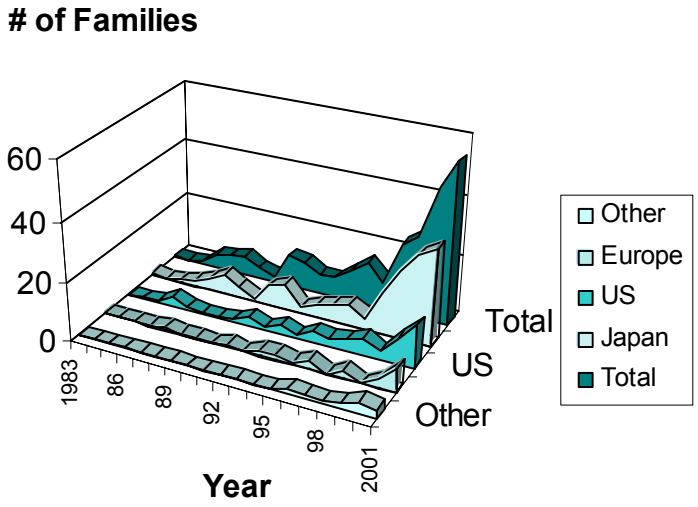
Figure 54: Ultracapacitor Patent Activity



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

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

Figure 55: Trends by Regions



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

Figure 56A: Indicators by Region

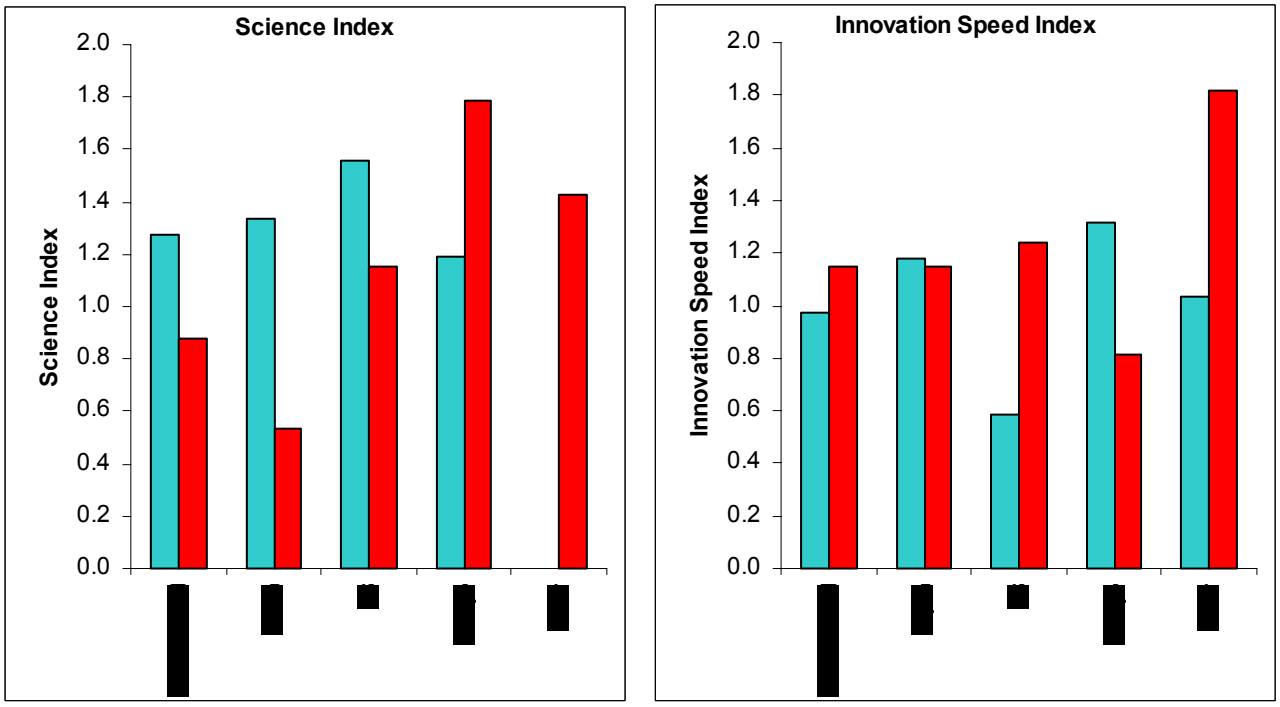
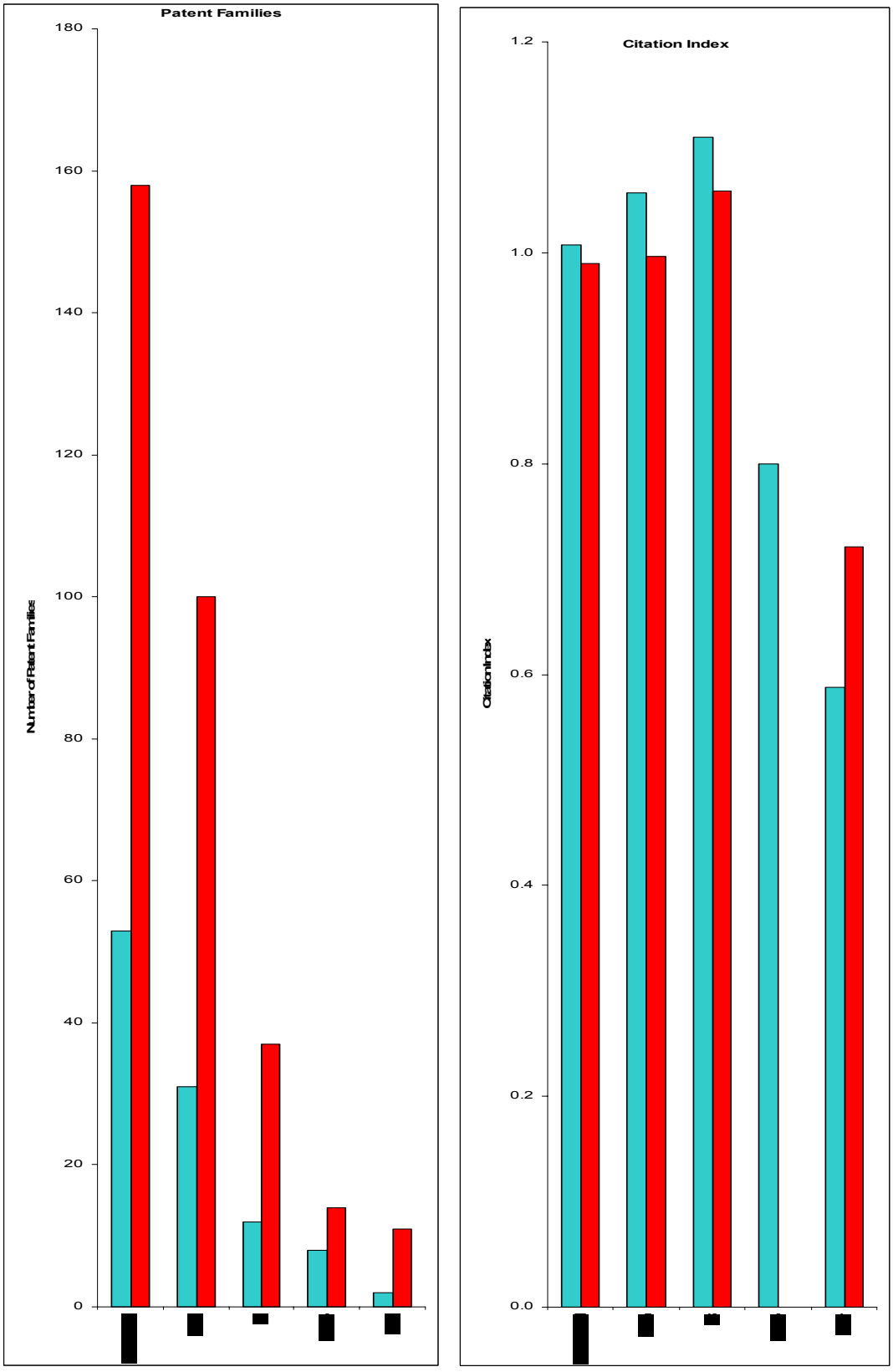
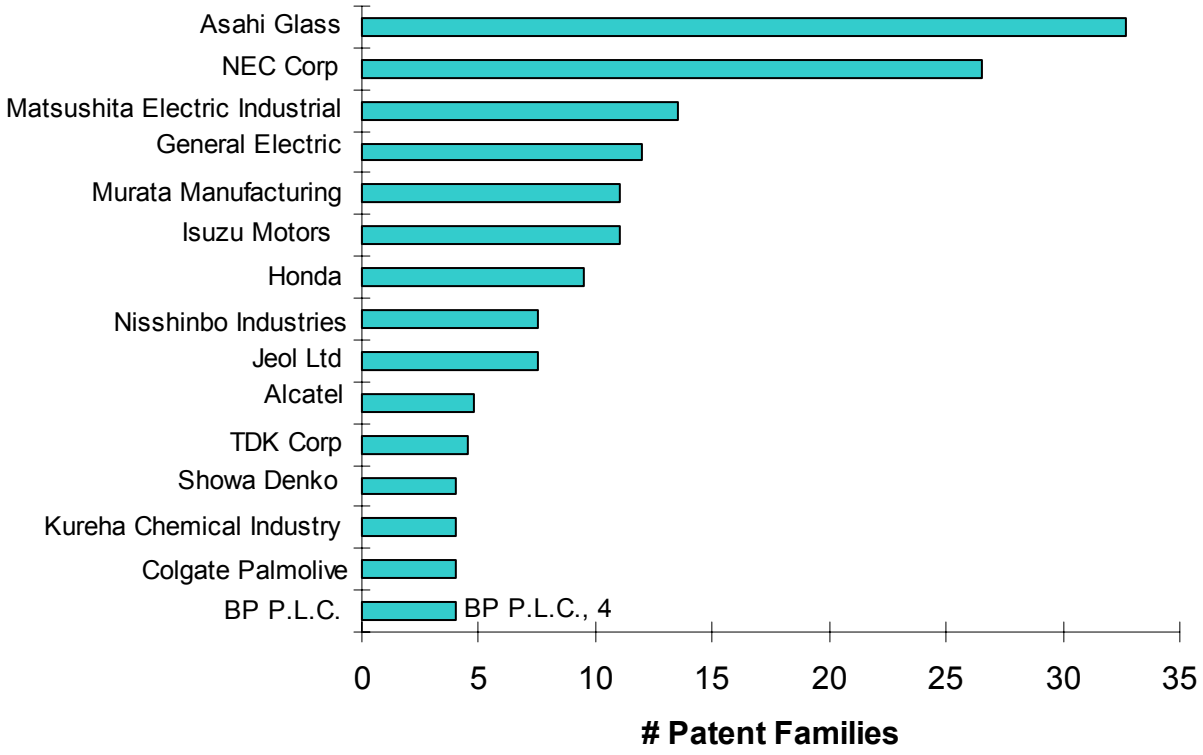


Figure 56B: Indicators by Region



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.

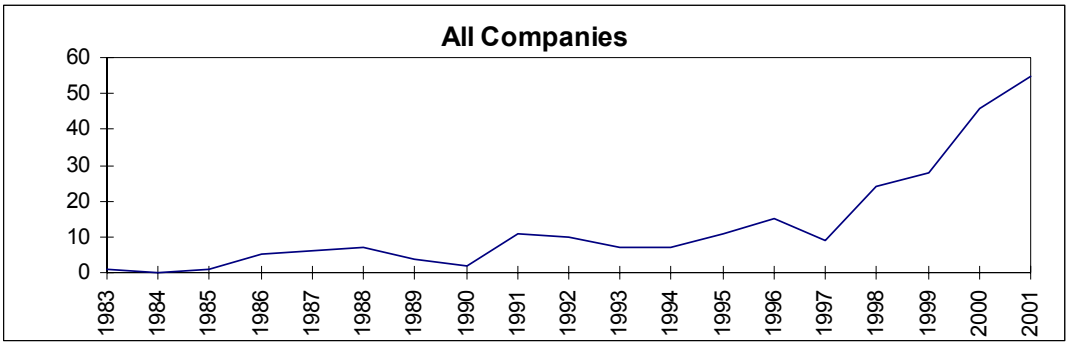
Figure 57: Most Active Companies

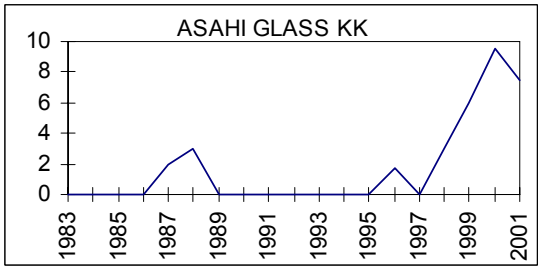


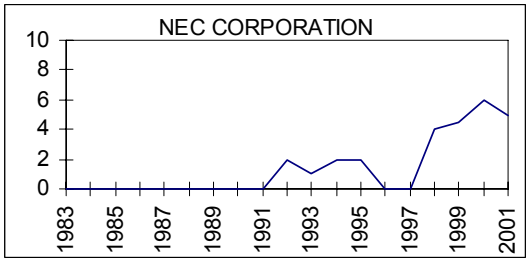
But, as we see in the trend comparisons in **Figure 58**, top-10 companies such as Alcatel and Isuzu are not taking part in the current growth (see next page). The active and growing players are mainly Asahi Glass, NEC, Honda and General Electric (GE).

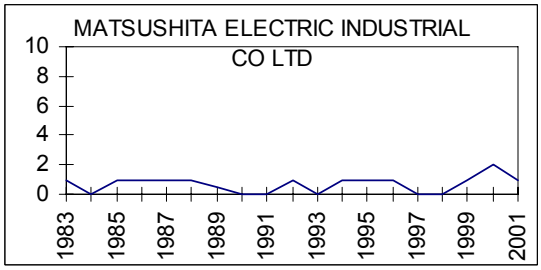
Indicators by company - Company indicators are compared in **Figure 59.** It would be nice if we could make much of GE's very high Citation Index value for 1992-1996, but this is for just a single patent (which happens to be very highly science linked)! Just the same, GE is definitely a growth player, 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.

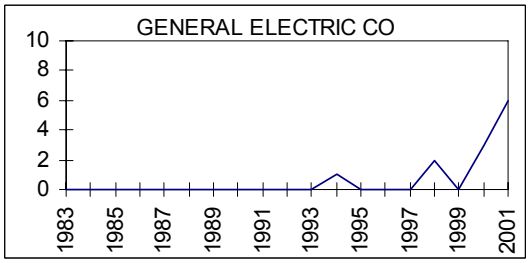
Figure 58: Most Active and Growing Companies

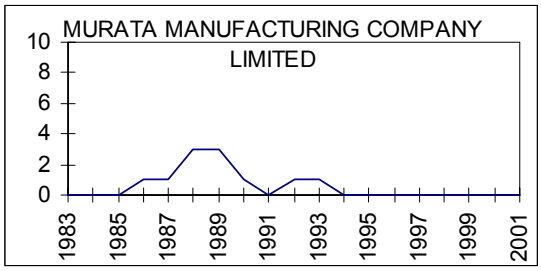


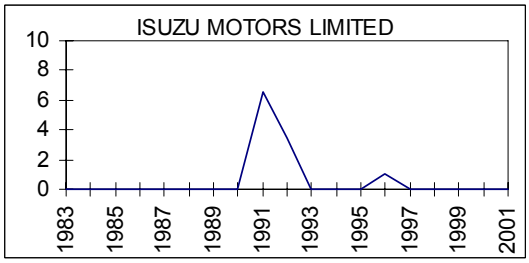


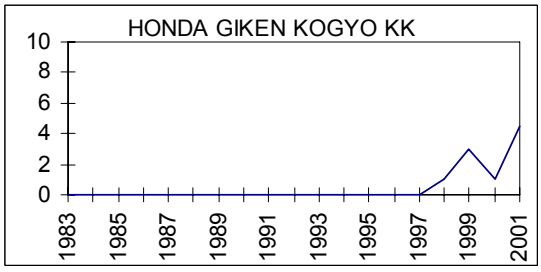


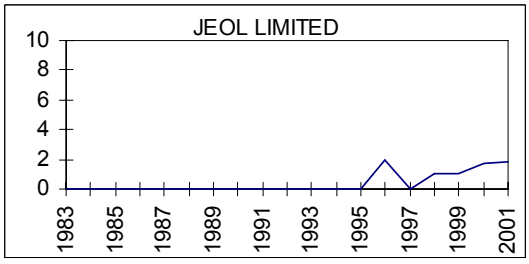


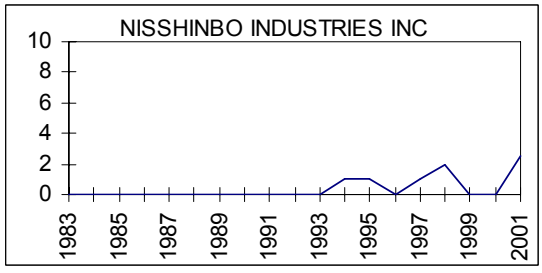












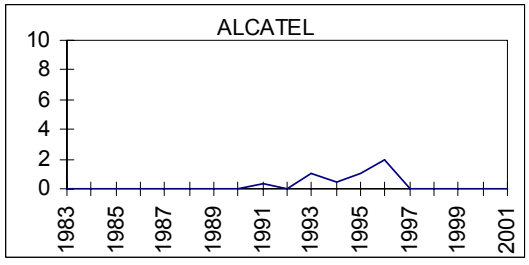
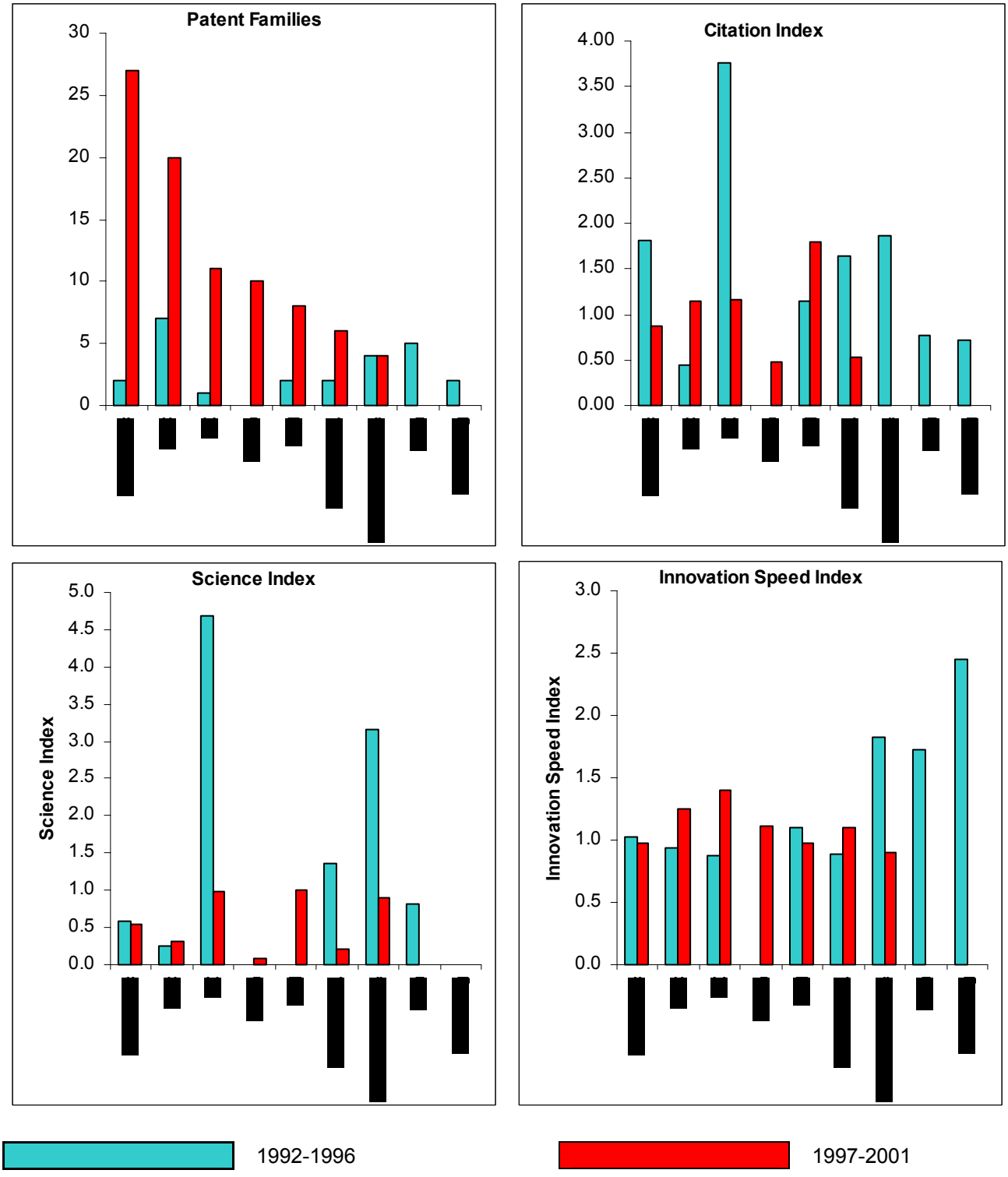


Figure 59: Indicators by Company



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.

