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Innovation Trends in Patent Applications for Electric Vehicles (Europe, Asia, USA)

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Abstract

With the significant improvement of electric storage technologies, vehicle control systems and automotive production methods in the last 15 years, electric vehicles were launched into the mass market at first in the USA, later also in Japan, Europe and China. For the purposes of predicting innovation trends for battery/capacitor electric vehicles, extended range electric vehicles and fuel cell vehicles, some specific trends on first and second filing of patent applications, particular electric drive train architectures, countries and applicants have been calculated based on the EPODOC database of the European Patent Office (EPO). This database contains currently more than 70 million patent and non-patent literature documents from all over the world in over 100 daily updated databases to support the work of the EPO's patent examiners. For the calculation of technology trends only published patent documents and their publication dates have been considered. The trends show a tremendous increase in the number of filed inventions for electric vehicles in Japan and China during the last few years. Furthermore, they also indicate that some European and Chinese applicants have already made up an initial shortfall in R&D activities for electric vehicles compared to Japanese and American applicants. Additionally, successive changes in R&D and filing strategies from OEMs to TIER 1 suppliers are identified. Due to the enormous growth of the Chinese R&D activities for electric vehicles during the last few years, Chinese applicants have already closed the gap with Japanese and American applicants in key technologies for electric vehicles.

Keywords: EV, EREV, electric drive, infrastructure, market

1 Technology evolution

In reality, recently hyped battery, capacitor and fuel cell driven electric vehicles are not a new phenomenon having been around for a long period of time. For instance, the first European patent application for a battery driven electric vehicle was filed in Germany and France in the 19th century [1]. During the last 100 years battery, capacitor and fuel cell technology for electric vehicles has been further improving step by step. However, due to the enforced development of crude oil based engine technology in the last century, comfort, reliability and cruising range of conventional vehicles have been increasing even faster. Furthermore, the cost benefit ratio of these vehicles has also improved enormously despite the exploding complexity of conventional drive trains (especially of down sized turbo engines and multispeed gear boxes) [2]. As a result, until the 21st century, the development of rather less complex, but due to slow development of electric storage systems still more expensive electric vehicles remained almost exclusively in the small

production batch phase. With the large improvement of electric storage technologies, vehicle control systems and automotive production methods electric vehicles were launched into the mass market at first in the USA (Tesla Roadster) and later also in Japan (Mitsubishi i MiEV), Europe (Renault Fluence Z.E.) and China (BYD e6). Parallel to this technology improvement the complexity and interdisciplinary nature of electric drive trains also exploded in a virtual manner (figure 1).

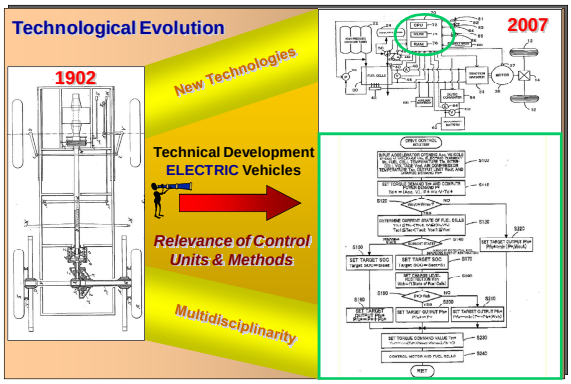

Figure 1: Improving complexity and interdisciplinary nature of electric drive trains in patent applications [3]

2 Research & Development Trends

Patent strategies as part of innovation, research and development strategies represent typically the business strategy of inventors. Because patent applications are the commonly used basic element of each patent strategy, they contain, in the form of trends, detailed information about the specific patent strategy and in general also about the strategic development in OEMs and suppliers. Therefore patent applications are able to hint at future development directions and technology trends related to countries, particular drive train architectures and applicants also in the field of electric vehicles.

Filing trends for patent applications help to estimate the future development in related technology fields, R&D activities, protection strategies for inventions and technology improvements related to applicants and countries. All trends in this paper have been created based on the EPODOC database of the European Patent Office (EPO). This database has been developed by the EPO to carry out more efficient searches for the worldwide state of the art in different technologies. Currently the EPODOC database includes more than 74.000 examples of published patent and non-patent literature documents related to the field of battery/capacitor electric vehicles, range extended electric vehicles and fuel cell vehicles. Only 9 % of these documents are related to extended range electric vehicles and just 4 % to fuel cell electric vehicles. The remaining 64 000+ documents are specific to battery/capacitor electric vehicles. In order to predict all trends in the paper, only published patent documents with their publication dates have been considered. Priority documents for these patent applications may have already been filed 18 months before their publication date.

