White Paper

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The Hydrogen Revolution

An evaluation of patent trends in the fuel cell industry

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Executive Summary

From a space-race era technology to a modern ecological messiah, the fuel cell has caused mass media interest in the last few years and has spawned the "Hydrogen Revolution". Last year, the possible use of hydrogen as a major energy source was elevated to a political issue, with President Bush highlighting fuel cell research and development spending levels in his State of the Union address.

Issues such as rising oil prices and increasing awareness of environmental concerns have forced companies to think about alternatives to the traditional internal combustion engine and find ways to reduce the global reliance on fossil fuel energy sources.

This report describes the explosive rise in fuel cell patenting over the past five years (1999 to 2003). The number of patented inventions has more than quadrupled during this time period and companies are fiercely competing to stake ownership on intellectual property that could one day become multi-billion dollar products.

Using data mining tools to analyze the *Derwent World Patents Index*® database, we survey the state of fuel cell patenting globally, revealing the players involved and the technology at stake.

The rise in the number of fuel cell patent applications has been punctuated by the shift in industry interest from pure energy fuel cell research companies to car manufacturers and consumer electronics firms. We will look into more detail at the forces at work in this shift.

Examining the technology itself, we will look at some of the potential problems that must be overcome before fuel cells can become mass-market items and what exactly is being patented. We will look at novel solutions to infrastructure problems, such as the storing of highly inflammable hydrogen.

We will also investigate the geographical shifts that have occurred during the survey period, with applications to the United States Patent and Trademark Office becoming a major factor for the first time in fuel cell patenting.

Finally, we discuss how attention in the media and in George W. Bush's 2003 State of the Union address is now being matched by real R&D dollars being spent by companies whose bottom line is shareholder value.

Background – Why hydrogen?

Mankind's use of resources has been an issue since the beginning of civilisation. Whether it is food, water, fuel to keep warm or jet fuel needed for a 747, resources (and their finite supply) have been the single biggest influence on the ability of mankind to explore, work, eat or even procreate. Resources are what we need in order to survive.

So what would happen if the resources we need to keep society innovating and developing become cheap and bountiful? What would be the impact of a "post-resource" society on mankind? This is not imminent and is mostly conjecture – indeed it has been said before, if one looks back to the promises of nuclear power in the 1950s. However, scientists and engineers are working on devices that would take mankind a big step closer to a cleaner, less polluted, less resource-dependent future.

In 1839, Sir William Robert Grove, a Welsh judge, invented a piece of apparatus. It was an eccentric device that took in hydrogen and oxygen and produced small amounts of electricity, as well as water. At the time, it was mostly dismissed as quirky, not very useful.

Over one hundred years later, Sir Grove's breakthrough gained meaning when the space race began in the 1960s and America decided to reach for the moon. NASA needed a high efficiency power source that could be stored on the spacecraft but did not produce waste products. Up stepped the fuel cell.

The fuel cell, in its modern post-1960s form, uses hydrogen and oxygen as fuel and combines the two using electrochemical reduction/oxidation or "redox" reactions. Out of these reactions come three by-products: electricity - needed to power NASA's fragile spacecraft; water - when hydrogen and oxygen combine, they produce water for astronauts to drink and also for cooling equipment; and heat - keeping the same astronauts from freezing in space. This single engineering innovation fulfilled the mission-critical needs for power, sustenance and warmth.

What was the potential back on Earth?

Hydrogen and oxygen are two of the most abundant elements on Earth. Oxygen can be easily taken from the atmosphere (of which it makes up 21%), plants emit it, we inhale it and it is constantly renewed. Hydrogen is a fundamental component of water. By using a little electricity, hydrogen can be extracted from seawater, which covers some 70% of the Earth's surface.

Despite the abundance of these elemental resources, little potential was seen back on Earth for these fuel cell devices. The reason - the raw materials that went into fabricating them (e.g. platinum, alkali chemicals, ultra pure hydrogen and oxygen) were very expensive to manufacture and source, restricting any large scale commercialisation. Platinum was fiscally justifiable for the space race, but not for a family car.

Engineers and scientists did not, however, totally dismiss or forget the fuel cell. If ever Earth's oil or coal resources were depleted, or became rare enough to be uneconomical, the fuel cell was a viable alternative energy source.