Figure 60: Emerging and Fading Companies
(Companies With Largest Increase and Decrease Among Those with 2+ Patents)

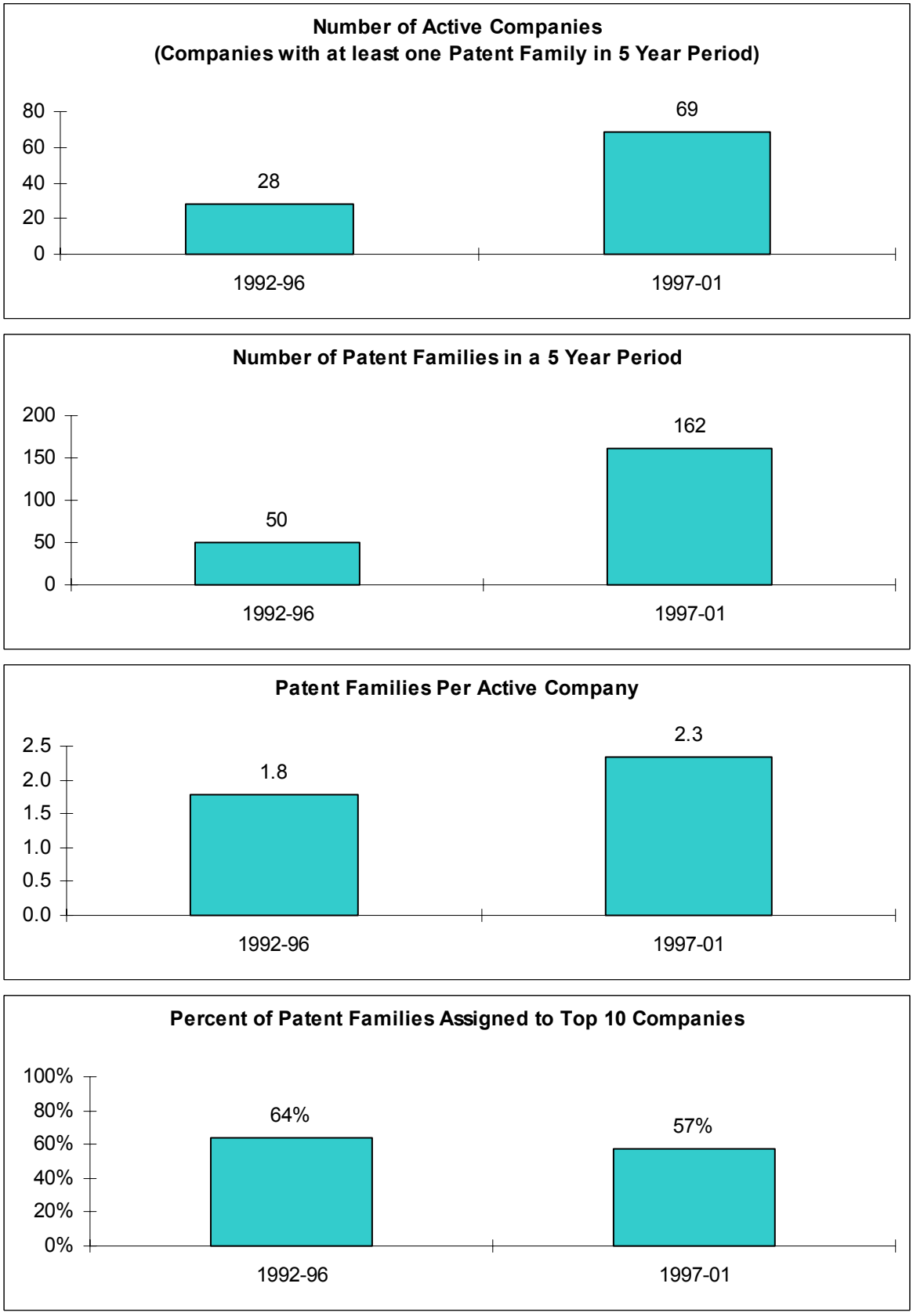
Emerging Companies	1996-1998	1999-2001	Increase	% Increase
Asahi Glass KK	4.7	23	18.3	389%
NEC Corporation	4	15.5	11.5	288%
Honda Giken Kogyo KK	1	8.5	7.5	750%
General Electric Co	2	9	7	350%
TDK Corporation	0	3.5	3.5	Infinity
Matsushita Electric Industrial Co Ltd	1	4	3	300%
Science Applications Int'L	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%

Fading Companies	1996-1998	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%

Life cycle statistics - The 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 the major U.S. company showing increased, recent activity.

Figure 61: Life Cycle Statistics



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 clear that this category must be treated separately from Ultracapacitors. If the two categories had been combined, the 1,157 Other Power Electric patent families we identified would have overwhelmed the data about Ultracapacitors.[13]

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 General Electric, Emerson Electric and Bosch.

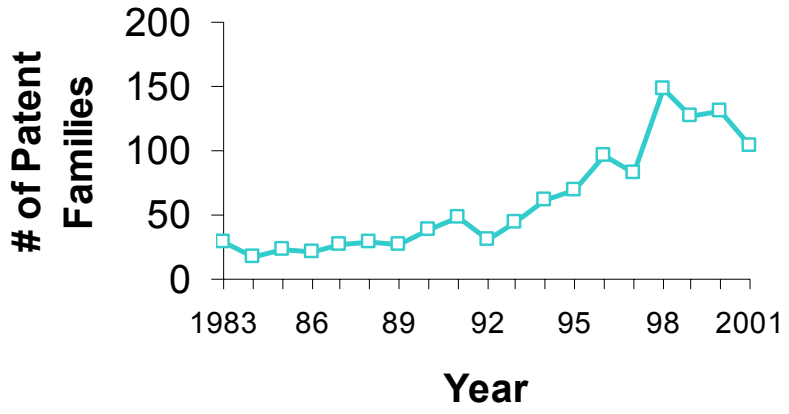
Figure 62: Top-Cited Other Power Electronics Patents

Patent	Patent Family	Issue Date	Cites Rec.	Assignee Name	Title
04743815	10098	5/10/1988	149	EMERSON ELECTRIC CO.	Brushless permanent magnet motor system
05343970	10283	9/6/1994	80		Hybrid electric vehicle
05257828	10252	11/2/1993	72	TRW INC.	Method and apparatus for controlling damping in an electric assist steering system for vehicle yaw rate control
04403527	10017	9/13/1983	70	ROBERT BOSCH GMBH	Apparatus for decreasing jolts during gear shifts in automatic transmissions in motor vehicles
05190539	10226	3/2/1993	64	TEXAS A & M UNIV SYSTEM	Micro-heat-pipe catheter
04772839	10107	9/20/1988	53	GENERAL ELECTRIC CO.	Rotor position estimator for switched reluctance motor
05075610	54	12/24/91	48	HONEYWELL INC.	Switched reluctance motor control circuit with energy recovery capability
04481450	10034	11/6/1984	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	9/25/1990	47	GENERAL ELECTRIC CO.	SWITCHED RELUCTANCE MOTOR DRIVE SYSTEM AND LAUNDERING APPARATUS EMPLOYING SAME

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

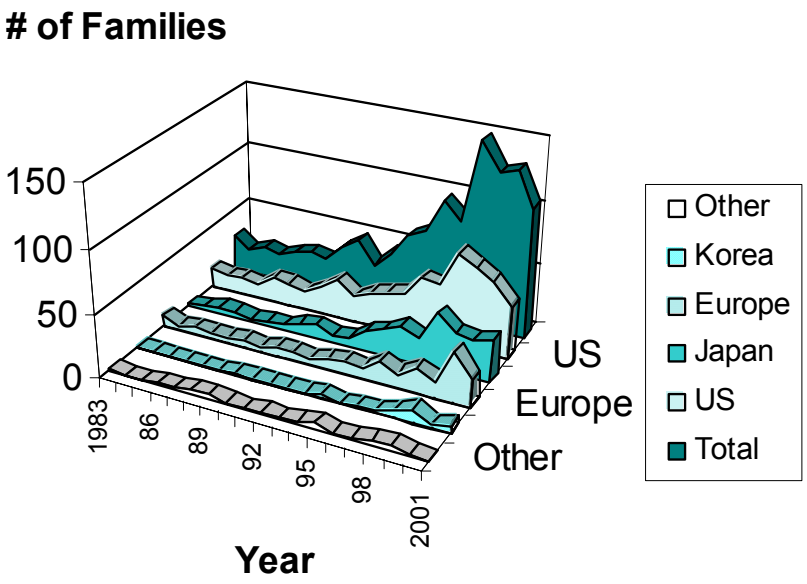
[13] This category is one of the two with the least enlarging of patent families by inclusion of EP documents. Of the 1157 patent families, only 117 come from the EP, an addition of only 11 percent.

Figure 63: Patent Activity



Trends by region - We can see from the regional trends in **Figure 64** that the post-1998 drop-off occurs relatively at relatively the same time in both the United States and Japan, and finally hits Europe in the last year.

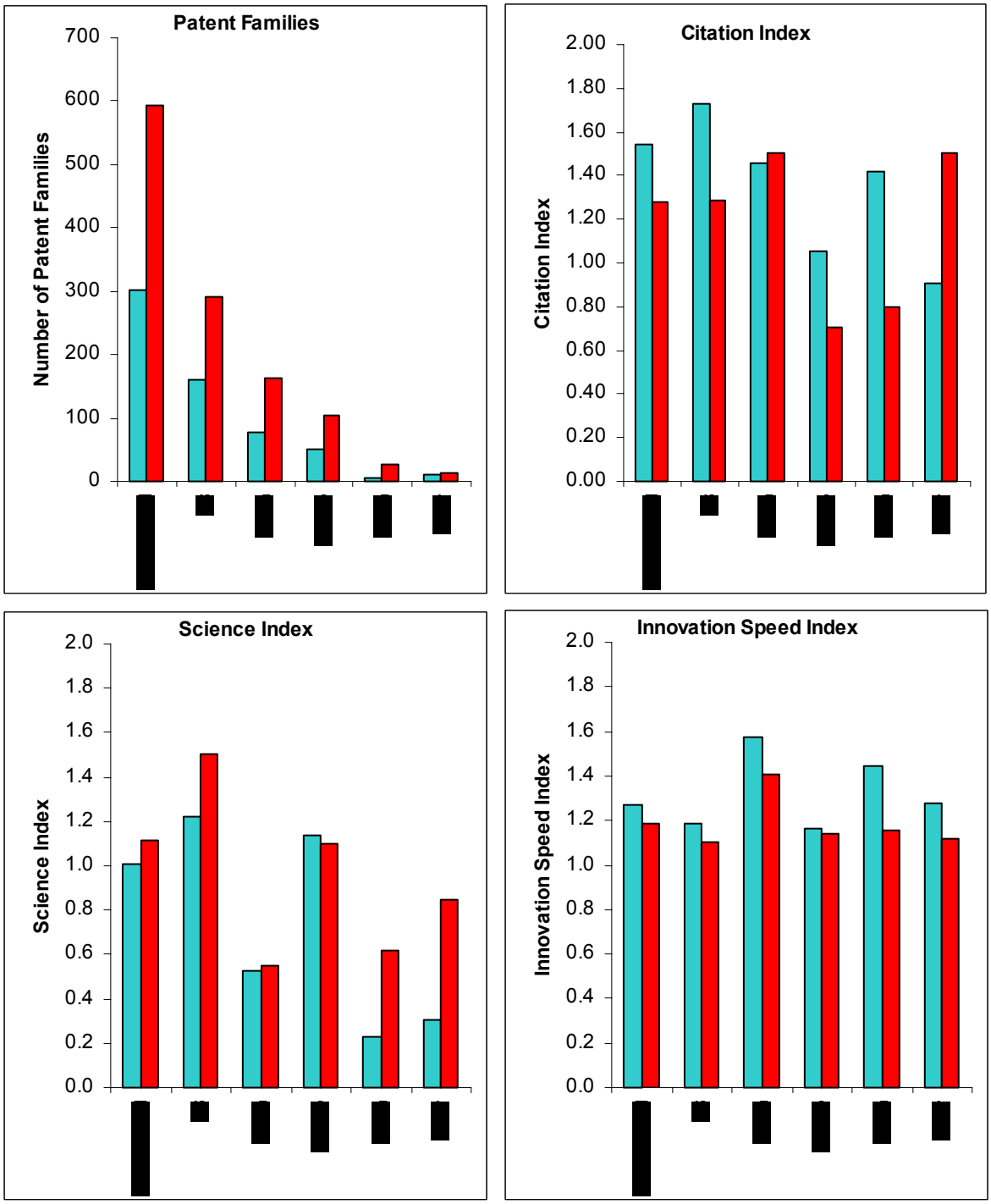
Figure 64: Trends by Region



Indicators by region - **Figure 65** shows comparisons of regional patent indicators. While the United States has more Other Power Electronics patents than second-place Japan, Japan's patents are slightly more highly cited than those of the United States -- much more than Europe or Korea's patents in the category --- and have the fastest innovation speed.[14] Japanese patents have a much lower Science Index than those of the United States, Europe, and are even slightly less science linked than the patents of Korea.

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

Figure 65: Indicators by Region



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.