Between 1997 and 2011, the number of filed inventions (first filed patent applications) for battery/capacitor, range extender or fuel cells driven electric vehicles jumped up by 369 %, from 835 to 3916 inventions per year. In comparison with this, the number of filed inventions for combustion engine driven conventional vehicles increased in the same period by just 55 %, from 2347 to 3638 inventions per year. In this period, the number of filed inventions for hybrid vehicles (comprising parallel and serial-parallel engine-electric drive trains) rose by 418 %, from 285 to 1477 inventions per year, however on a substantially lower level. Furthermore, in 2011 **more inventions** have already been published for battery/capacitor, range extender or fuel cells driven **electric vehicles** than for combustion engine driven conventional vehicles (figure 2).

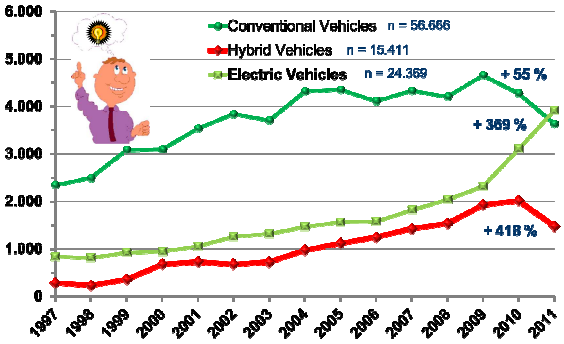

Figure 2: Filing trends on inventions for electric, hybrid and conventional vehicles between 1997 and 2011

Figure 2 also shows the significantly higher importance of research and development activities for electric vehicles in comparison with the same activities for hybrid vehicles, especially over the last few years. This indicates that despite the current middle-term future vision of hybrid driving worldwide, **electric driving technology** could provide a realistic alternative drive train for the **long-term future** for OEMs and suppliers.

2.1 Country-specific trends

Usually the first filing of a patent application is made in the same country where most of the applicant's research and development activities for the base invention of an application have been carried out. Therefore the participation of countries in first filing of patent applications is another indicator for innovative capacity of countries in addition to the number of patented inventions per country. Thus the number of first filed patent applications for electric vehicles per country indicates the countries in which the applicants carry out most of their research or development activities in the field of electric vehicles.

Between 1997 and 2011, most of the research and development work for electric vehicles (driven by battery/capacitor, range extender or fuel cell) was executed in Japan, China and Europe (figure 3).

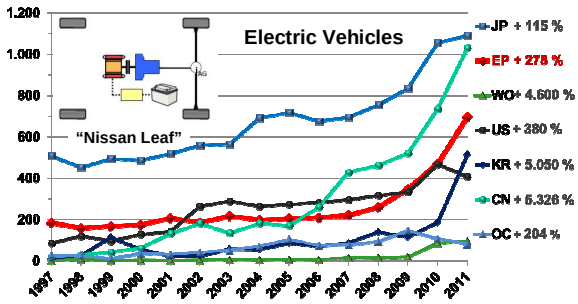

Figure 3: Country-specific inventions for electric vehicles between 1997 and 2011

Figure 3 confirms the exploding research and development efforts in the field of **electric vehicles**, especially **in China** (+ 5326 % more inventions in 2011 compared to 1997), in Korea (+ 5050 % more inventions in 2011 compared to 1997), and the USA (+ 380 % more inventions in 2011 compared to 1997), over the last 15 years. In comparison to the enormous technical efforts in these countries, the research and development activities for electric vehicles outside of Japan, China, Europe, Korea and USA have been less intensive in this period (+ 204 % more inventions in 2011 compared to 1997).

Compared to the electric vehicles, for serial-parallel distribution type full **hybrid vehicles** (e.g. Toyota Prius/Lexus), for parallel full hybrid vehicles (e.g. VW Touareg TSI Hybrid) and for parallel mild hybrid vehicles (e.g. Honda Civic Hybrid), the dominant research and development activities were made **in Japan**, Europe and the USA (figures 4, 5, 6).