New Horizons

The environmental worries, economic realities and scientific advances of the last few decades have pushed the fuel cell to the forefront of the energy agenda. New horizons are emerging: If all cars were fuel cell powered, or if every house had its own fuel cell, would there be a need for expensive and environmentally damaging coal or nuclear-fired power stations?

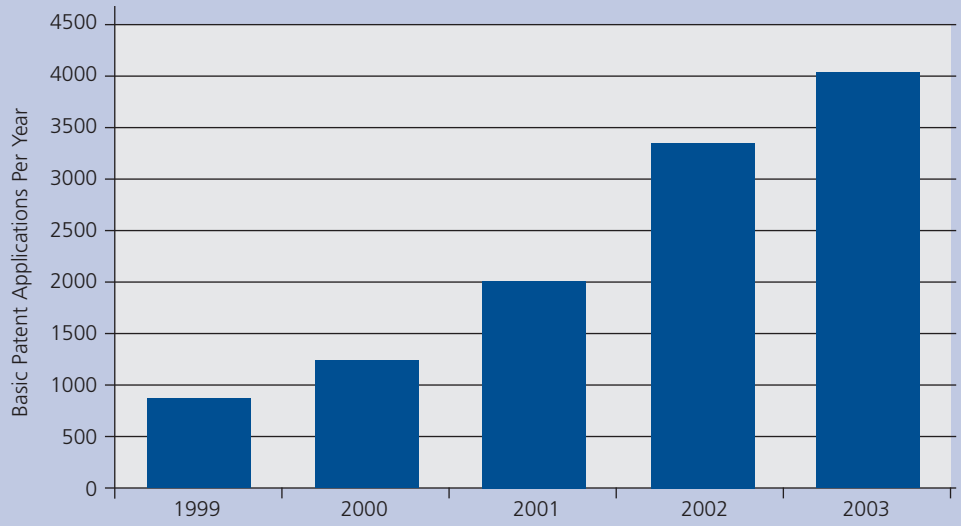
The environmental justification for developing fuel cell technology is clear and the potential business returns are massive. The challenge is in the creation of cost-effective fuel cell technology, so that every car, home, Walkman, laptop, mobile phone and MP3 player is fuel cell powered.

Against this backdrop, who is investing and where makes for fascinating reading.

Global Patent Trends

One of the most insightful means of analyzing fuel cell research trends is to examine the concurrent patenting trends (Figure 1). Patents are a significant financial investment and signal that a company is committed to bringing an innovation to market. Investment in intellectual property through patents is a strong indicator of a technology transferring from basic research into an applied product.

Figure 1: Fuel Cell Basic Patent Applications



Source: *Derwent World Patents Index, Derwent Analytics*℠

To investigate fuel cell patenting trends, we used a search strategy on *Derwent World Patents Index*® (DWPI®), the world's most extensive database of value-added patent documents, containing over 13 million inventions from 23 million patents. The search used keywords in conjunction with standardized technology classifications (manual codes[1] and international patent classifications) to profile fuel cell research over a five-year period from 1999 through to 2003.

This search produced approximately 11,000 records across the 40 patent-issuing authorities. This large result was analyzed using the *Derwent Analytics*℠ *powered by VantagePoint* data mining and visualization software. Using this software, we were able to chart the change in the number of patent records over the sample period.

There is a significant upward trend in the number of fuel cell patents published during this time period as shown in Figure 1. As an invention can be patented multiple times in several different patent authorities, we have used Basic Applications, i.e. the first application received into *DWPI* for any single invention.

The increase from 1999 to 2003 is over 360% (approximately 870 applications increasing to approximately 4,000). It is clear that significant research is going into fuel cells technology.

During 1999, at the start of our survey period, the investment in hydrogen fuel cells was not as pronounced as it is today. Figure 2, shows us which companies were actively patenting and to what extent.