Figure 66: Most Active Companies

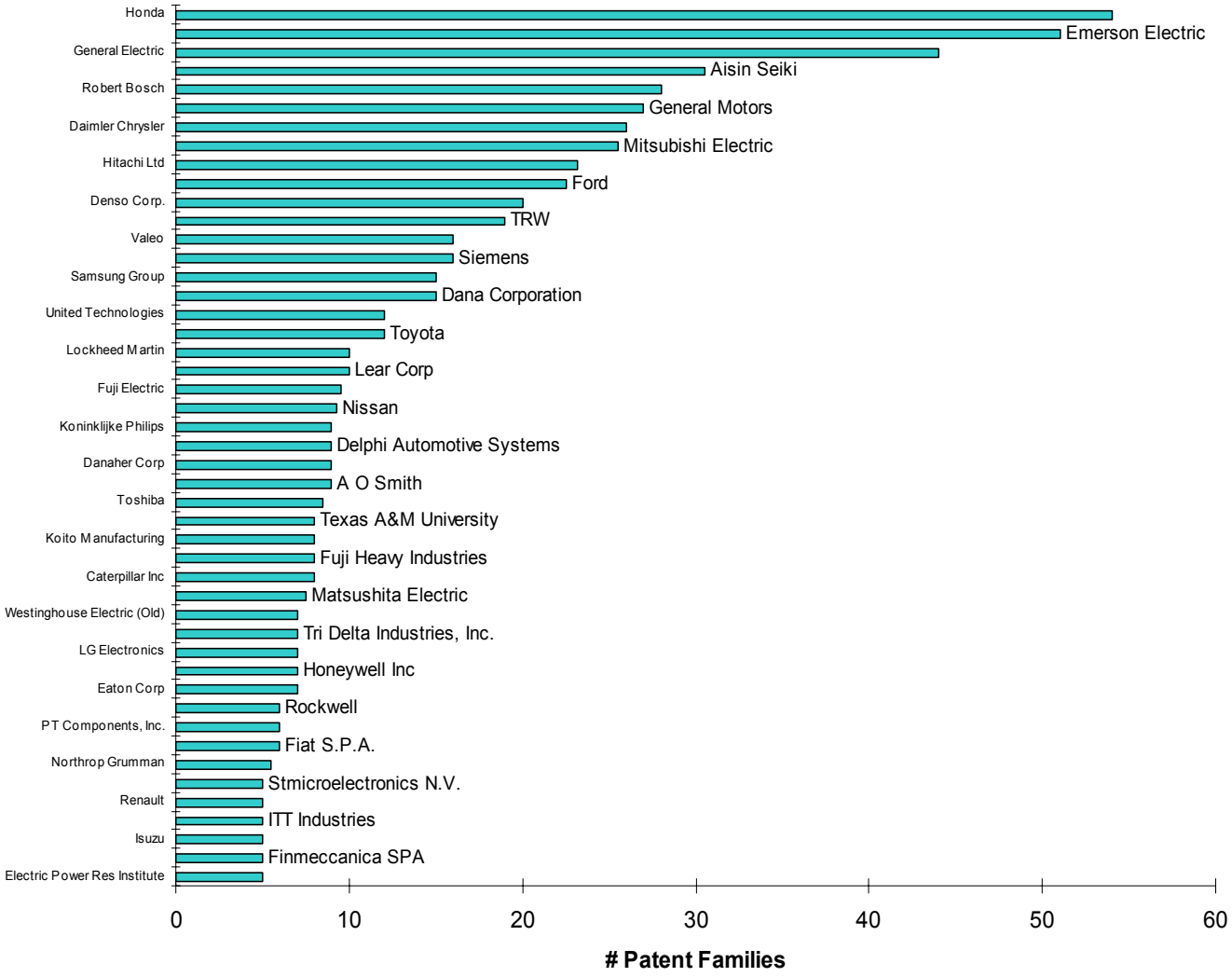
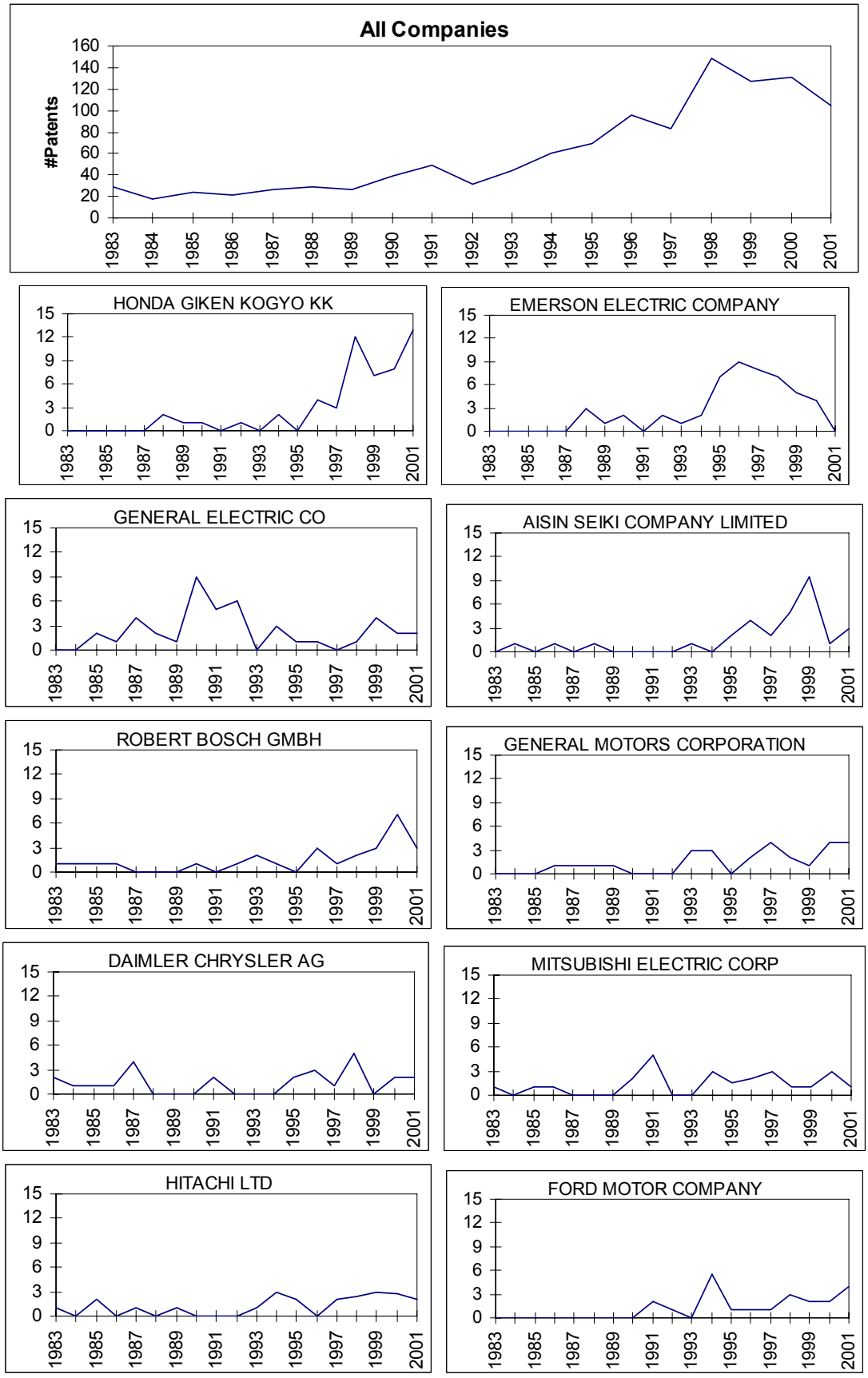
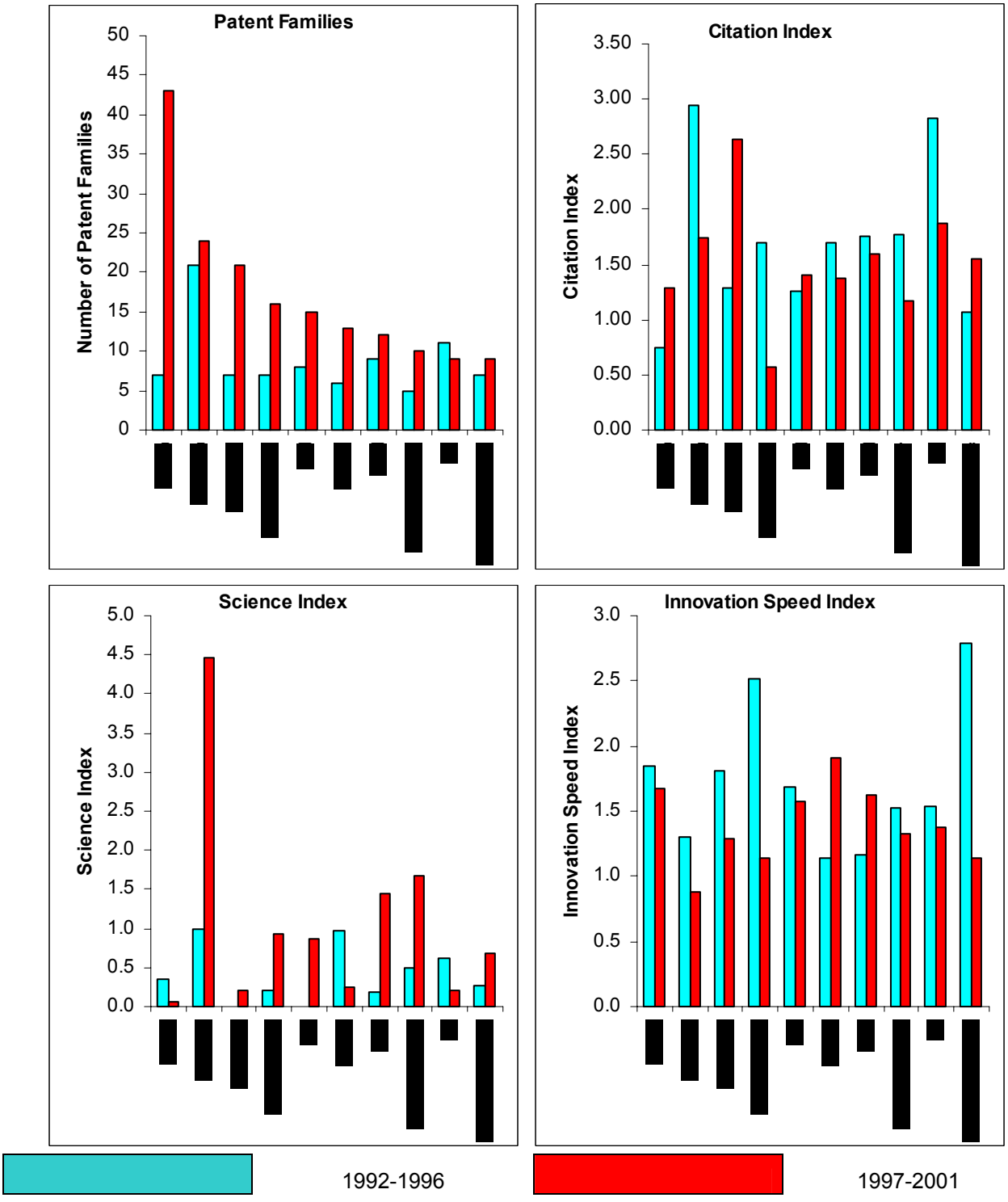


Figure 67: Patent Family Activity Trends



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 means among the highest cited; it is Aisin Seiki's Other Power Electronics patents that are by far the most highly cited. Bosch's are the least most cited.

Figure 68: Indicators by Company



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.

Figure 69: Emerging and Fading Companies
(Companies With Largest Increase and Decrease Among Those with 2+ Patents)

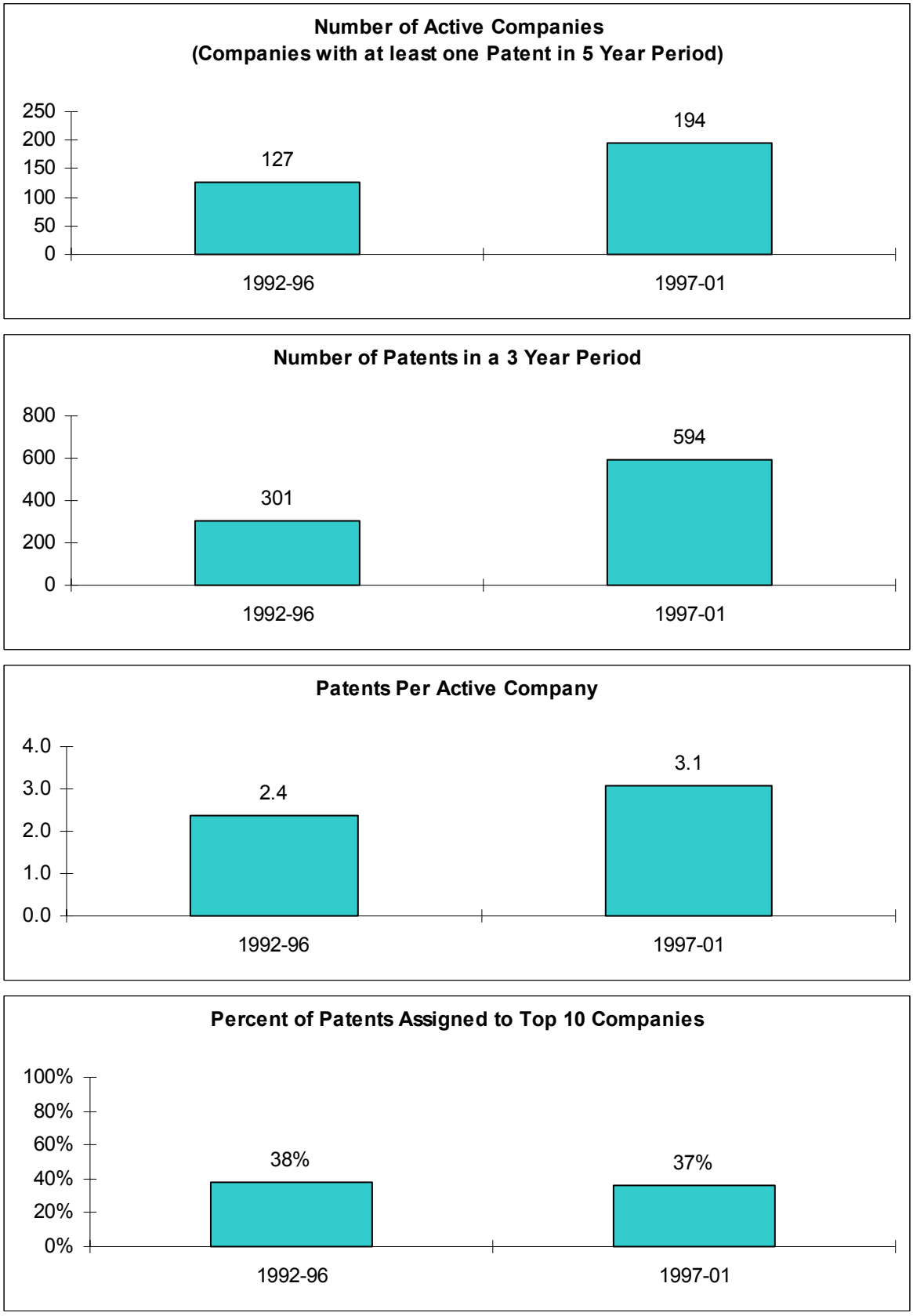
Emerging Companies	1996-1998	1999-2001	Increase	% Increase
Honda	19	28	9	47%
Robert Bosch	6	13	7	117%
General Electric Co	2	8	6	300%
TRW Incorporated	3	8	5	167%
Dana Corporation	5	10	5	100%
Tri Delta Industries, Inc.	1	6	5	500%
ITT Industries Inc.	0	5	5	Infinity
Siemens Ag	4	8.5	4.5	113%
Toyota Motor 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	1996-1998	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%
Finmeccanica 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%

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 there is an obviously real drop off in activity in the last three years, particularly for the United States. Due largely to companies like Honda and Aisin Seiki, it appears that Japan will probably overtake the United States within a few years. The slide in U.S. activity comes from declines for companies like Emerson and GE, and continued low activity from General Motors, Ford and others.

Figure 70: Life Cycle Statistics



Direct Injection Combustion (DI)

This category principally covers diesel engine technology, but is slightly broader than diesel because it also includes spark ignited direct injection (SIDI) 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.

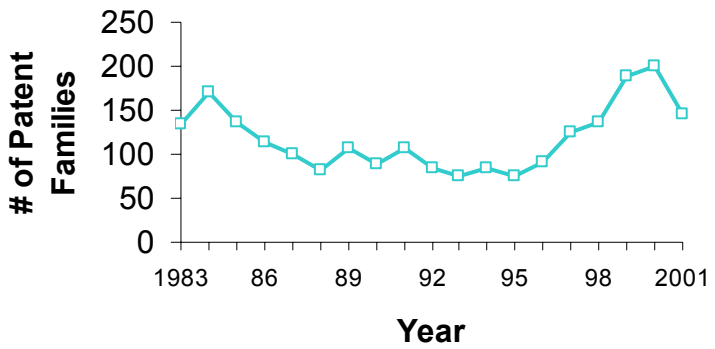
Top-cited representative patents - This is the third largest of the categories, with a total of 2,245 patent families (EP-only patent families account for 639 of these). **Figure 71** lists the 50 top-cited DI patents. At the top of the list is a patent for a fuel injector from Diesel Technology Co., 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.

Figure 71: Top-Cited Direct Injection Combustion Engines

Patents	Family	Issue Date	# Cites	Assignee Name	Title
4392612	1122	7/12/83	87	DIESEL TECHNOLOGY CO.	Electromagnetic unit fuel injector
5313924	10713	5/24/94	54	CHRYSLER CORP.	Fuel injection system and method for a diesel or stratified charge engine
4777921	624	10/18/88	53	NIPPON DENSO CO., LTD.	Fuel injection system
4653455	135	3/31/87	51	ROBERT BOSCH GMBH	Electrically controlled fuel injection pump for internal combustion engines
4482094	1104	11/13/84	50	DIESEL TECHNOLOGY CO.	Electromagnetic unit fuel injector
4493303	1108	1/15/85	45	MACK TRUCKS, INC.	ENGINE CONTROL
5156132	10649	10/20/92	40	NIPPON DENSO CO., LTD.	Fuel injection device for diesel engines
4566416	10321	1/28/86	39	GANSER-HYDROMAG AG	ACCUMULATOR NOZZLE FUEL INJECTION SYSTEM
4397285	10056	8/9/83	38	PHYSICS INT'L CO.	Closed loop diesel engine control
4430978	10126	2/14/84	38	SIEMENS-BENDIX AUTOMOTIVE	Direct liquid injection of liquid petroleum gas

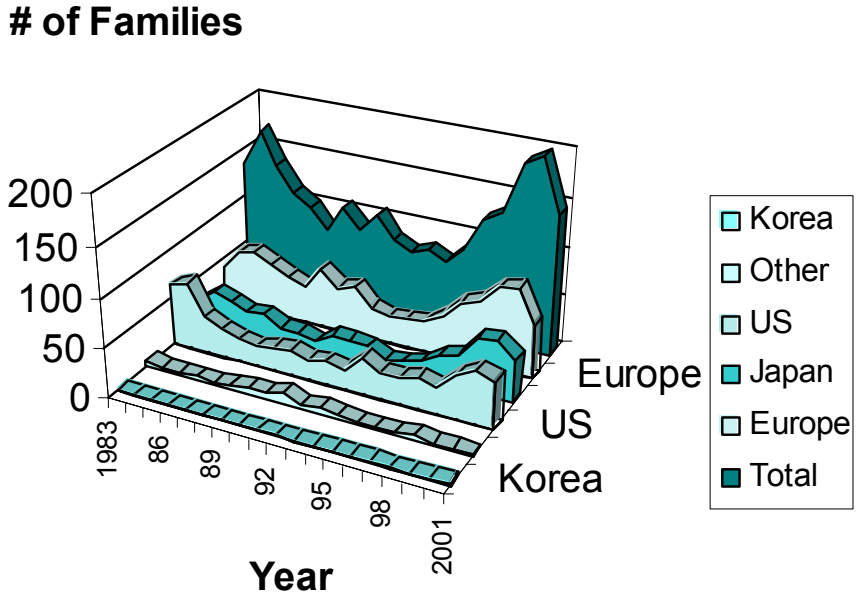
Activity - This is a category that has had its ups and downs. **Figure 72** shows activity declining steadily from the mid-1980s, but starting to heat up again quite strongly starting in 1996. It is too soon to tell if the drop in 2001 is the beginning of a long-term decline or not.

Figure 72: Direct Injection Combustion Patent Activity



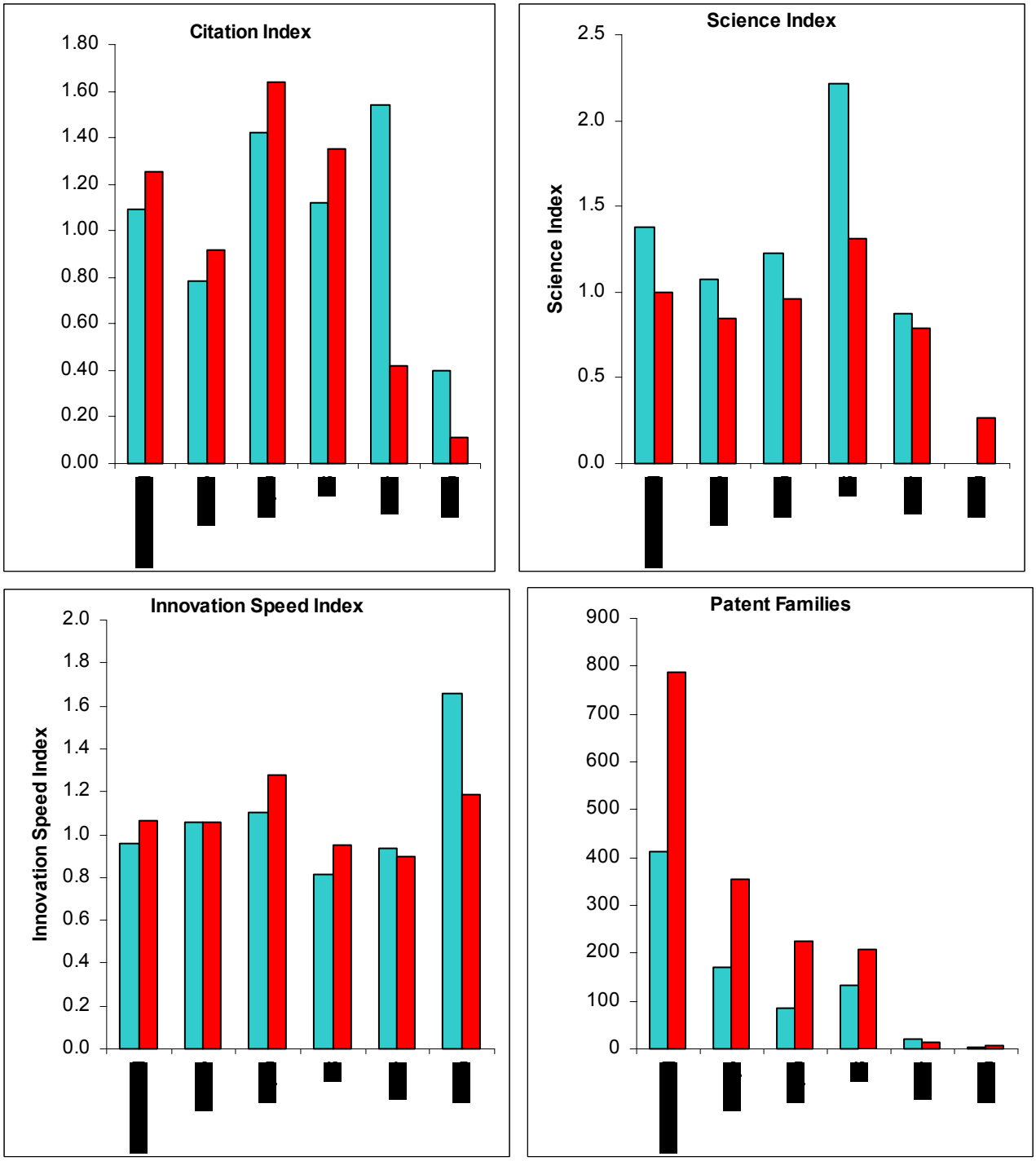
Trends by region - Europe holds more patents than any other region. But, as is shown in **Figure 73**, all regions share the general pattern of the trends, including the decline and increase, the slowing rate between 1999 and 2000 and a drop-off in the last year. We wonder if last year's drop-off is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