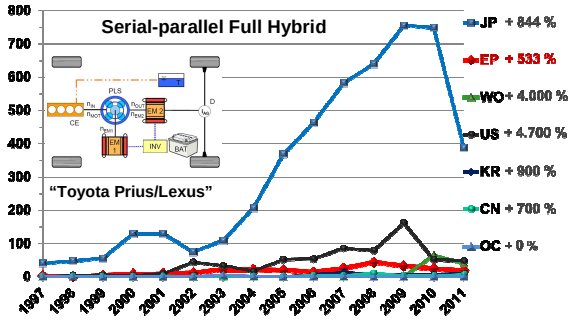

Figure 4: Country-specific inventions for serial-parallel differential distributing type full hybrid vehicles between 1997 and 2011

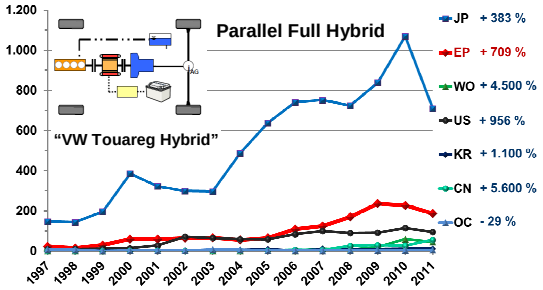

Figure 5: Country-specific inventions for parallel full hybrid vehicles between 1997 and 2011

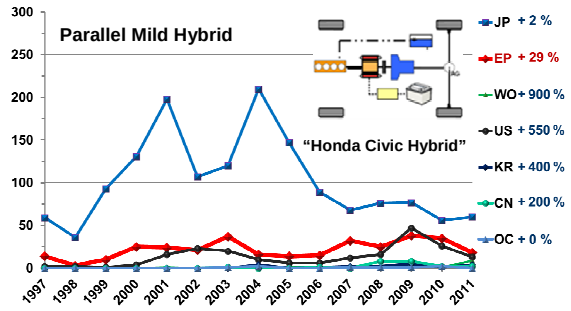

Figure 6: Inventions for parallel mild hybrid vehicles between 1997 and 2011 related to specific countries

From figure 4 it can be deduced that most of the research and development activities for serial-parallel distribution type full hybrid vehicles were executed between 1997 and 2011 in Japan (but "only" + 844 % more inventions in 2011 than in 1997) and the USA (+ 4700 % more inventions in 2011 than in 1997). However, the number of inventions in the USA began at a significant lower level than in Japan. Compared to the huge technical efforts in these countries, the research and development work in the field of serial-parallel distribution type full hybrid vehicles did not play an important role outside of Japan, the USA, China and Korea in this period (no more inventions in 2011 than in 1997).

Figure 5 indicates that between 1997 and 2011 most of the research and development activities for **parallel full hybrid vehicles** were made in Japan (+ 383 % more inventions in 2011 compared to 1997), Europe (+ 709 % more inventions in 2011 compared to 1997) and the USA (+ 956 % more inventions in 2011 compared to 1997), but in all three countries on a significantly lower level than for electric vehicles.

Figure 6 shows that between 1997 and 2011 most of the research and development activities for **parallel mild hybrid vehicles** were made in Japan (only + 2 % more inventions in 2011 than in 1997), Europe (+ 29 % more inventions in 2011 than in 1997) and the USA (+ 550 % more inventions in 2011 than in 1997) but in all three countries again on a significantly **lower level** than for electric vehicles.

2.2 Drive train architecture trends

Between 1997 and 2011, almost 86 % of the inventions related to particular electric drive train architectures in EPODOC disclose the state of the art as battery/capacitor driven architecture (e.g. Nissan Leaf), 10 % as a range extended electric drive train architecture (e.g. Fisker Karma) and 4 % as a fuel cell driven architecture (e.g. Mercedes F- Cell).

The **sharpest increase** in the number of first filed inventions for electric vehicles can be seen between 1997 and 2011 for **battery/capacitor driven architecture** (+ 384 % more inventions in 2011 than in 1997). Compared to this, in the same time period the yearly based first filing numbers for range extended drive train architecture and for fuel cell drive train architecture went up by + 450 % and 220 % respectively, however, on a significant lower level than for battery/capacitor driven drive train architecture (figure 7).