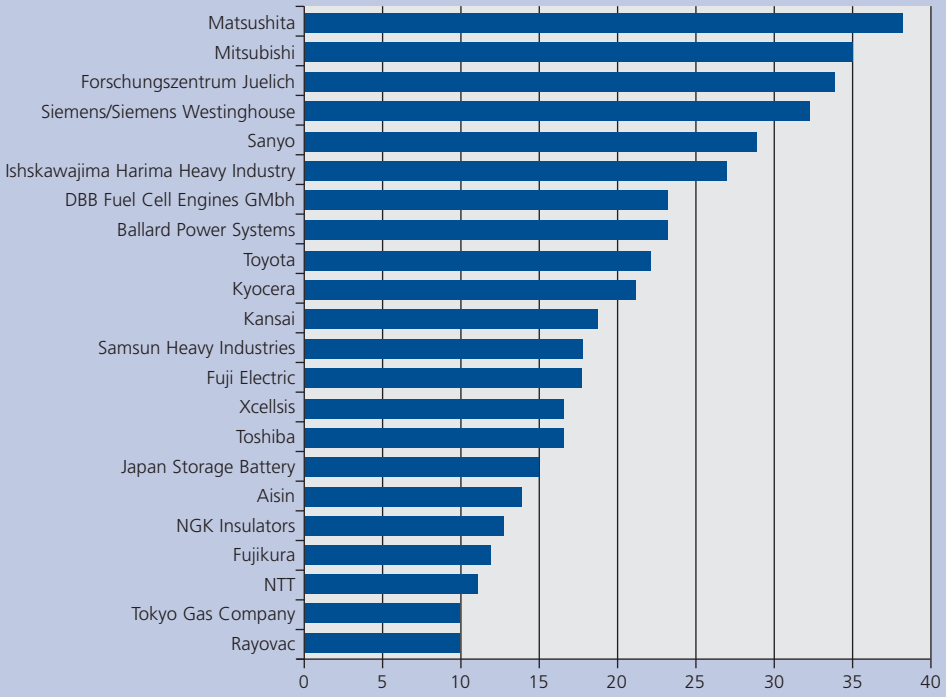
It is clear that the major patentees were Japanese companies, with Matsushita and Mitsubishi, two of the Japan's industrial giants, leading the way. It is also clear that the situation in 1999 was dominated by companies interested in fuel cell technology in general, and not in any single core application. Matsushita and Mitsubishi have large energy divisions. You must look down the list for an indication of application, for example Toyota and automobiles.

Toshiba too have been very active in patenting new technology, especially in the direct methanol fuel cell (DMFC)[2] area. Toshiba have developed a compact version that can be used in mobile headsets and audio players. The patented active DMFC technology allows for a 10-hour life for its micro fuel cells, compared with about 5 hours for a traditional lithium ion battery.

1 Manual Codes are assigned by the Thomson Scientific analysts and subject specialists that categorize patent documents using a simple, consistent system for all technologies, enabling precision searches. This is superior to relying purely on International Patent Classifications on subject areas, as inconsistencies are frequent across different patent authorities.

2 Direct methanol fuel cells – DMFC - use methanol instead of hydrogen. Direct methanol fuel cells are being considered for use in the transportation industry but as yet have limited application uses. There are also new applications for portable devices that look very promising. Signs are that DMFC technology can improve on traditional battery life for PDA's and mobile phones by up to 10 times.