Figure 73: Trends by Region



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

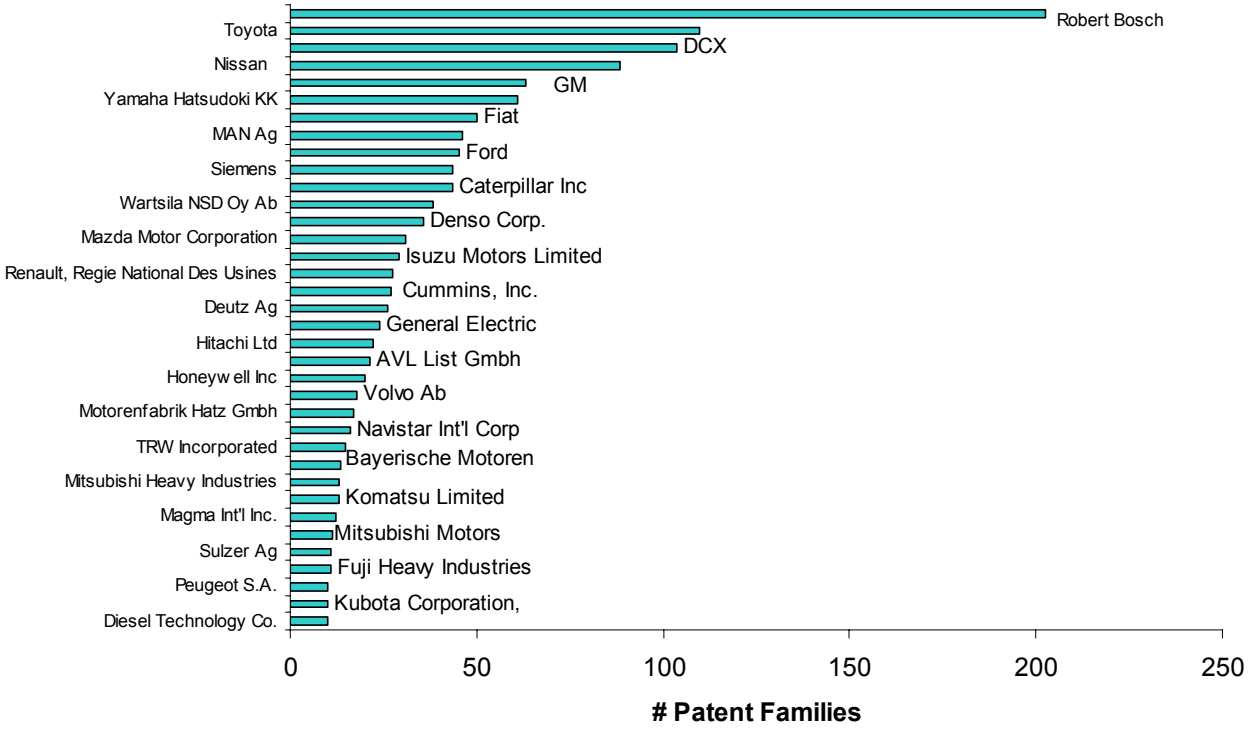
Figure 74: Indicators by Region



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, DaimlerChrysler[15], Fiat, and MAN AG. It appears that the strong European overall count is coming from a very large number of smaller players.

[15] 88 of Daimler Chrysler's Direct Injection patents are European-invented.

Figure 75: Most Active Companies



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 DaimlerChrysler, 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 with the exception of Robert Bosch are significantly up in patenting activity. The companies with the higher citation indices are Caterpillar, MAN AG, Fiat, GM and Ford. Caterpiller'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.

Figure 76: Trends for the Top 10 Companies

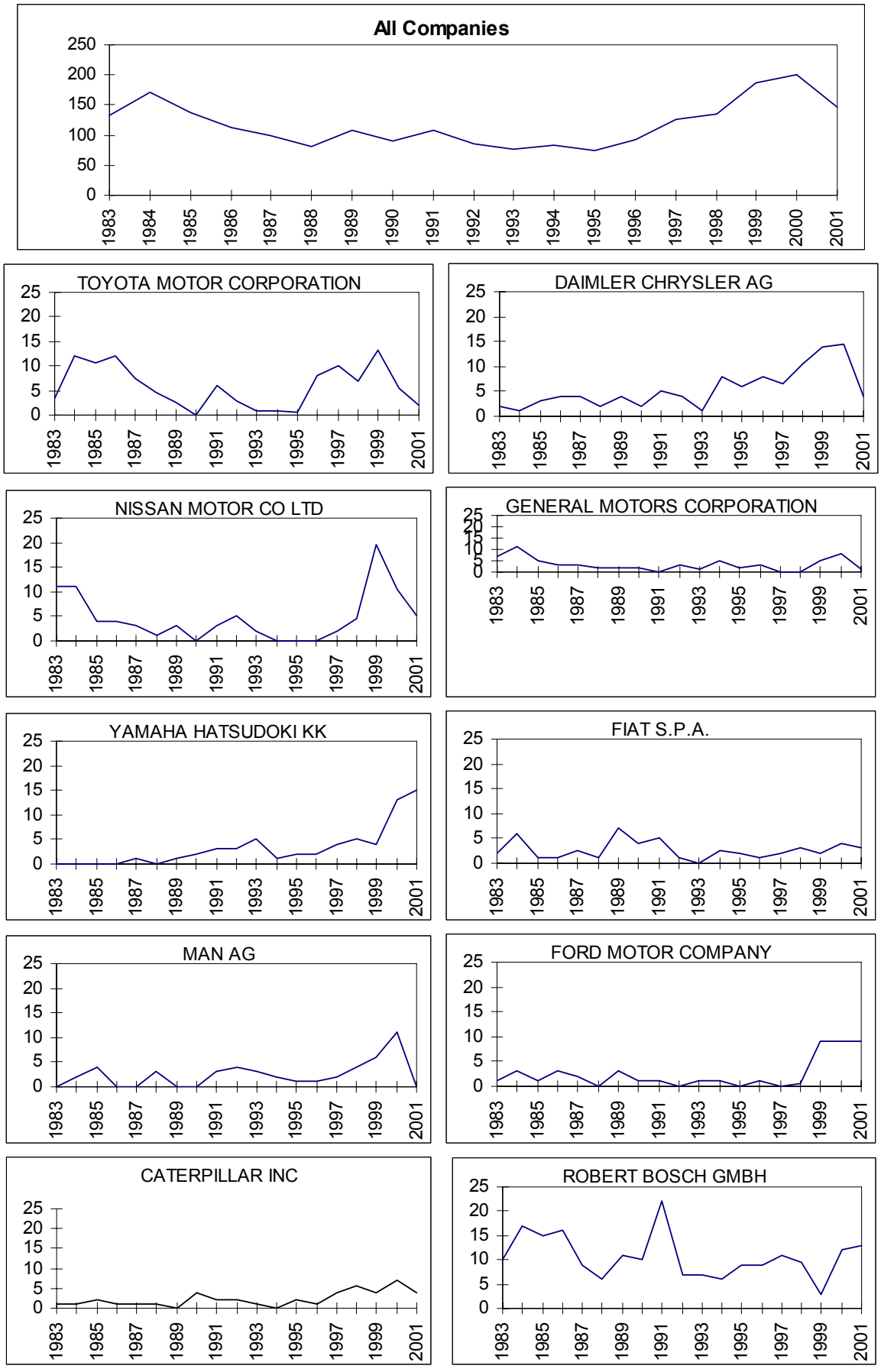
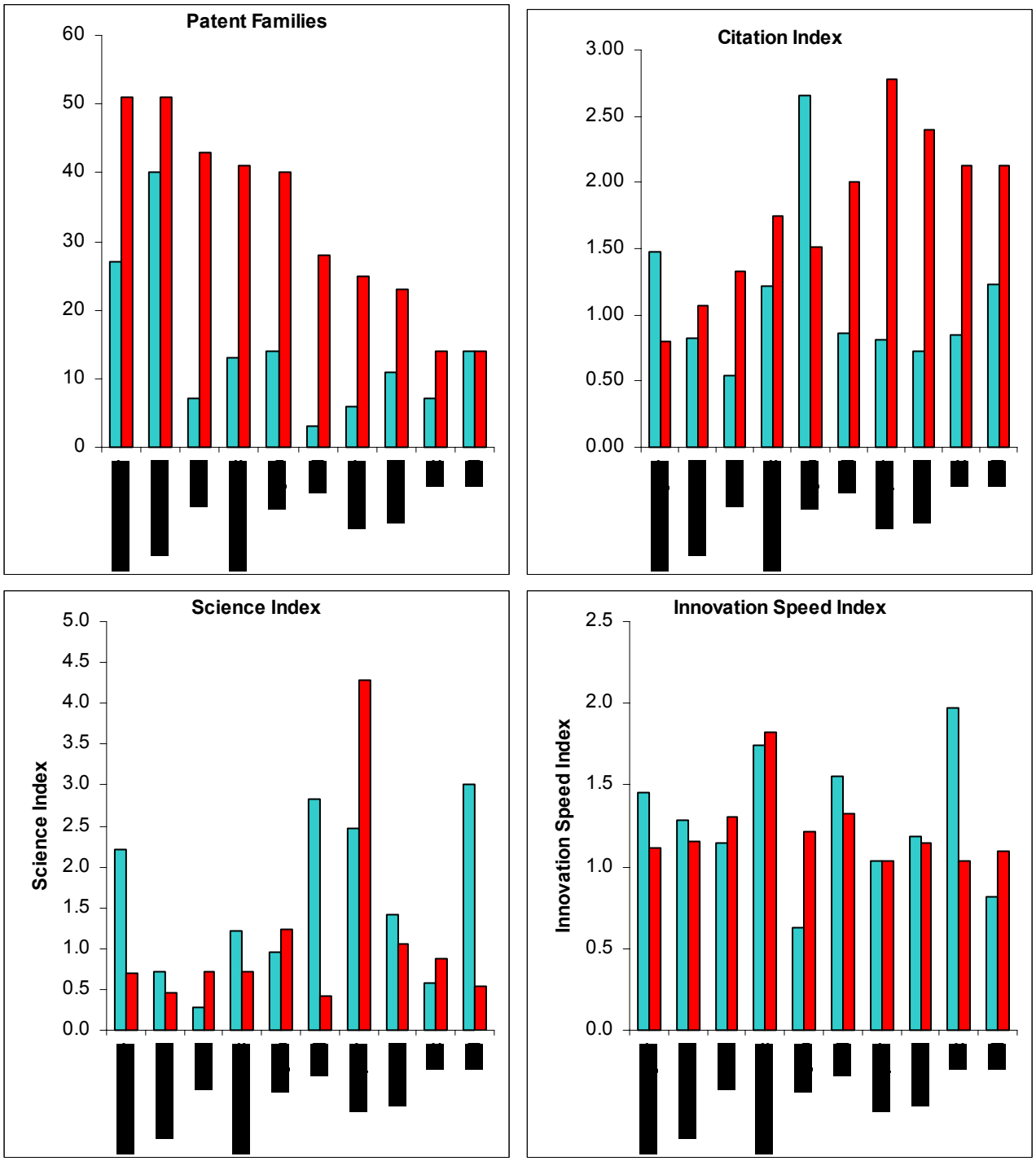


Figure 77: Indicators by Companies



Emerging and fading companies – As shown in **Figure 78**, automobile companies, plus Man AG, Siemens and Hitachi, dominate the emerging companies. 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.

Figure 78: Emerging and Fading Companies (Companies With Largest Increase and Decrease Among Those with 2+ Patents)

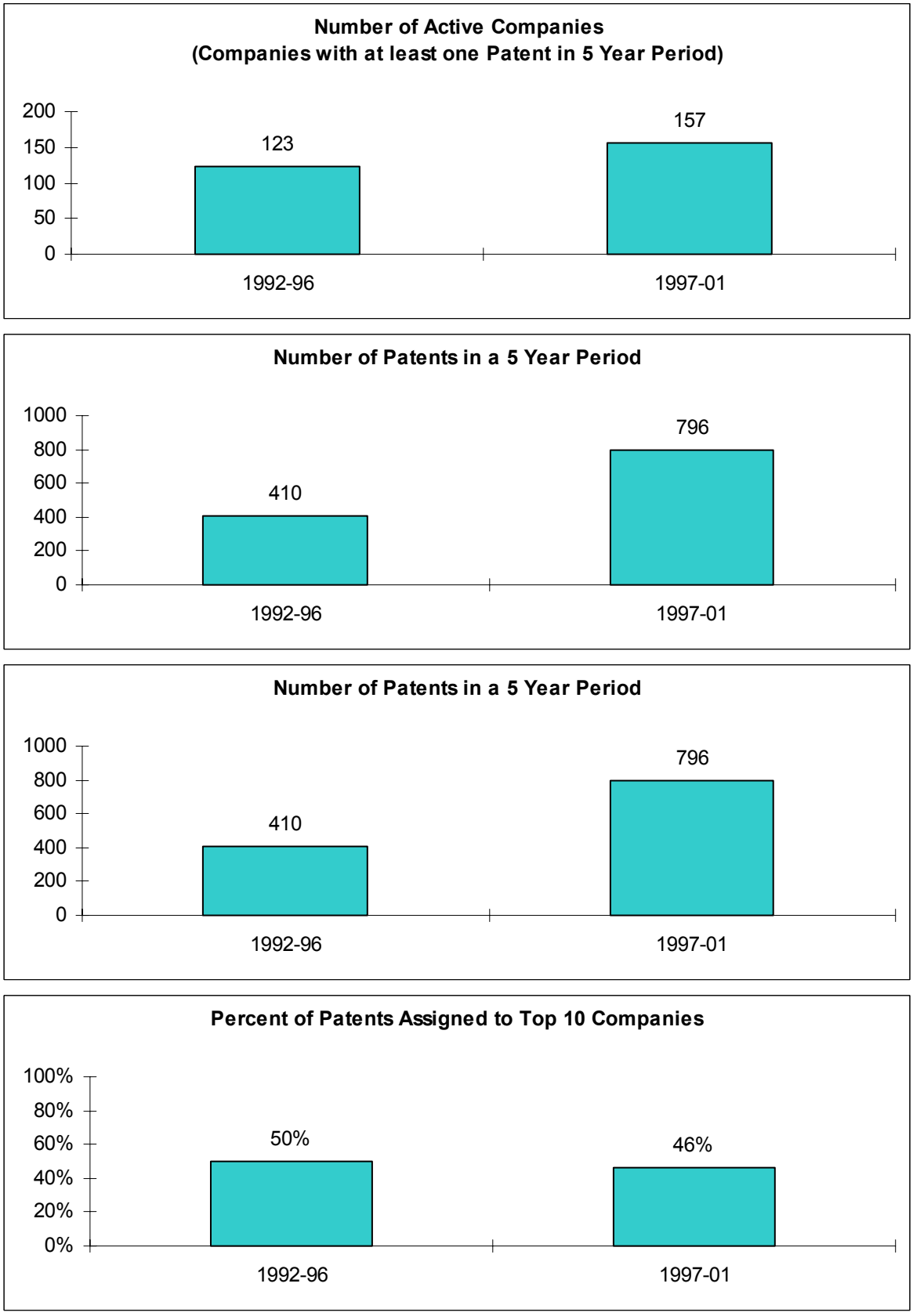
Emerging Companies	1996-1998	1999-2001	Increase	% Increase
Nissan Motor Co Ltd	6.5	35	28.5	438%
Ford Motor Company	1.5	27	25.5	1700%
Yamaha Hatsudoki Kk	11	32	21	191%
Isuzu Motors Limited	4	18	14	350%
General Motors Corporation	3	14	11	367%
MAN Ag	7	17	10	143%
Volvo Ab	0	9	9	Infinity
Mazda Motor Corporation	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	1996-1998	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%

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. 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 United States 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 United States still remains third, slightly behind Japan.

Figure 79: Life Cycle Statistics



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 6,064 identified patent families, of which 1980 of the families are EP-only.

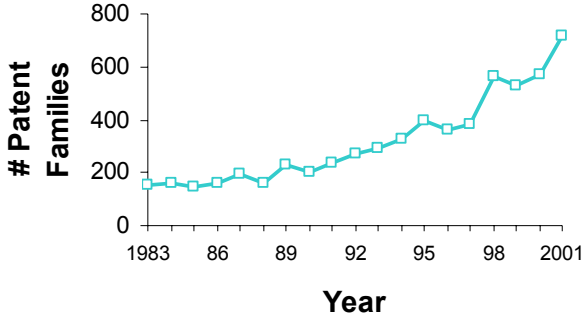
Top-cited representative patents – The approximately 50 top-cited Emissions Control patents are listed in **Figure 80**. At the top of the list are a few patents concerned with emissions noise reduction, in spite of the explicit filter terms to try to exclude them! Such patents may or may not be relevant, depending on one's point of view, but in any case, noise reduction patents constitute a minority of the patents. The vast majority of patents 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.