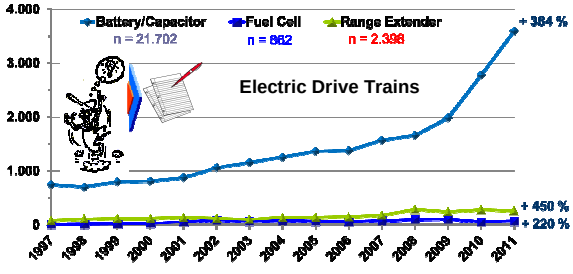

Figure 7: Inventions for electric vehicle drive trains with battery/capacitor, range extender and fuel cell between 1997 and 2011

Between 1997 and 2011, nearly 52 % of the inventions related to particular architectures for energy storage charging/replacement in EPODOC disclose the state of the art as a conductive charging architecture, 27 % as a battery replacement architecture and 21 % as an inductive charging architecture.

For inventions relating to particular charging/replacement architectures the **highest rise** in the number has been registered for the inventions with **conductive charging** architecture (+ 1667 % more inventions in 2011 compared to 1997) and for the inventions with inductive charging architecture (+ 1133 % more inventions in 2011 compared to 1997). The battery replacement architecture has shown between 1997 and 2011 "only" a lesser annual based increase of + 520 % (figure 8).

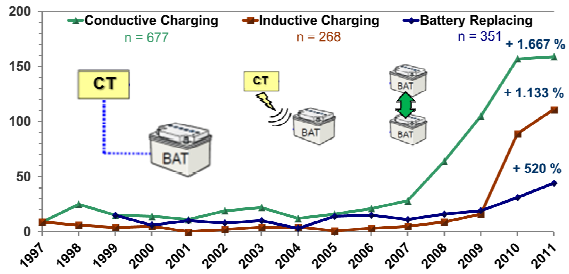

Figure 8: Inventions for conductive and inductive charging as well as battery replacement between 1997 and 2011

Figure 8 also shows the **growing importance** of research and development activities for **inductive charging** and battery replacement in comparison with the same activities for conductive charging, especially over the last few years.

Between 1997 and 2011, in EPODOC almost 40 % of the inventions for safety and reliability purposes in electric vehicles are related to fuel cell failures, 28 % to battery failures, 13 % to isolation failures (e.g. ground fault failures), 5 % to electric machine failures and only 4 % to control unit failures.

Under inventions relating to safety and reliability purposes in electric vehicles, the **highest** annual based **rise** has been registered with + 1000 % for **inverter failure managing inventions** and with 833 % for isolation failure managing inventions. Compared to this, between 1997 and 2011, inventions managing electric machine failures and controller failures have shown a lesser increase of + 250 % and 20 % respectively (figure 9).

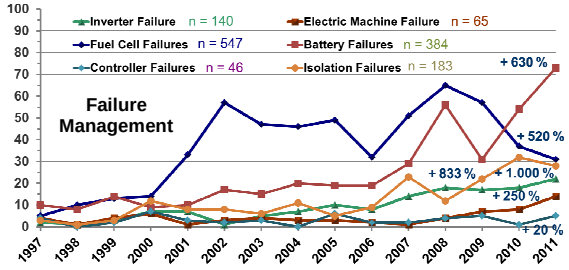

Figure 9: Safety and reliability related inventions for electric vehicles between 1997 and 2011

2.3 Technology trends

Generally the inclusion of particular technologies in patent applications indicates the importance of these technologies in the ongoing research and development activities of applicants.

For example, in 2008, the **majority** of the of the first and second filed patent applications for electric vehicle architecture dealt with application of **wheel hub machines** in vehicle traction, controlling and cooling electric machines for vehicle traction, application of batteries and fuel cells in vehicles, defining the battery position in vehicles and using **wind/solar power** for driving the electric vehicle.

With respect to the number of first and second filed patent applications concerning electric vehicle architecture, the **importance** of using wind/solar power for vehicle traction motors, controlling battery temperature, **conductive charging** and charging stations, using fuel cells as well as the importance of **battery monitoring** has increased between 2006 and 2008 (figure 10).