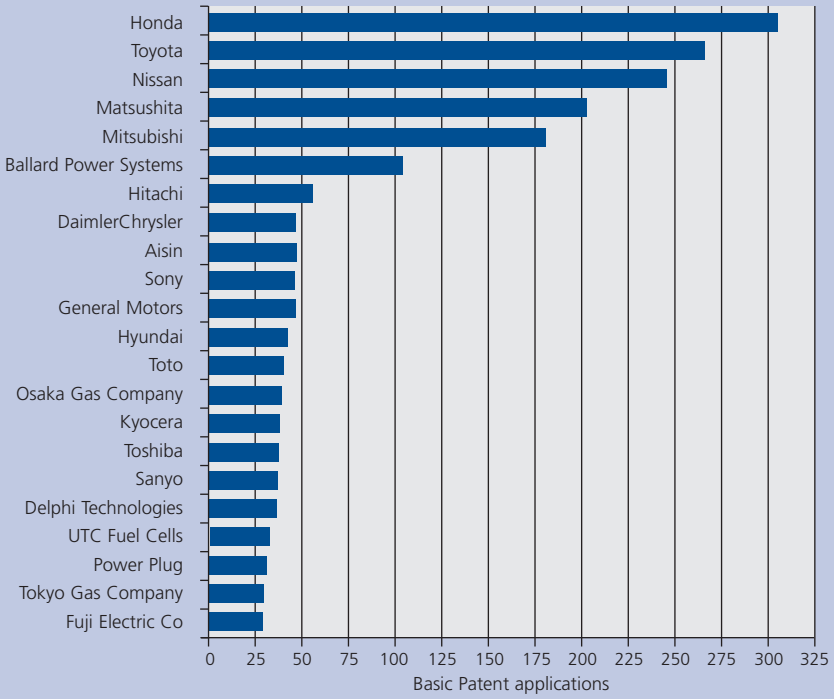
Figure 2: 1999 Top Fuel Cell Assignees



Source: *Derwent World Patents Index, Derwent Analytics*

Looking at a similar chart using data from 2003, in Figure 3, an interesting shift in the type of assignees[3] takes place. Half of the top ten assignees are major car manufacturers, with General Motors just outside in eleventh place. Clearly, something happened to fuel cell technology during our survey period. To find the answer, we looked more closely into exactly what technology applications fuel cells were being applied to.

Figure 3: 2003 Top Fuel Cell Assignees



Source: *Derwent World Patents Index, Derwent Analytics*

3 The Patent Assignee is the person(s) or corporate body to whom all or limited rights under a patent are legally transferred.

Fuel Cell Applications

Since the alkaline fuel cells were first used by NASA, several new types of fuel cells have been developed, all of which have different pros and cons.

The NASA alkaline cells, as stated above, are expensive and require very pure fuels. This still suits the space market as they tend to carry very pure hydrogen and oxygen to power their rocket motors and indeed this type of fuel cell is still employed on the Space Shuttle.

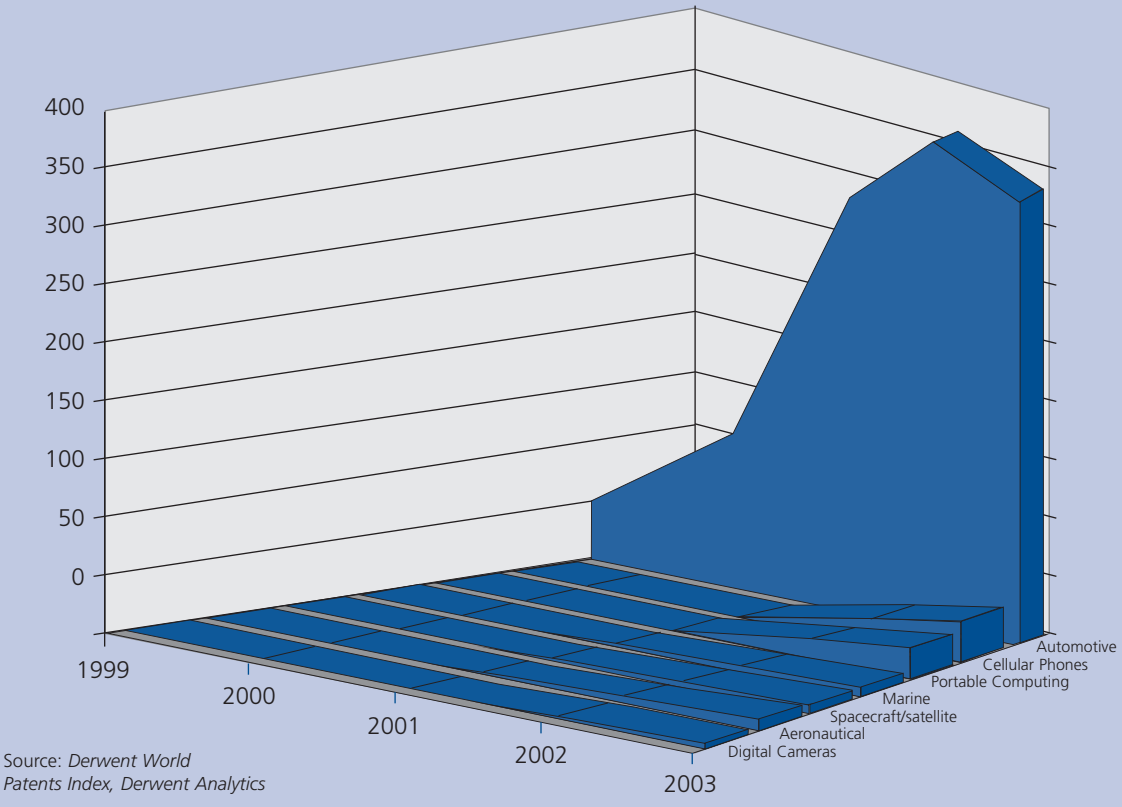
For mass supply, fuel contamination is a problem, so they do not lend themselves easily to the consumer marketplace.