Figure 80: Top-Cited Emissions Control Patents

Patent	Family Number	Issue Date	# Cites	First Assignee	Title
04677677	10507	6/30/1987	96	NELSON INDUSTRIES, INC.	Active sound attenuation system with on-line adaptive feedback cancellation
04473906	10208	9/25/1984	86	NOISE CANCELLATION TECHNOLOGIES	Active acoustic attenuator
04976929	10858	12/11/1990	74	GRACE (W.R.) & CO.	ELECTRICALLY HEATED CATALYTIC CONVERTER
04622809	10440	11/18/1986	70	DAIMLER-BENZ AG	METHOD AND APPARATUS FOR MONITORING AND ADJUSTING +80 -PROBE-CONTROLLED CATALYTIC EXHAUST GAS EMISSION CONTROL SYSTEMS OF INTERNAL C
04368705	10006	1/18/1983	68	CATERPILLAR INC.	Engine control system
04928485	3919	5/29/1990	61	GRACE (W.R.) & CO.	METALLIC CORE MEMBER FOR CATALYTIC CONVERTER AND CATALYTIC CONVERTER CONTAINING SAME
04427418	10127	1/24/1984	56	TOYOTA CHUO KENKYUSHO KK	Device for collecting particulates in exhaust gases
04748959	10585	6/7/1988	55	FORD MOTOR CO.	Regulation of engine parameters in response to vapor recovery purge systems
05445128	11650	8/29/1995	55	DETROIT DIESEL CORP.	Method for engine control
E0485179	2796	5/10/1995	54	NGK INSULATORS, LTD.	Heater and catalytic converter

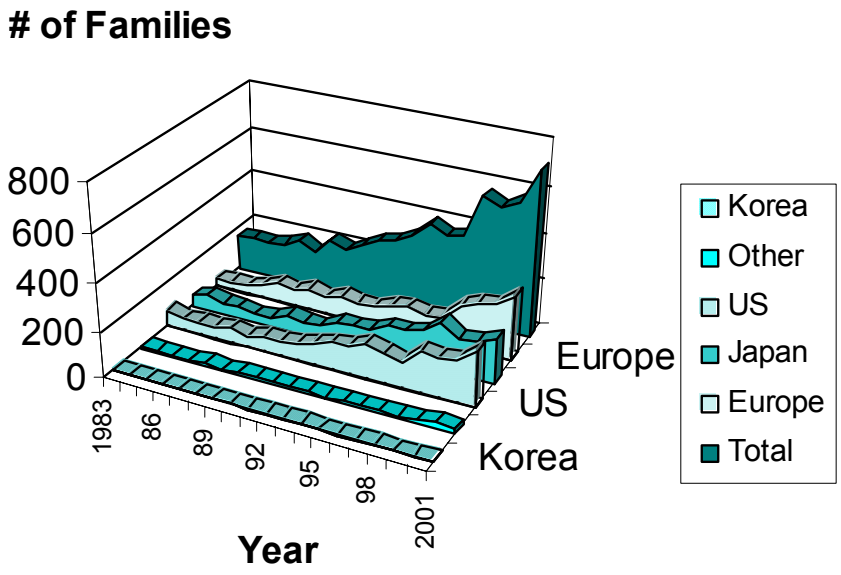
Activity – Obviously this is a very major area of technology under any terms of reference. Not only are there thousands of patents, **Figure 81** clearly shows that patenting activity is up strongly, and has been climbing throughout the last decade. In 1991 the rate was about 200 a year and in 2,001 it is 700 a year.

Figure 81: Emissions Control Patent Activity



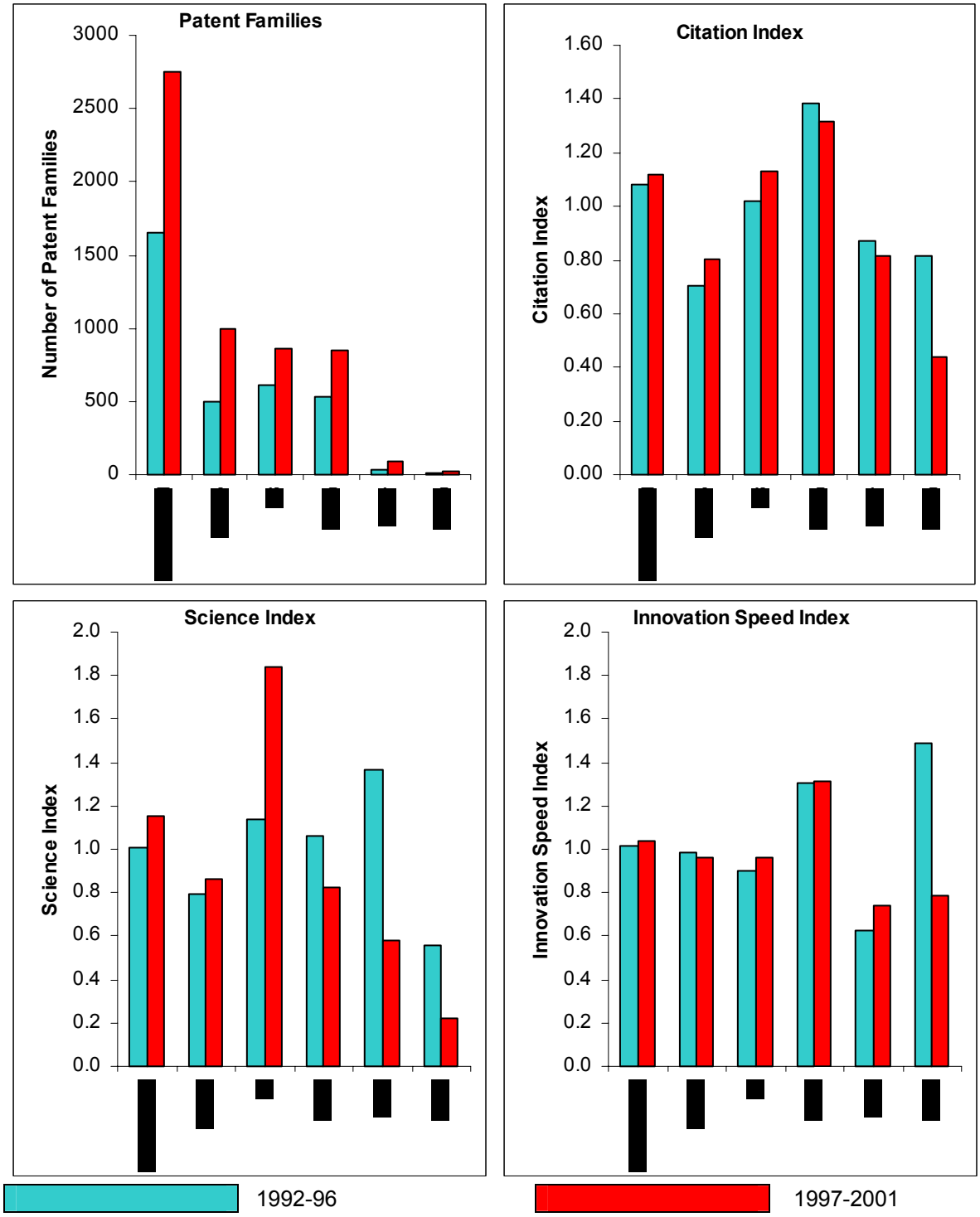
Trends by region - Regional trends are compared in **Figure 82**. The amount and growth of patenting activity has been fairly evenly divided among the United States, Japan and Europe, with Japan only falling behind in the last several years.

Figure 82: Trends by Region



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 with Europe having 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, U.S. 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). U.S. 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.

Figure 83: Indicators by Region



Most active companies – The companies with the most patent families (see ranking in **Figure 84**) are led by Toyota, Ford, Honda, Nissan, DaimlerChrysler, 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.

Figure 84: Most Active Companies

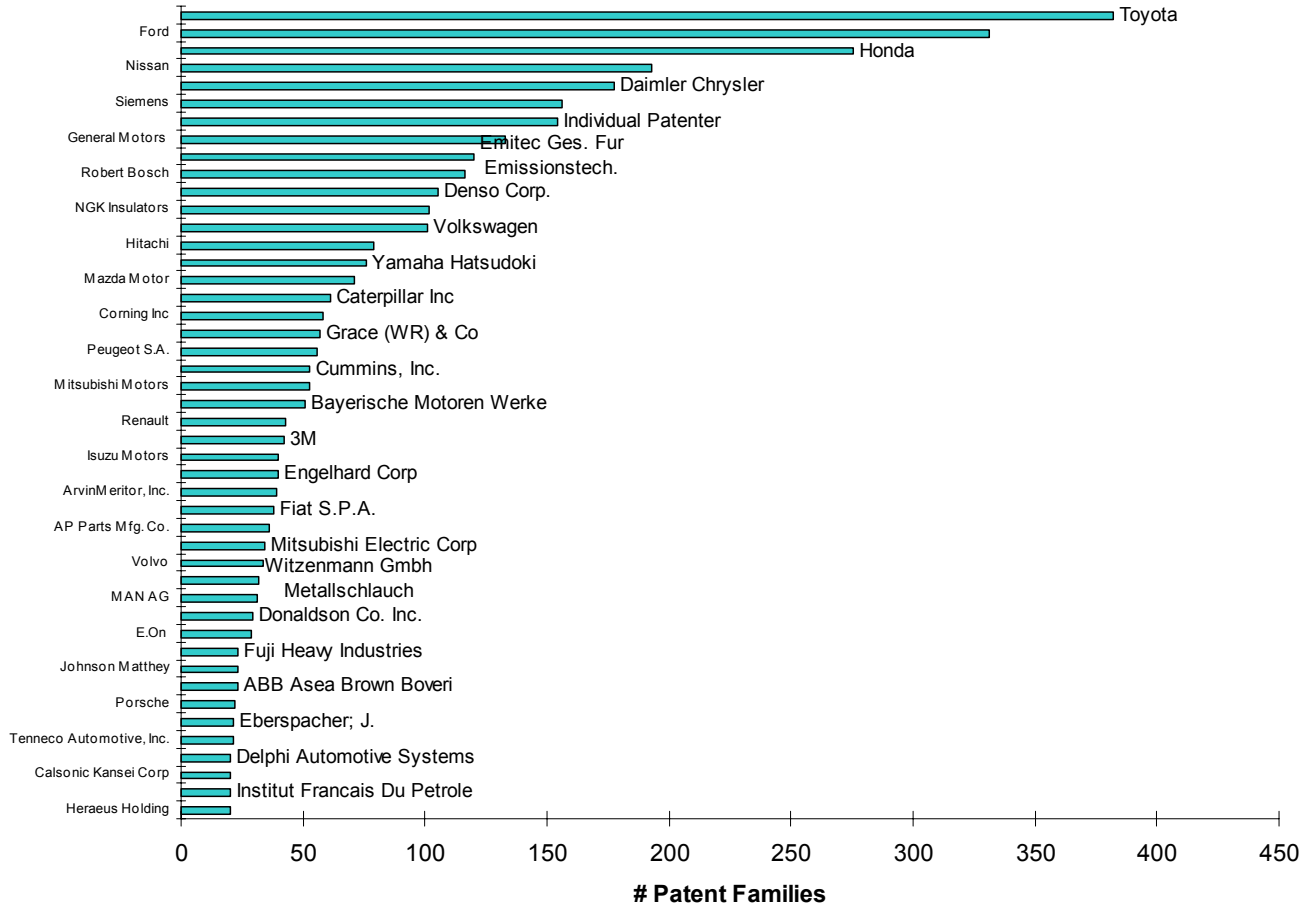
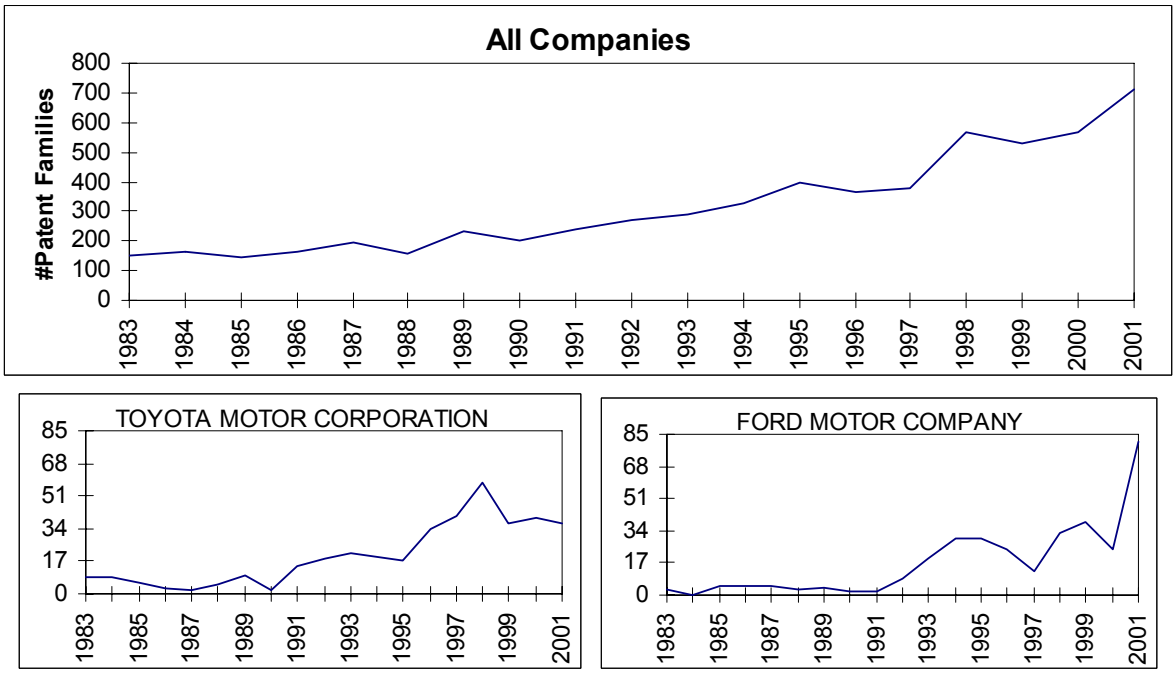
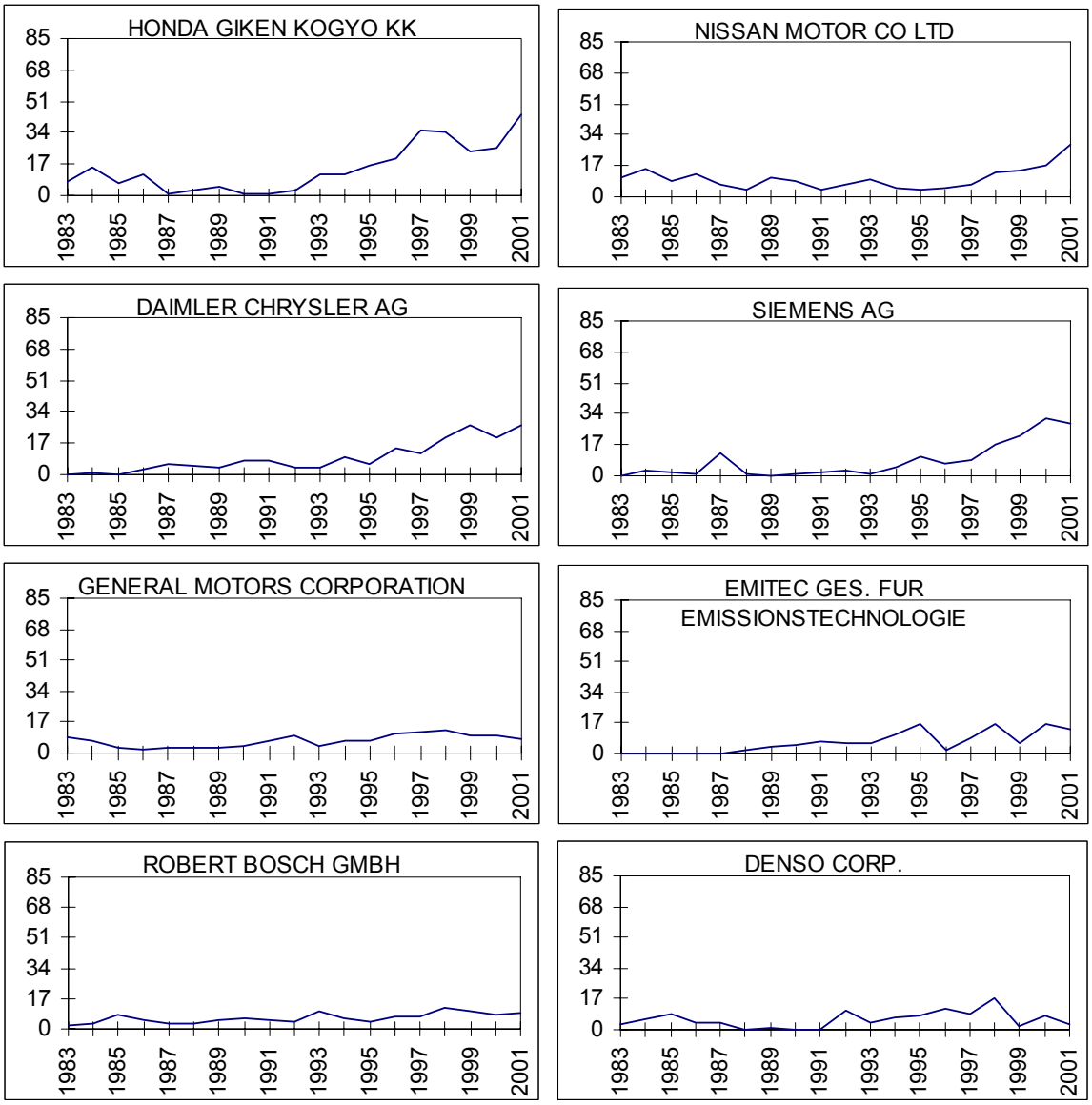


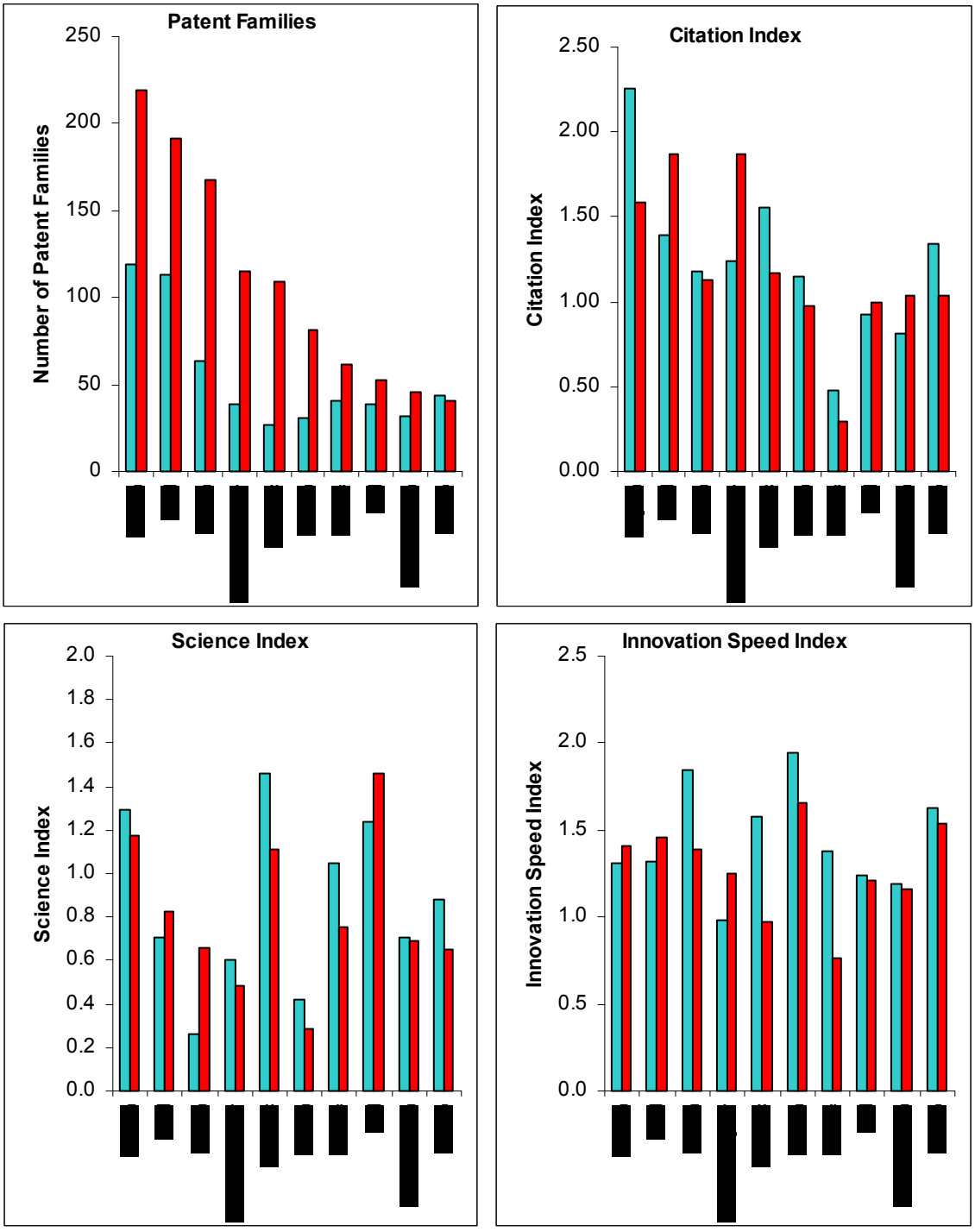
Figure 85: Patent Trends for Top Ten Companies





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 DaimlerChrysler). 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.