What is needed is a fuel cell that is relatively inexpensive to make, is "open" to fuels (i.e. will accept hydrogen and oxygen even when not pure), whilst keeping the energy output from the cell as high as possible. Also important if usable and popular products are to be developed are issues such as weight, how long the cell takes to start up and react to changes in supply.

Cells have been developed over the past two decades that promise exactly these characteristics, though not simultaneously. This means that there now exist a range of specialized fuel cells for applications.

For example, in all likelihood the fuel cell one would develop for a London bus, will not be the same as that of a (relatively) high performance car. The same applies to a cell used to supply power to a hospital, a home or a Walkman – all will be different, with capabilities suitable to its use.

Figure 4: Patent Application Volumes, by Industry Sector



Source: *Derwent World Patents Index, Derwent Analytics*

While it is possible to go into the specific statistics for each type of cell, we will instead look at the applications themselves (Figure 4).

Again, unsurprisingly, the automotive industry has far exceeded all other industries in the number of patent applications. More interestingly, however, is the sudden rise in patent applications concerning both cellular telephones and portable computers. The relatively small number of patent applications for space technology is most likely explained by secrecy acts and government classification, avoiding the public domain publication that results from patenting.

These are two areas where the need for power supply life is currently acute. The modern rechargeable lithium battery in a laptop computer is expected to last approximately four hours of constant use, before running flat. What if you were able to use hydrogen based fuel cells to supply a laptop, which you could replace when it ran out after a month of constant use?

It should be noted that trends in patent applications for cellular phones and laptops are connected, as assignees are likely to have claimed or at least detailed both applications as relevant in their patents. However, there were slightly more applications for inventions relating to telecommunications, but again, in 2003, the usage of these applications have blurred with the increase in R&D in mobile PDAs and the like.

Activity in Japan for mobile or portable computer/phone patents has again been strong. This is in line with mobile technology developments in network technologies. DoCoMo, the dominant mobile operator in the region, has been driving handset vendors to create more efficient power supply to the ever-more sophisticated handsets in the region. The launch of 3.5G and hybrid Wi-Fi networks, have created demand for new power hungry devices to take advantage of the new bandwidth.

One new application in the mobile arena has been the use of fuel cells for the powering of Bluetooth headsets. Nokia has been testing solutions that would give 60 hours of conversation and 200 hours of standby from a 12ml bottle of methanol.

The graph, including companies such as Hitachi, Sony, Toshiba and Matsushita, highlights the potential of fuel cells within portable consumer electronics.

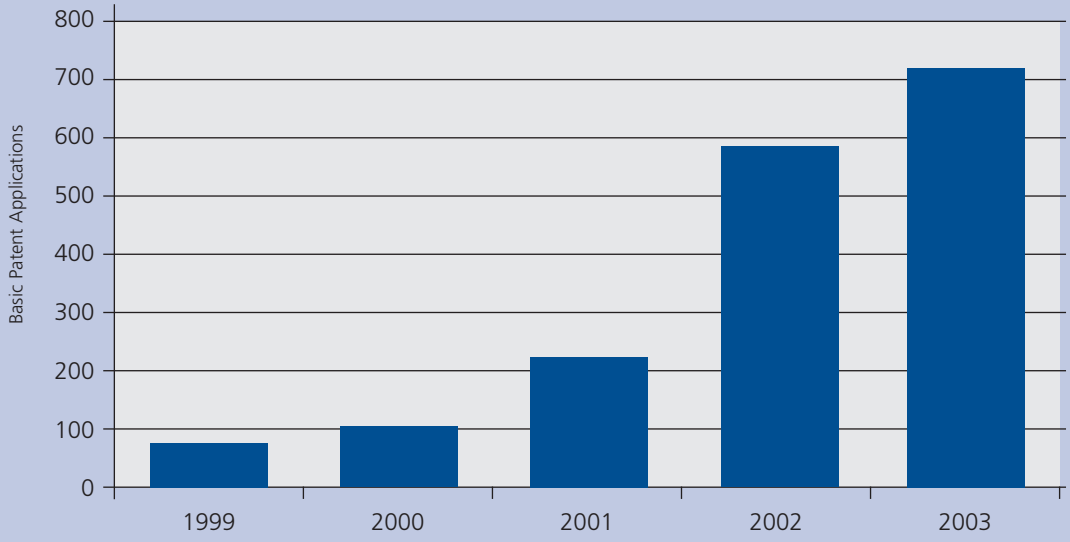
There is, however, a potentially explosive issue.