Figure 86: Indicators by Company



Emerging and fading companies – The top of **Figure 87** lists the emerging players, most notably Ford, Volkswagon (VW's patent count is too small to make into the top 10 here, but the increase in patenting here appears significant)[16], Siemens, Nissan and DaimlerChrysler. Significant fading players indicated in that list are Denso, W. R. Grace (now out of this area entirely?) and Porsche.

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

Figure 87: Emerging and Fading Companies (Companies With Largest Increase and Decrease Among Those with 2+ Patents)

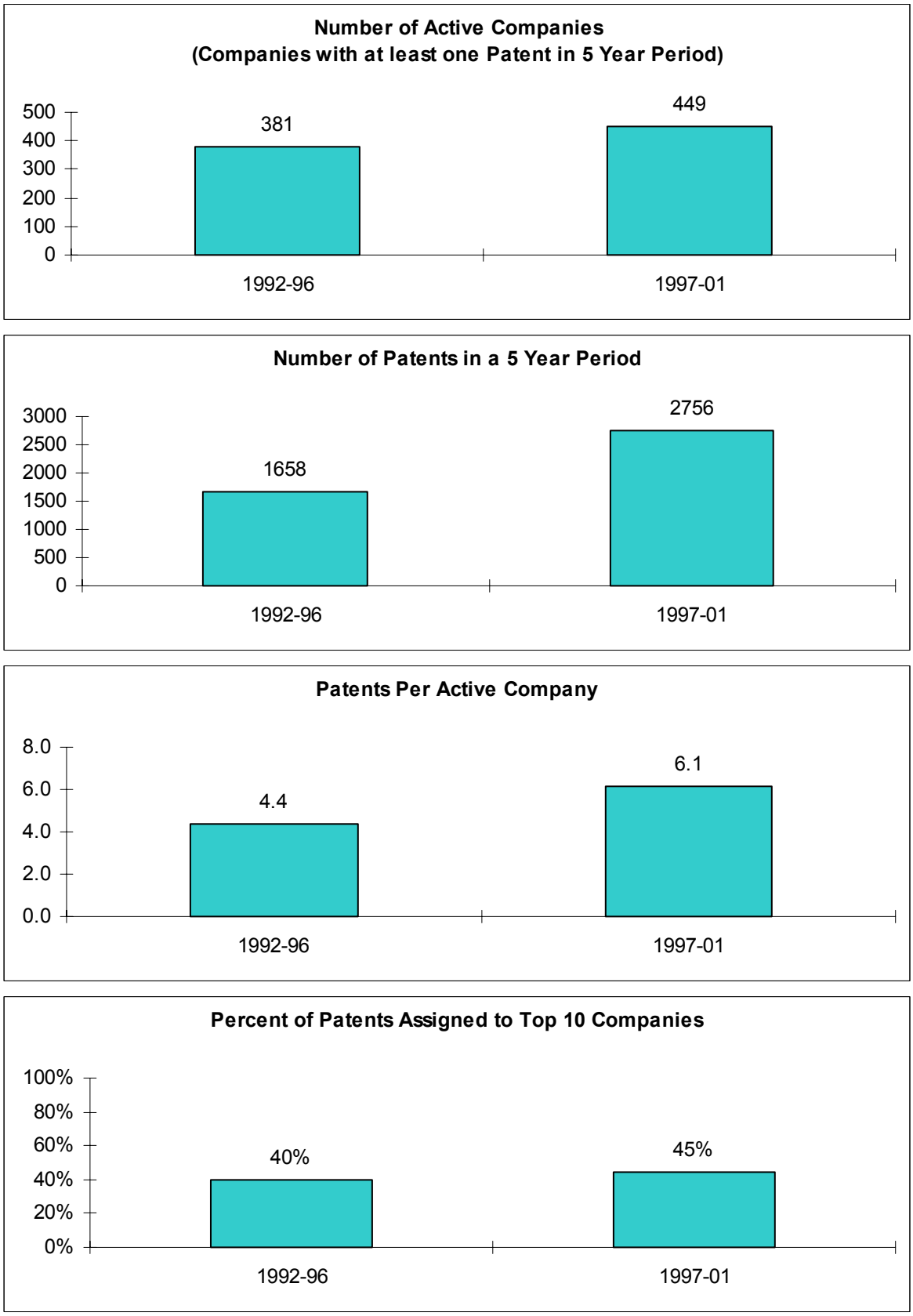
Emerging Companies	1996-1998	1999-2001	Increase	% Increase
Ford Motor Company	70	144	74	106%
Volkswagen Ag	15.9	72.7	56.8	357%
Siemens Ag	32.5	82.5	50	154%
Nissan Motor Co Ltd	25	60.5	35.5	142%
Daimler Chrysler Ag	45.9	73.9	28	61%
Mazda Motor Corporation	5	30.5	25.5	510%
Delphi Automotive Systems	0	20.5	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%
Arvinmeritor, 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%
Litex 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	1996-1998	1999-2001	Decrease	%Decrease
Denso Corp.	37	12.5	24.5	66%
Toyota Motor Corporation	132.6	113.5	19.1	14%
Grace (Wr) & Co	12	0	12	100%
Corning Inc	23	14	9	39%
General Motors Corporation	36	28	8	22%
Porsche Ag	9.8	1.9	7.9	81%
Calsonic Kansei 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%
Kioritz 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%

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 in terms 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 United States, Europe and Japan. Drop-off aside, Japanese patenting has the strongest quality and innovation speed.

Figure 88: Life Cycle Statistics



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 chosen carefully 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.

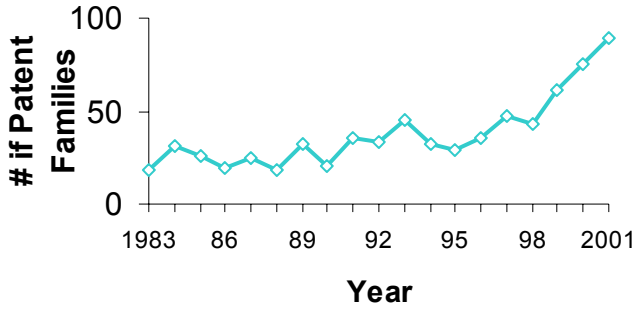
Top-cited representative patents - **Figure 89** lists approximately 50 top-cited patents for this category. Regrettably, few of the titles reveal why these patents were picked. There was, however, something in the abstracts and exemplary claims of these patents that caused them to be selected.

Figure 89: Top-Cited New Combustion Regime Patents

Patent	Patent Family	Issue Date	# Cites	Assignee Name	Title
04988074	10156	1/29/1991	42	HI-RAM INC.	Proportional variable force solenoid control valve
04485768	10035	12/4/1984	35		Scotch yoke engine with variable stroke and compression ratio
05051631	10171	9/24/1991	32	SPX CORP.	Electromagnetic solenoid valve with variable force motor
05277664	10242	1/11/1994	28	BORG-WARNER TRANSMISSION & ENGINE COMPONENTS	Hydraulic tensioner with a molded valve base and cap
05315973	10248	5/31/1994	26	UNIV BRITISH COLUMBIA, CANADA	Intensifier-injector for gaseous fuel for positive displacement engines
05115782	10189	5/26/1992	25	ROBERT BOSCH GMBH	Method for controlling a spark-ignition engine without a throttle flap
05211370	10216	5/18/1993	25		Variable orifice sealing valve
04440134	10018	4/3/1984	24	KOMATSU SEISAKUSHO KK	Fuel injection system for internal combustion engines
05259820	10237	11/9/1993	24	BORG-WARNER TRANSMISSION & ENGINE COMPONENTS	Hydraulic tensioner having a variable orifice check valve and a double helix internal ratchet
04377279	10002	3/22/1983	23	STEADLEY CO INC	Steel wire foundation

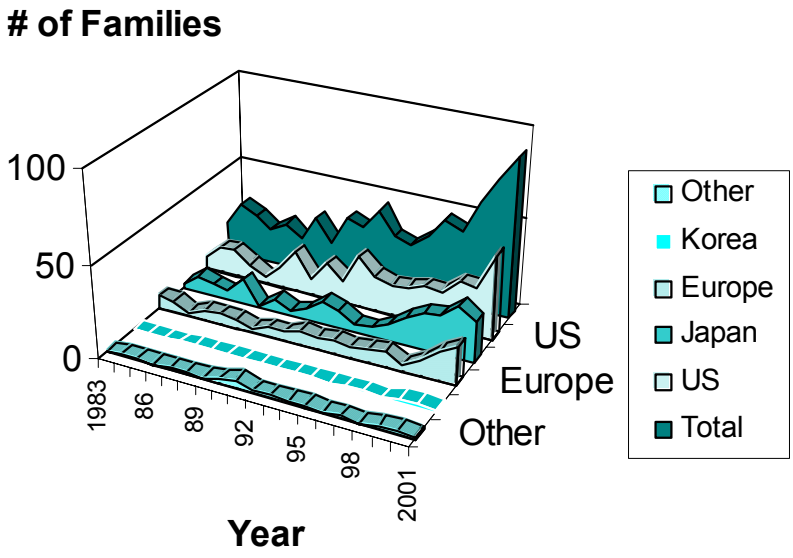
Activity - **Figure 90** clearly shows that after a long period of gradually increasing activity, there has been significant upswing in New Combustion Regimes patenting in just the last three years. In 2001, the count was over 90, coming up from 50 in 1998.

Figure 90: Patent Activity



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.

Figure 91: Trends by Region



Indicators by region - **Figure 92** provides comparisons of regional patent indicators. In terms of activity, the regions are ranked the United States 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.)

Figure 92: Indicators by Region

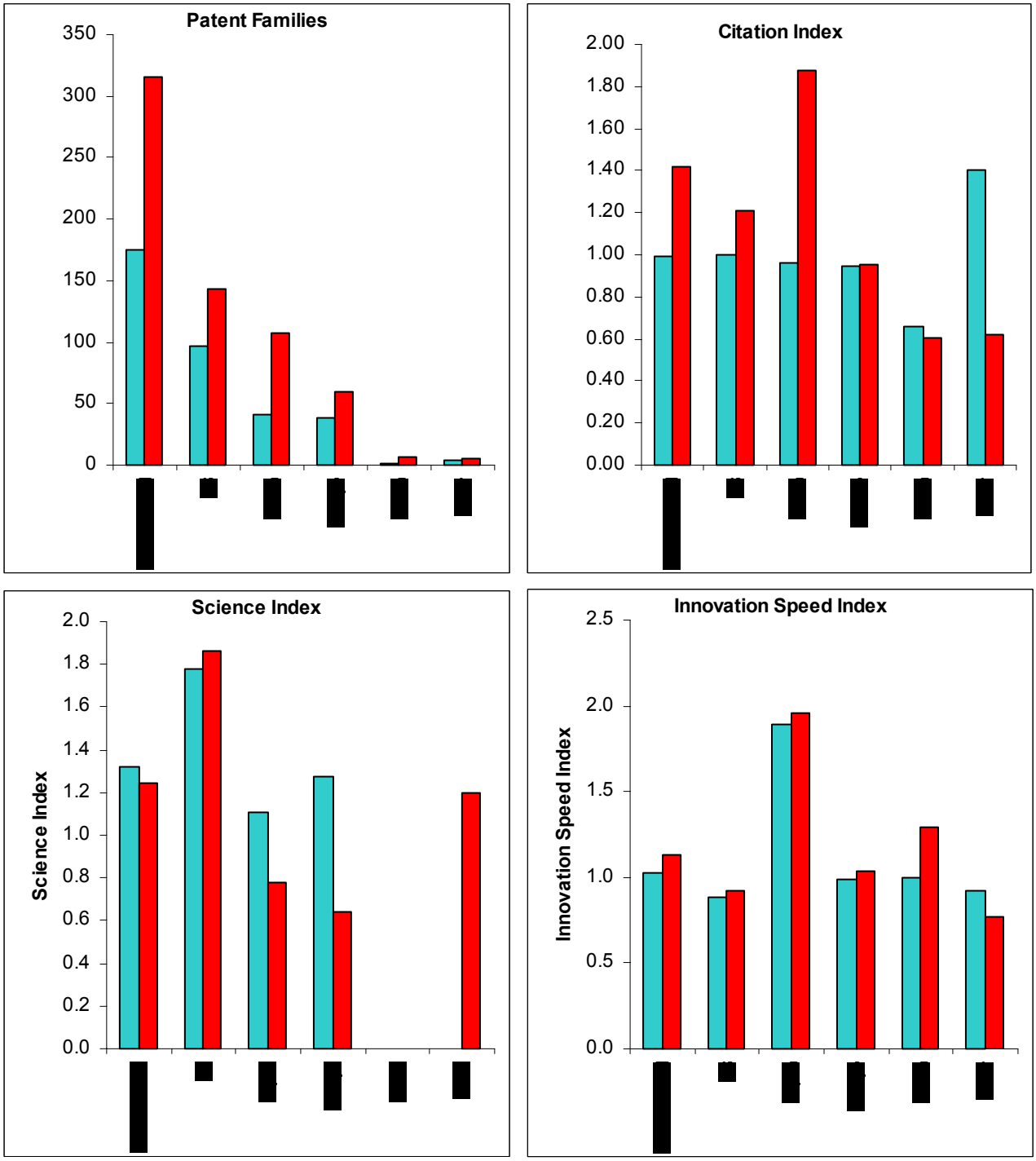


Figure 93: Most Active Companies

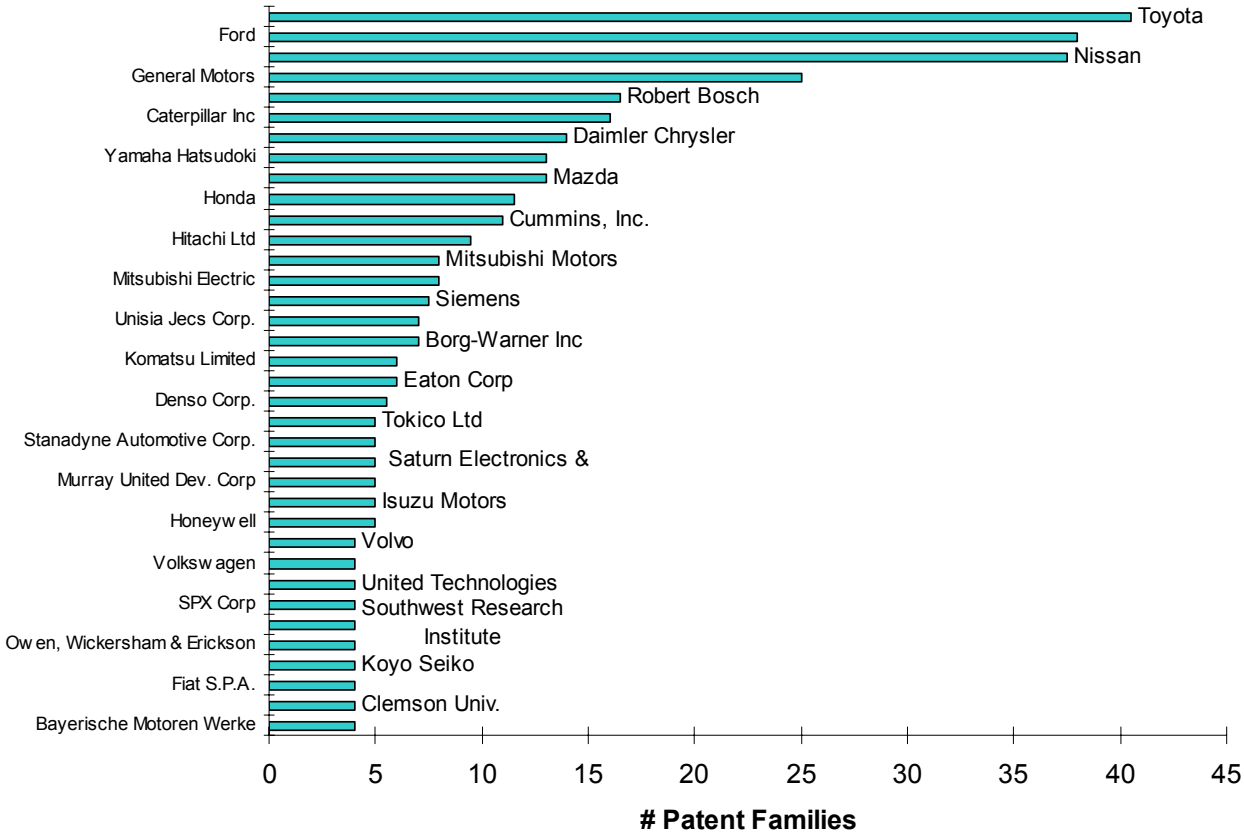
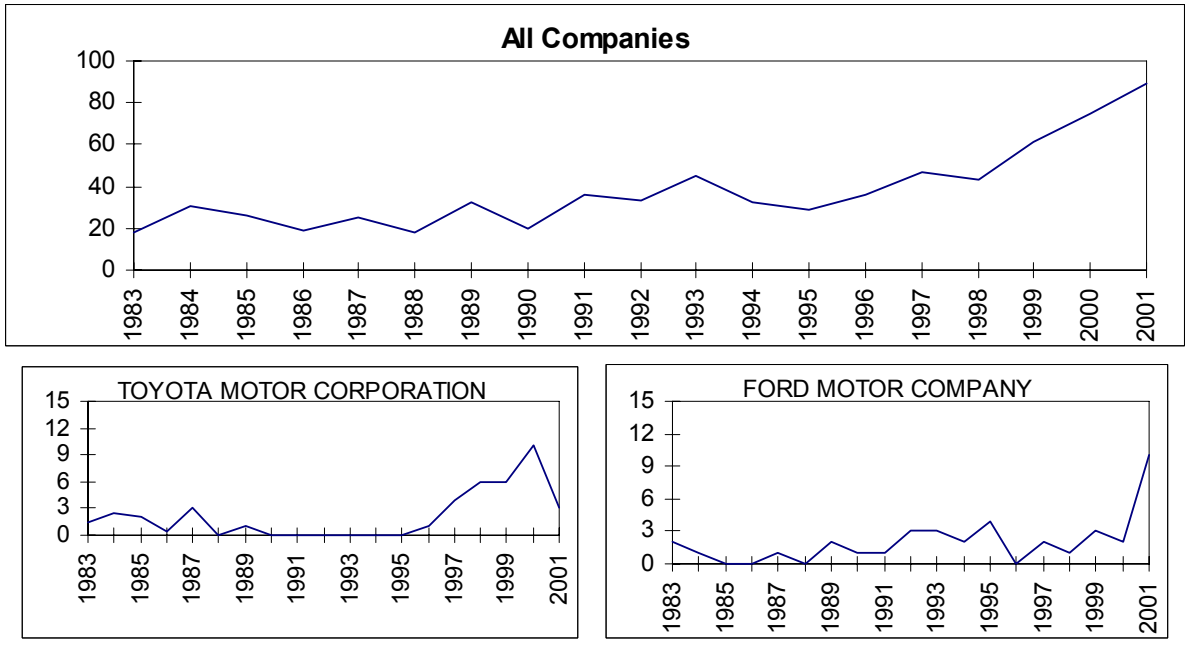
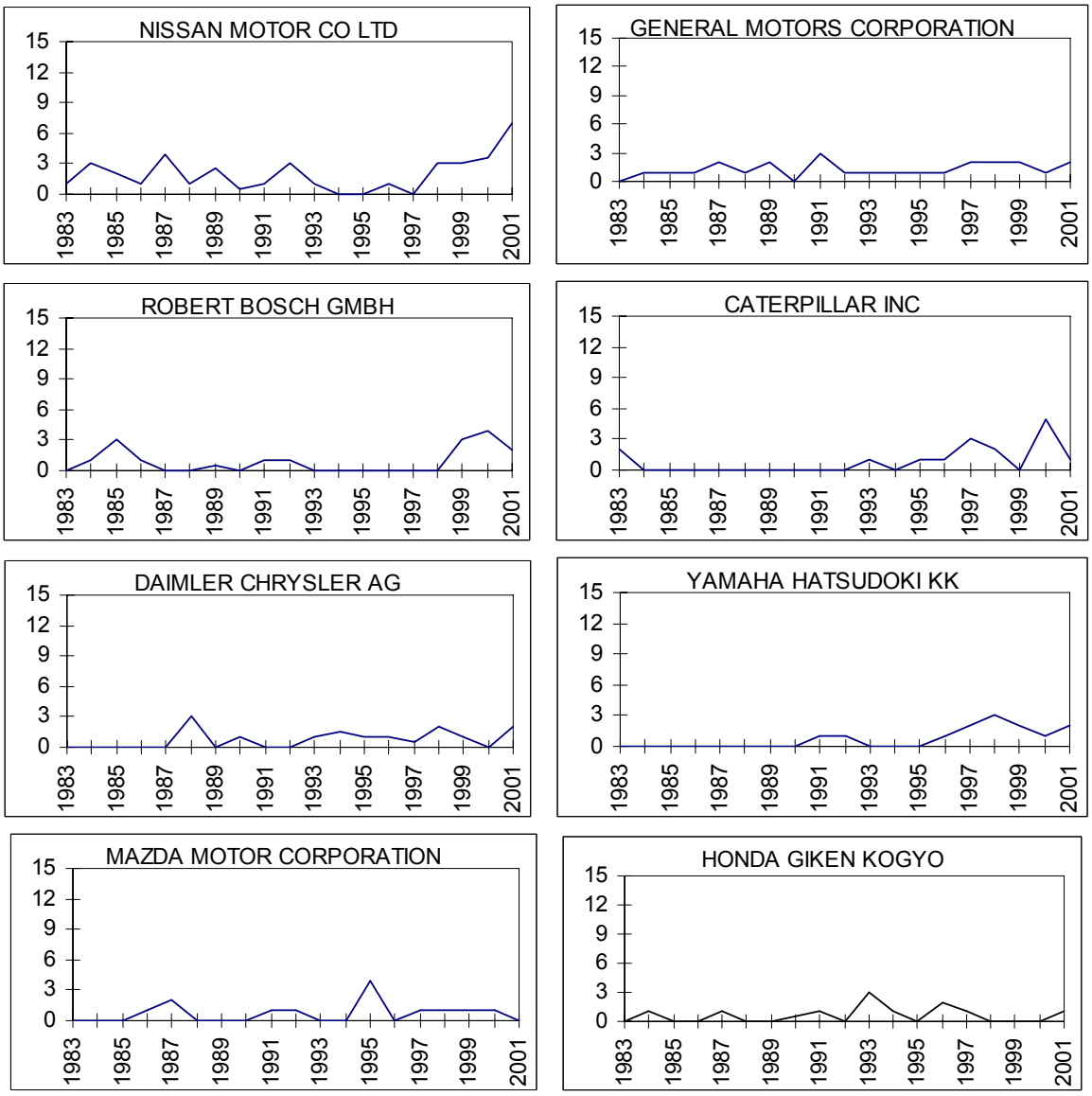