Portable Consumer Electronics – Safety Issues

There are serious safety issues, or at least the perception of safety, affecting the use of fuel cells in laptops and cellular phones. It is not hard to imagine the public outcry and associated media sensationalism at the prospect of using laptop computers with small but very explosive, canisters of hydrogen inside! This is particularly acute since laptops and mobile phones have to be safe to be carried on aircraft. It may be that, in the same way aerosol canisters need to be carried in hand luggage, the same has to be applied to fuel cells.
Whilst in a car, consumers are unconcerned about riding with inflammable liquids, this is not the case when making a phone call or using a laptop. Clearly, safety is an issue for all applications, but particularly when the fuel supply is close to hand and, more importantly, easily tampered with.

This concern with safety has become a patenting trend in its own right. Away from the electrolytes, electrodes, cases and cooling systems of the fuel cells themselves, heavy investment has been made into the storage arrangements and fuel supply for the cells.

Figure 5: Patent Application Volumes, Fuel Storage/Supply



Source: *Derwent World Patents Index, Derwent Analytics*

Figure 5, follows the same trend we have seen throughout, and reflects a difficult engineering problem. How do you store hydrogen in a format that is inert, non-combustible, yet is readily available for the fuel cell? As well as this, how can one pack enough hydrogen into the size of canister you need for the application, so that it provides power for considerably longer than a normal rechargeable battery, or else why would consumer make the switch?

The Potential of Nanotechnology

In the late 1980's, a form of carbon was discovered that had wrapped itself into a tight tube of atoms to form a single, long but almost unbelievably thin strand. So far these carbon nanotubes/nanorods/nanocarbons etc., have had few real uses.

Scientists have found that carbon canotubes (CNTs) can store hydrogen inside the tube structure of the carbon atoms in an inert manner. Additionally the tiny nature of these tubes means that the "energy density", i.e. the amount of useable hydrogen per square centimetre of nanotubes, is very high, once again neatly solving the problem for mass consumer product manufacturers.

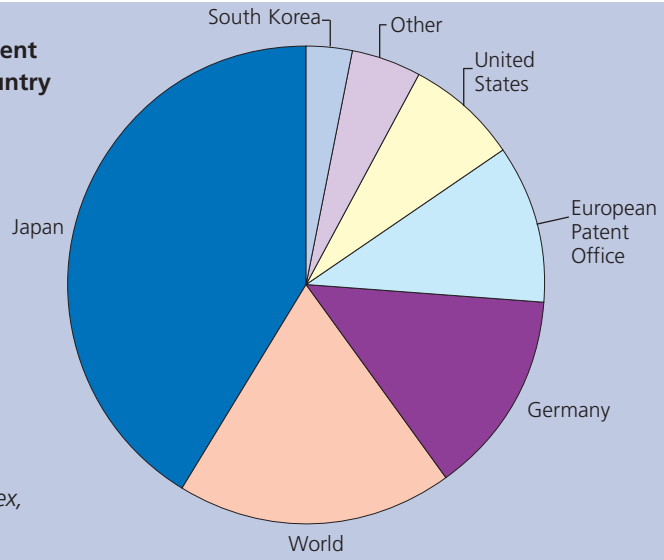
It should be noted that this example only really applies to small-scale devices. There is significant activity within this particular area of fuel cell patenting by car manufacturers, which do not yet use nanotechnology inspired solutions. Car manufacturers still require hydrogen tanking, pumping and fuel supply arrangements to make their fuel cell cars and buses work.