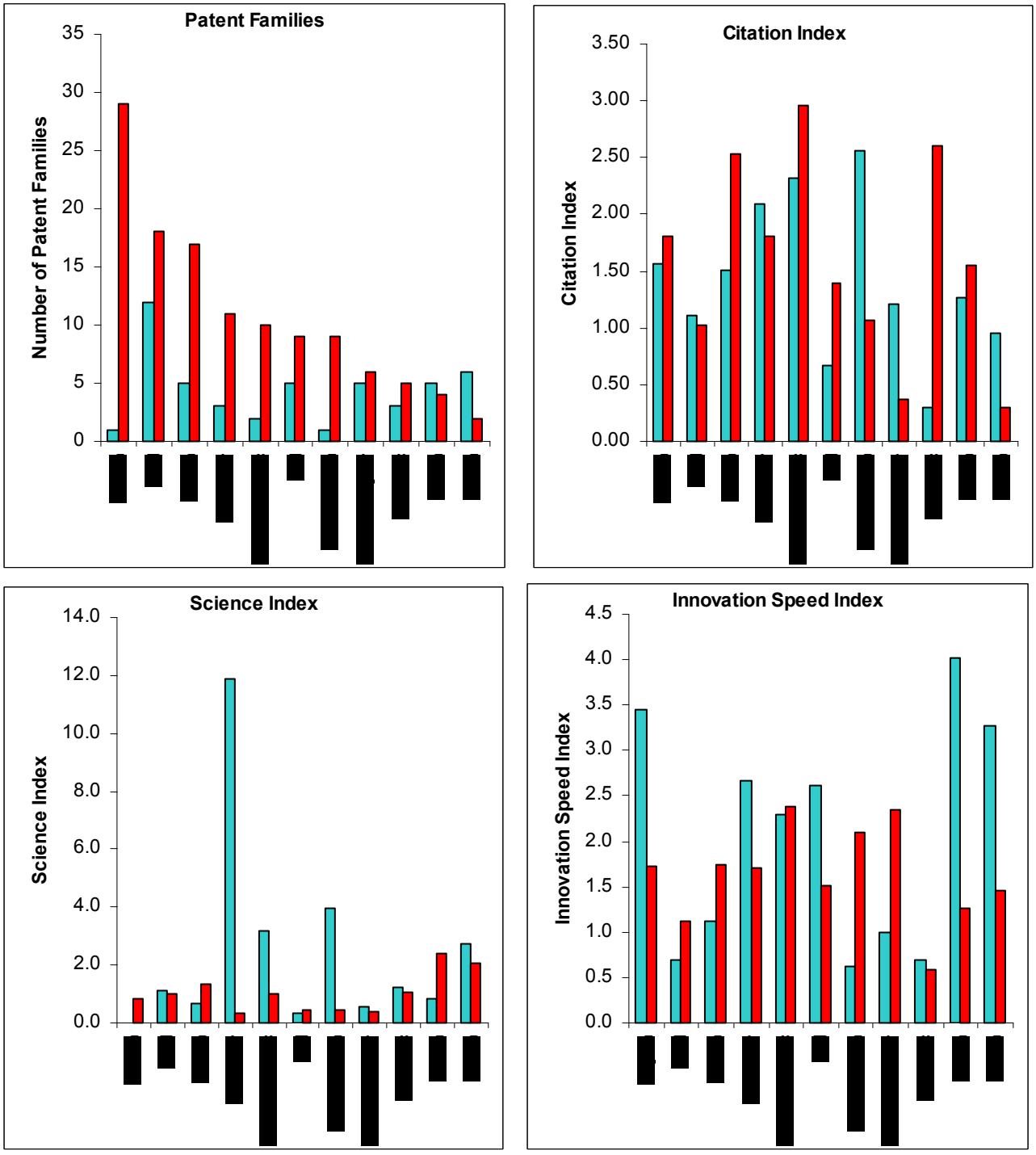
Figure 94: Activity Trends for Top Ten Companies





Indicators by company – Indicators for the top 10 are compared in **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. The very high Science Index for Caterpillar's three 1992-96 patent families should be disregarded.

Figure 95: Indicators by Company



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.

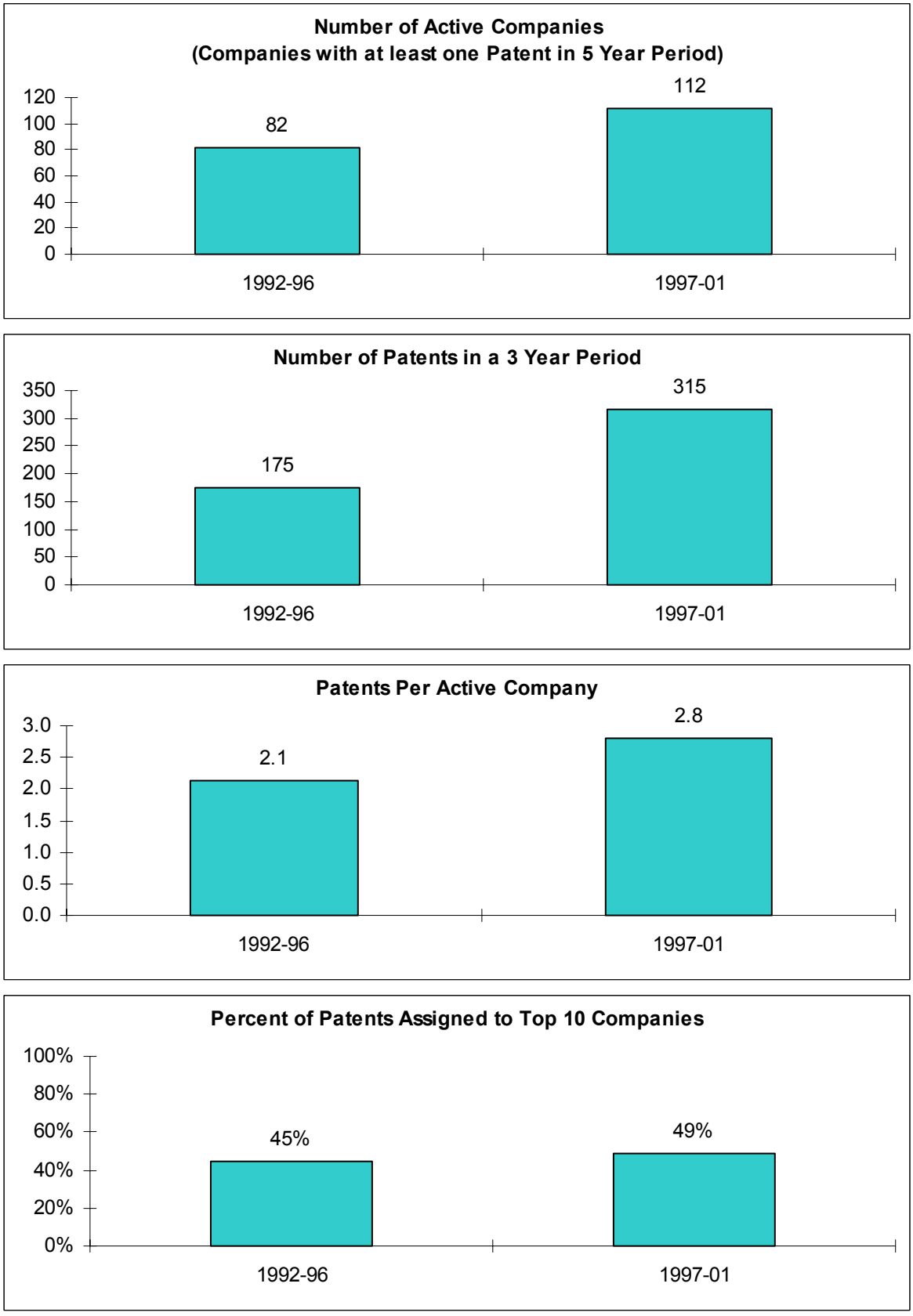
Figure 96: Emerging and Fading Companies
(Companies With Largest Increase and Decrease Among Those with 2+ Patents)

Emerging Companies	1996-1998	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	**1996-1998**	**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%

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, concentration has increased slightly, from 45 to 49 percent.

Overall Finding – While the U.S. region leads in overall activity, Japanese patenting stands above the United States (and Europe) in quality and innovation speed by a wide margin.

Figure 97: Life Cycle Statistics



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.

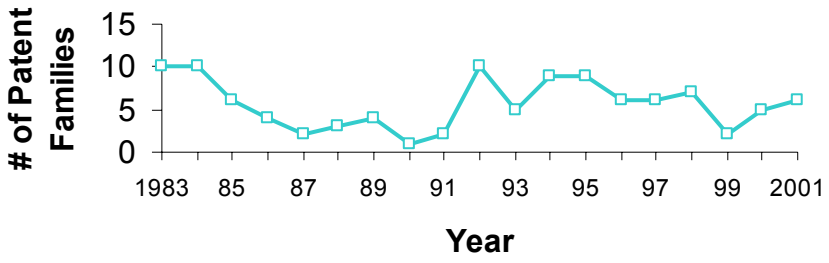
This is a very small area, with just 107 patent families. **Top-cited representative patents - Figure 98** is a list of top-cited patents, although the set is so small that the ones at the bottom of the list could hardly be termed highly-cited. This is another category where there is a large number of unassigned patents (assignee name is blank or "individual patenter"). 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.

Figure 98: Top-Cited Hydrogen ICE Patents

Patent	Family	Issue Date	Pub Date	# Cites	Assignee Name	Title
4567857	10031	2/4/86	2/4/86	26	USA NASA ADMINISTRATOR	COMBUSTION ENGINE SYSTEM
5207185	10057	5/4/93	5/4/93	26	HYDROGEN BURNER TECHNOLOGY	Emissions reduction system for internal combustion engines
4442801	10018	4/17/84	4/17/84	17	N/A	Electrolysis fuel supplementation apparatus for combustion engines
5139002	10049	8/18/92	8/18/92	17	HYDROGEN CONSULTANTS, INC.	Special purpose blends of hydrogen and natural gas
5159900	10052	11/3/92	11/3/92	17	N/A	Method and means of generating gas from water for use as a fuel
5156114	10051	10/20/92	10/20/92	15	N/A	Aqueous fuel for internal combustion engine and method of combustion
4876988	10040	10/31/89	10/31/89	13	N/A	COMBINED FUEL ENGINE
4448160	10019	5/15/84	5/15/84	12	N/A	Fuel injector
5143025	10050	9/1/92	9/1/92	11	N/A	Hydrogen and oxygen system for producing fuel for engines
4369737	10003	1/25/83	1/25/83	10	N/A	Hydrogen-oxygen generator

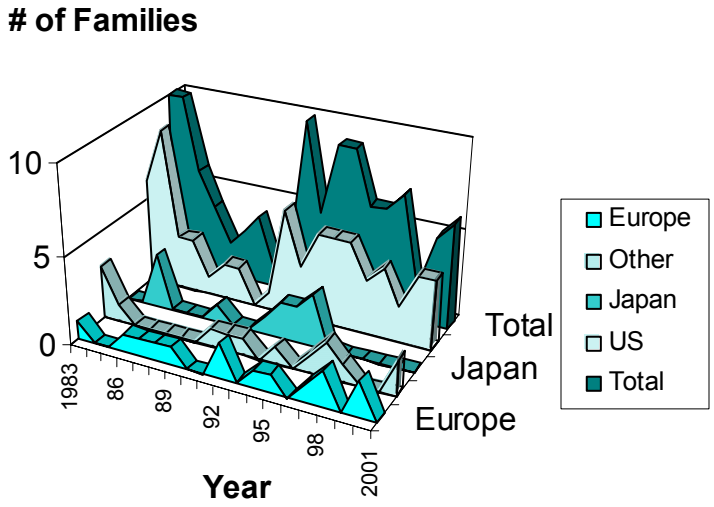
Activity – As is shown in **Figure 99**, this is both a small and declining area of patenting. The uptick in activity in the early 1990s probably reflects renewed interest in this area, but the subsequent decline in activity says that interest has gradually flagged.

Figure 99: Hydrogen ICE Patent Activity



Trends by region - **Figure 100** shows that patenting in this category is almost entirely occurring in the United States. There has been nothing out of Japan since the mid-1990s.

Figure 100: Trends by Region



Indicators by region – **Figure 101** looks at the regional indicators (see next page). While the United States is the main region of activity, the U.S. 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.