Regional Trends

The only American car company in the 2003 Top Fuel Cell Assignees list (Figure 3) is General Motors. The incentive to move to hydrogen-based locomotion maybe low when gasoline prices are low, but it appears that interest is increasing.

By charting where each invention was first filed as a patent (the priority country), we can begin to gain an insight into geographical trends. This is by no means scientific. Some assignees file in their own country as a matter of habit, may file under a specific authority for best protection, or because that is where the most lucrative market is.

Figure 6: 1999 Fuel Cell Patent Applications, by Priority Country



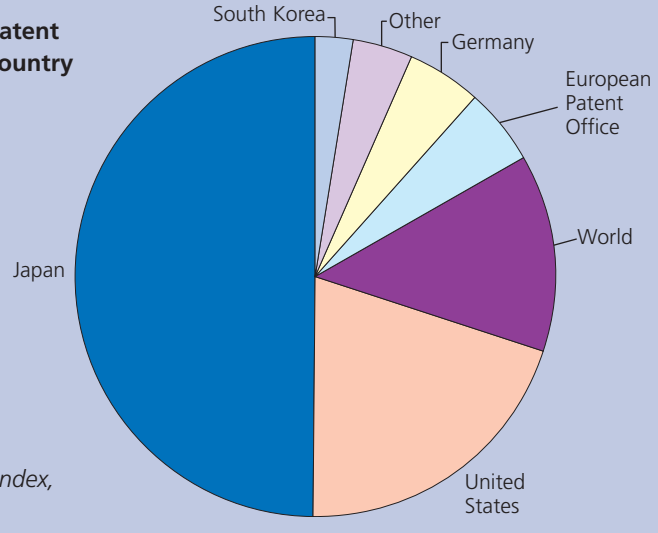
Source: Derwent World Patents Index, Derwent Analytics

They show where each patent was first filed for the years 1999 and 2003.

They show that whilst Japan has expanded its domination of this technology area (borne out by its companies dominating the Figure 3 Top Fuel Cell Assignees), the United States has seen a very large rise in priority applications between 1999 and 2003, having gone from fifth to second, leapfrogging both the major international patent authorities, the European Patent Office and the World Intellectual Property Organisation.

It should be noted that whilst Japan has maintained its domination, Germany and the rest of Europe has lost a large percentage of the overall number of patent applications. Even though the actual number has effectively doubled during the five years of the survey, matched against the increase in output from the Far East and America, Germany has dropped from third to fifth in Figure 7, and Europe has lost a significant percentage share.

Figure 7: 2003 Fuel Cell Patent Applications, by Priority Country



Source: Derwent World Patents Index, Derwent Analytics

Conclusion

Fuel cell technology has undoubtedly matured from a niche, space-based technology of the 1950s and 60s into a blossoming industry in the early 21st century.

Thirty years ago, the need to develop fuel cell technologies as an alternative to plentiful coal and oil supplies simply did not exist. NASA required them as coal and oil were not a suitable fuel for space exploration.

Now, however, with growing global concerns about severe climate change, corporations can no longer simply ignore environmental considerations, irrespective of how much the motivation is altruistic or economic.

The statistics provided in this paper give solid proof of interest from the world's manufacturers/users of fuel cells.

The automotive industry has become the single biggest patenter of fuel cell technology over the last five years and the biggest increases appear to be in patents filed in the United States and Japan.

However, notable exceptions are the European car manufacturers, who fail to make an impression in the survey. European patent applications have declined over the survey period, which may not bode well for the future health of this sector.
Moreover, this report shows that it is not just fuel cells for use in space and cars that companies are investing in. They are also looking at our phones, our computers, our digital cameras, and our homes, as viable places where we may use hydrogen, as a clean energy source.

This is because hydrogen powered fuel cells provide more power in less weight for less energy wasted than batteries and internal combustion engines.

Patent analysis shows us that R&D and patenting continue to thrive in this area, and that it may only be a matter of time before the "Hydrogen Revolution" really impacts - benefiting not only organizations and consumers but also our planet.

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