Figure 102: Most Active Companies

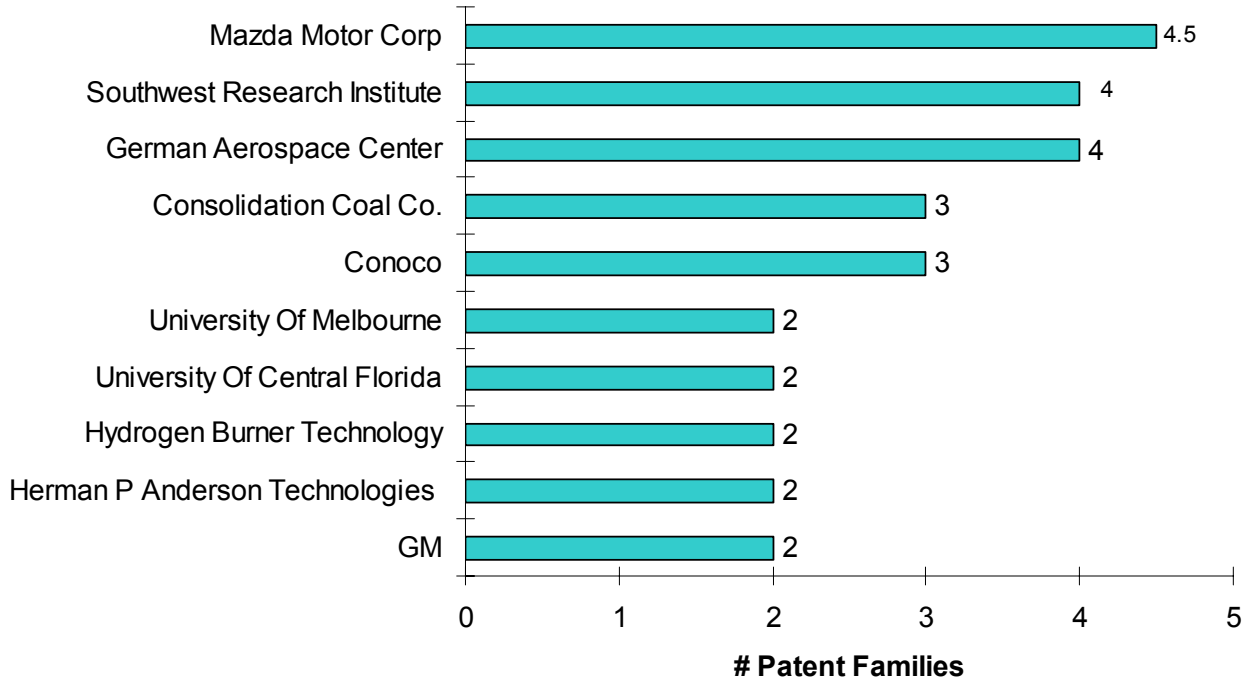


Figure 101: Regional Indicators

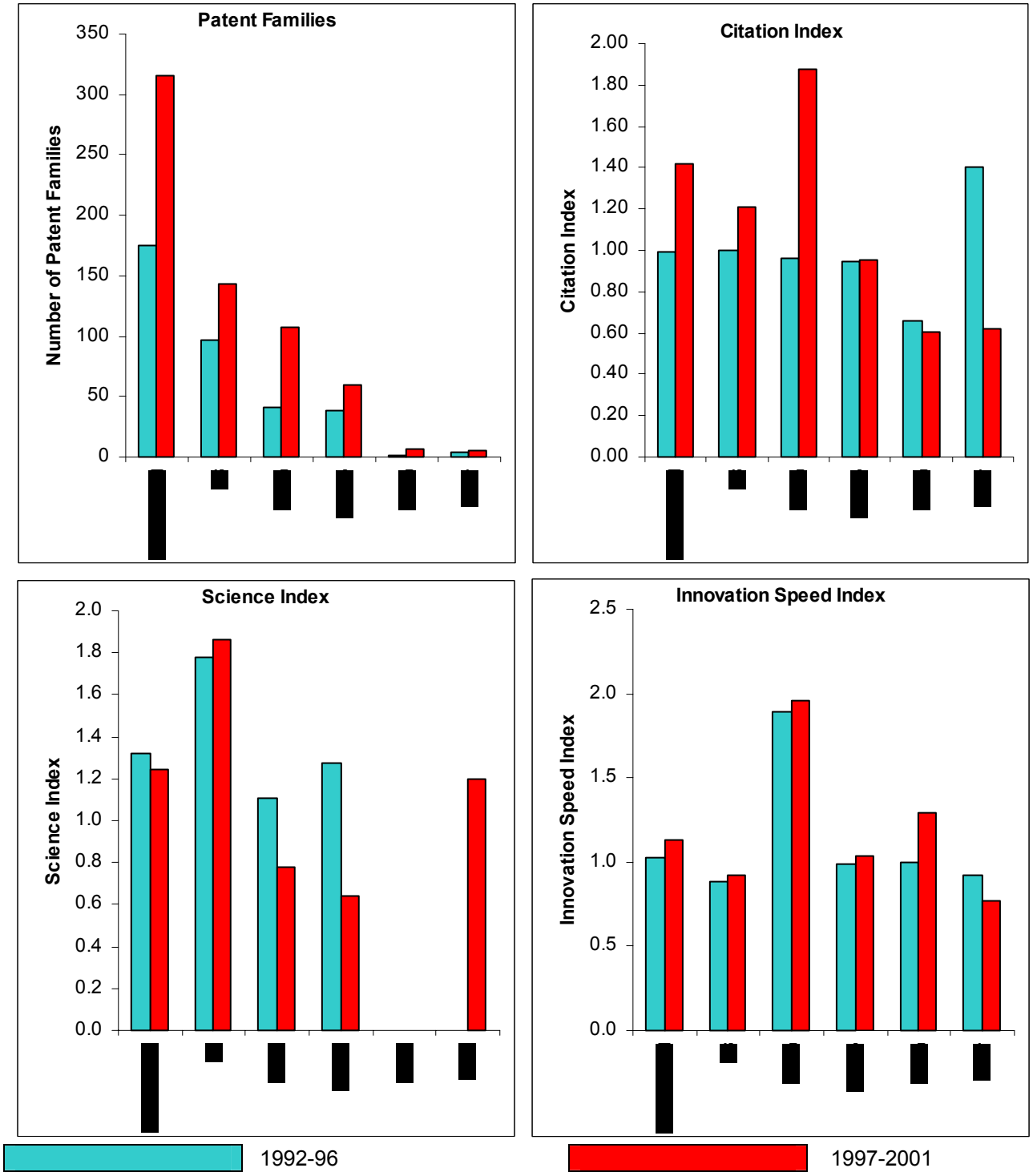
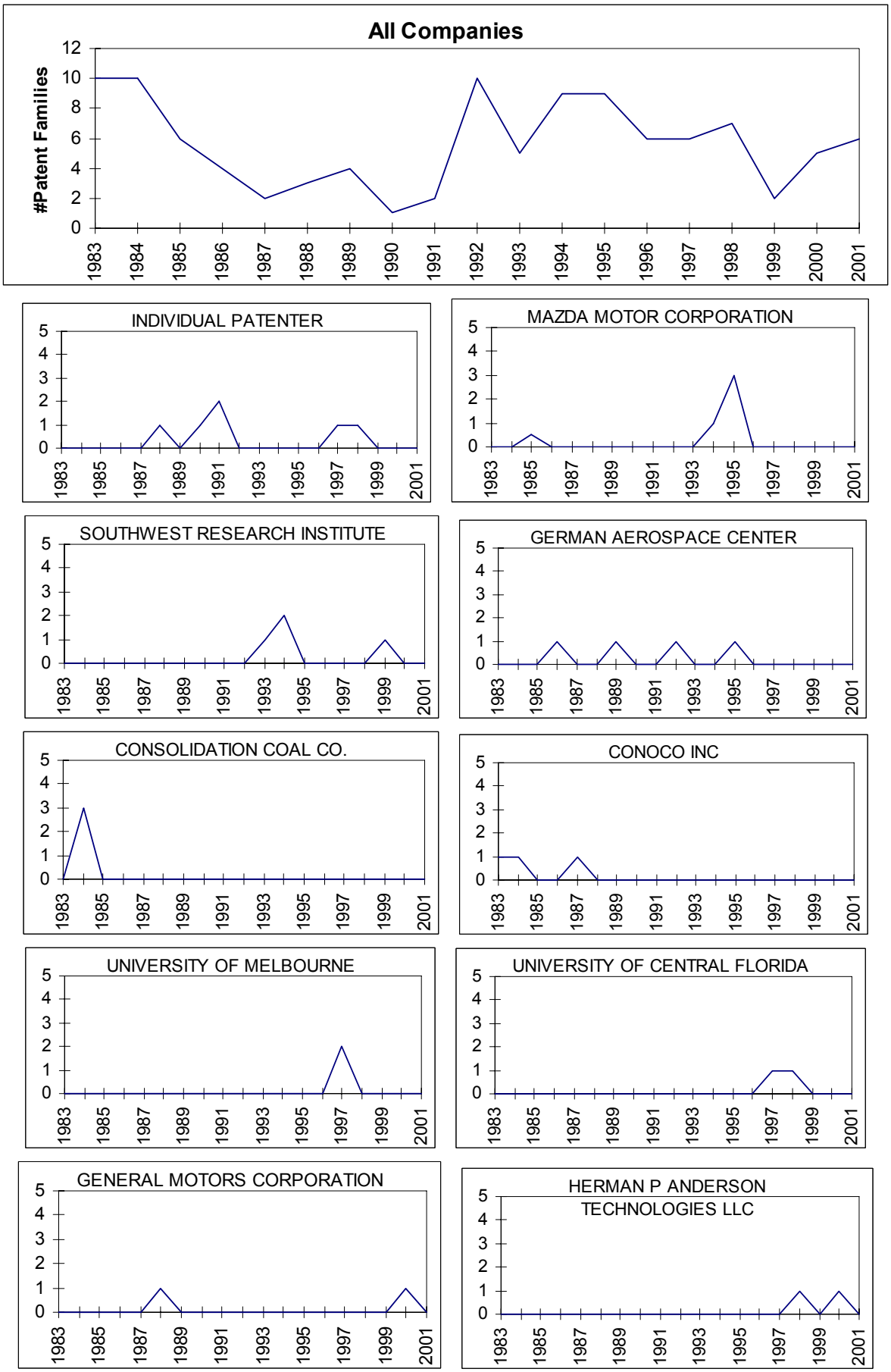
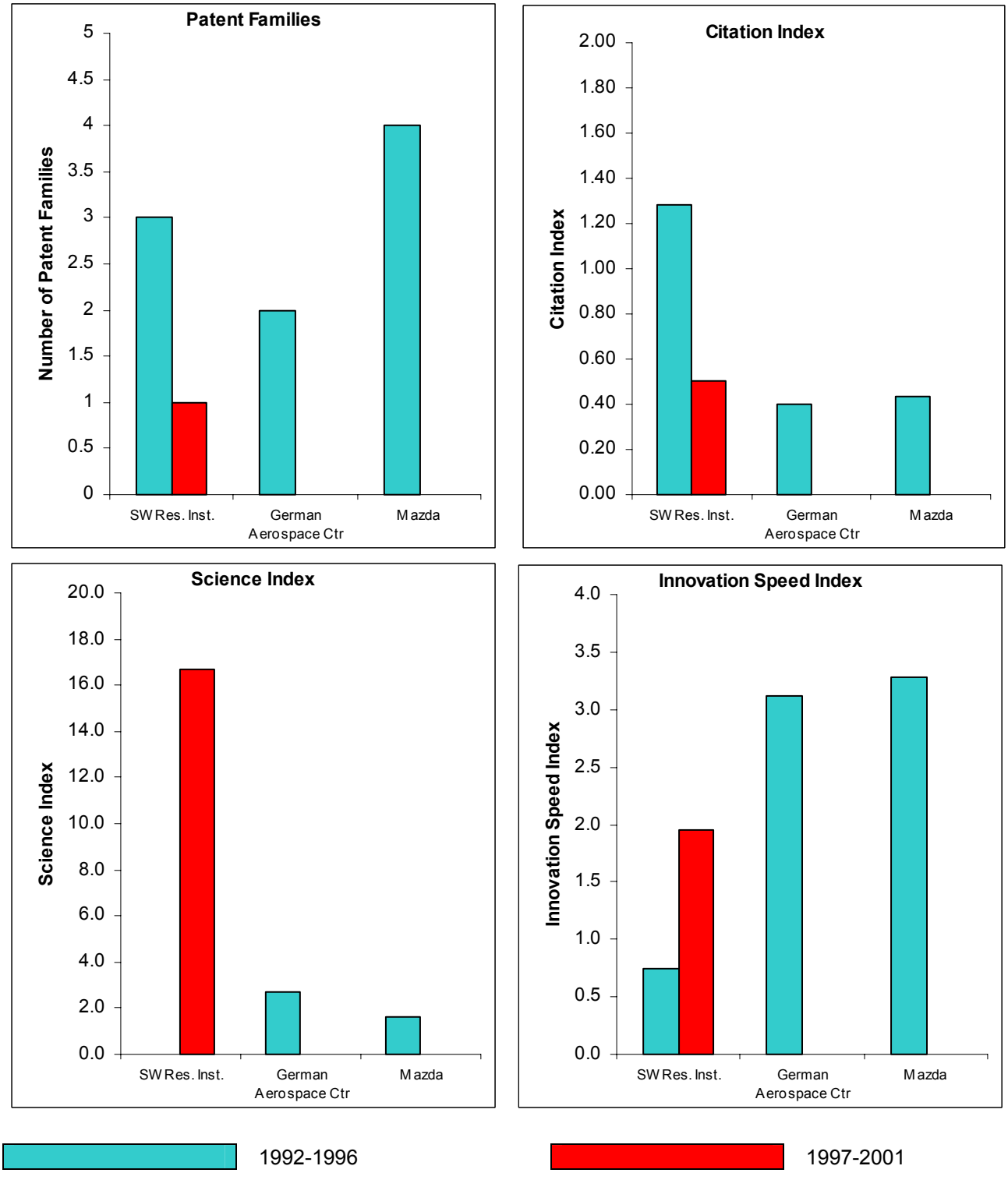


Figure 103: Activity Plots for Ten Most Active Companies



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.

Figure 104: Indicators by Company



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

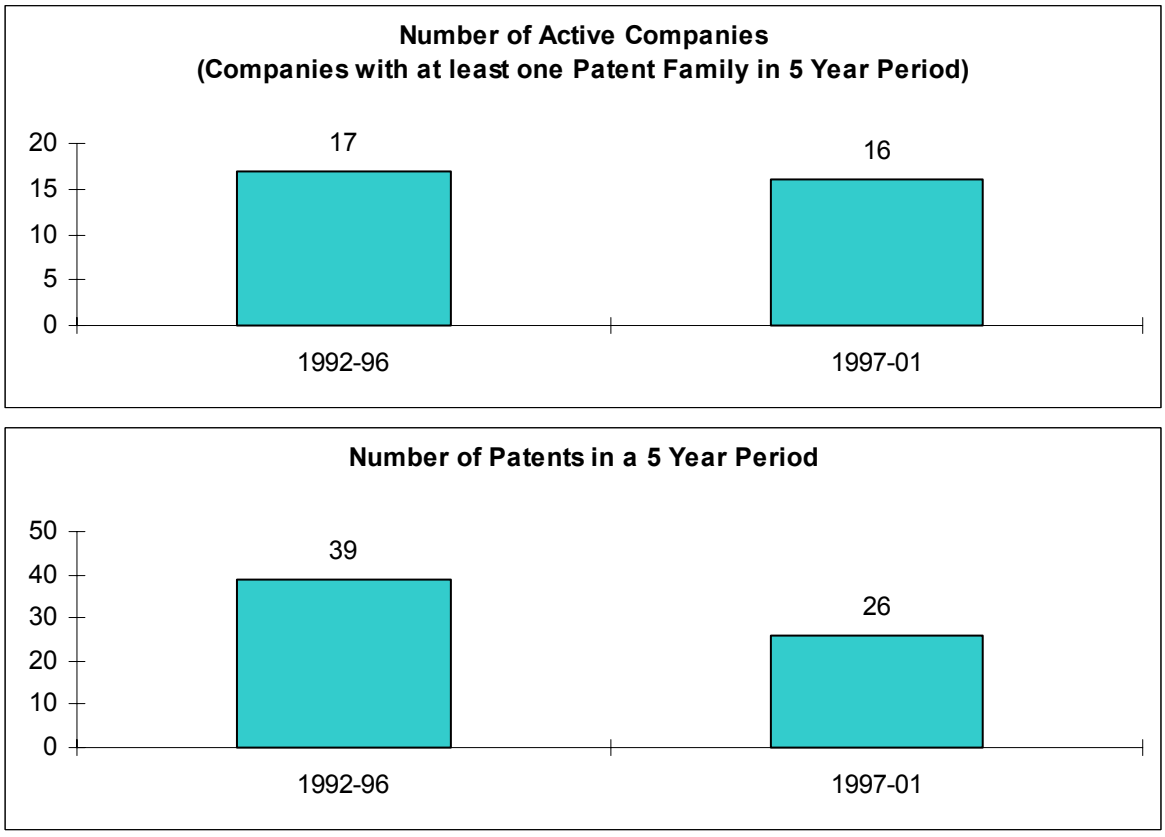
Figure 105: Emerging and Fading Companies
(Companies With Largest Increase and Decrease Among Those with 2+ Patents)

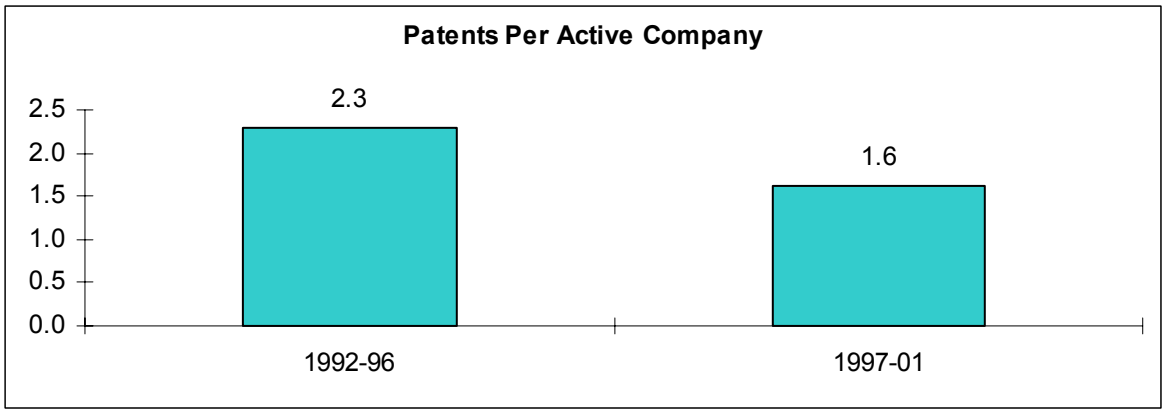
Emerging Company	1996-98	1999-2001	Increase	% Increase
Southwest Research Institute	0	1	1	Infinity
Fading Companies	1996-98	1999-2001	Decrease	%Decrease
University Of Melbourne	2	0	2	100%
University Of Central Florida	2	0	2	100%

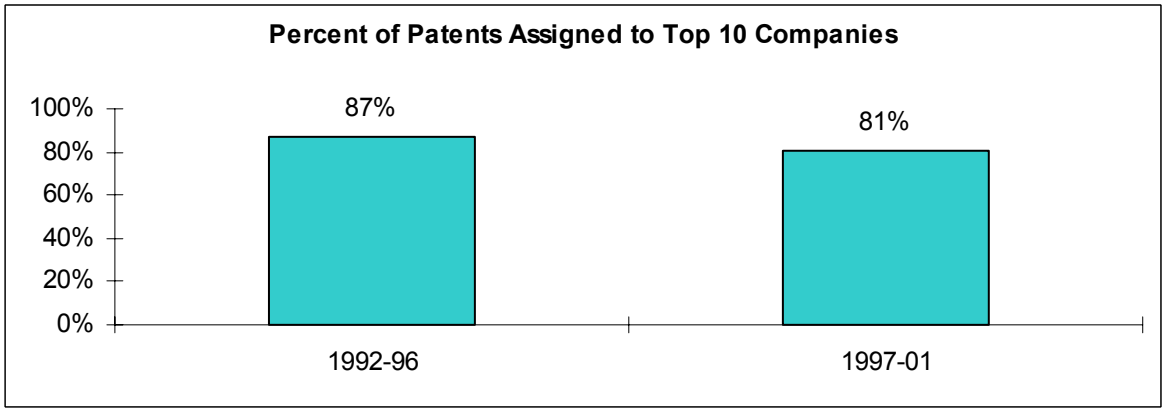
Life cycle statistics - **Figure 106** reinforces the view that thus technology is declining. There are fewer companies active in the last five years and less patents.

Overall finding – This is a very small and gradually declining area of activity centered in the United States. 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.

Figure 106: Life Cycle Statistics




Patents Per Active Company
2.5
2.0
1.5
1.0
0.5
0.0
2.3
1.6
1992-96
1997-01


Percent of Patents Assigned to Top 10 Companies
100%
80%
60%
40%
20%
0%
87%
81%
1992-96
1997-01

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Carpenter M, Narin F, and Woolf P. Citation Rates to Technologically Important Patents, *World Patent Information* 4 (1981) 160-163.

Harhoff D, Narin F, Scherer F.M. and Vopel K, Citation Frequency and the Value of Patented Inventions. (Submitted to *Reviews Economics & Statistics*, March 5, 1998).

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Thomas, P. The Effect of Technological Impact Upon Patent Renewal Decisions, *Technology Analysis & Strategic Management*, 11 (2) (1999) 181-197.

Trajtenberg. M. A Penny for your Quotes: Patent Citations and the Value of Innovations, *Rand Journal, of Economics* 21 (1990) 11.

APPENDIX A
PATENT SEARCH FILTERS

FUEL CELL FILTER[17]

Search #1:
[IPC] H01M008*[18]
[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)

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

---

[17] 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
adj$_n$ = adjacent within n words in the same direction
near$_n$ = nearby within n words in either direction

[18] H01M008* covers fuel cells and related materials

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*[19]

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

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

[19] Filters out IPC=H01M* (batteries and fuel cells IPC) to exclude electrodes

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 reinforc*
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 (AUTOMO* 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 bipolor 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