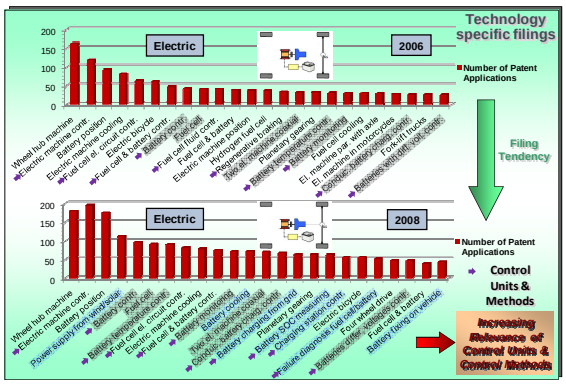

Figure 10: Inventions related to specific technologies for electric vehicles in 2006 and 2008 [4]

3 Protection Trends

Typically patent applications are published in countries in which the efficient protection of inventions against potential competitors is necessary.

In each year between 1997 and 2011, most of the filed inventions for **battery/capacitor driven electric vehicles** were published in China, Japan and the Europe. This shows the tremendous importance of the **Chinese** domestic car market for OEMs and suppliers and as well as the fast growing competition in the field of battery/capacitor driven electric vehicles in China (figure 11).

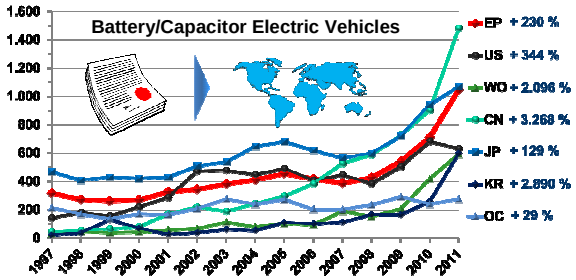

Figure 11: Country specific publication of patent applications for battery/capacitor driven electric vehicles between 1997 and 2011

Furthermore, in 2011 for battery/capacitor driven electric vehicles almost as many inventions were published in Europe as in Japan. This phenomenon shows the **increasing importance** of the **European** domestic car market for OEMs and suppliers and the fast growing competition in the field of battery/capacitor driven electric vehicles also in Europe.

For **fuel cell vehicles**, in each of the last 15 years, most of the filed inventions were published in **Europe** and the **USA** (figure 12).

This confirms the highest importance and the strongest competition for fuel cell vehicles in Europe and the USA compared to China and Japan.

As a phenomenon, in the last few years, in China and Japan the number of published inventions for fuel cell vehicles has been decreasing. This shows for fuel cell vehicles the **decreasing importance**

of the **Chinese** and **Japanese** domestic car market and also the weaker competition for OEMs and suppliers in China and Japan.

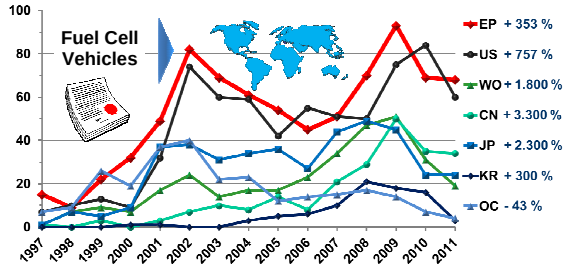

Figure12: Country specific publication of patent applications for fuel cell vehicles between 1997 and 2011

For almost every year between 1997 and 2011, most of the filed inventions for **range extended electric vehicles** were published in **Europe**, the **USA** and **Japan**. However, in 2011 for range extended electric vehicles almost as many inventions were already published in China as in Japan (figure 13). This shows the **increasing importance** of the **Chinese** domestic car market for OEMs and suppliers and also the fast growing competition in the field of range extended electric vehicles in China.

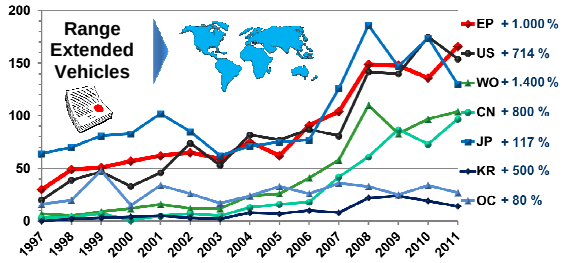

Figure13: Country specific publication of patent applications for range extended vehicles between 1997 and 2011

4 Applicant Trends

In 1998, as well as in 2010, the **majority** of first and second filed patent applications for electric vehicles were made by **Toyota**. This company aside, the remaining field changed over the same period. Between 1998 and 2010 **Honda, Nissan** and **Mitsubishi** intensified their R&D based filing activities and became key players behind Toyota. The same substantial development was achieved by some American OEMs such as **General Motors** and Ford as well as by some European OEMs such as **Renault** and Daimler as well as by some Asian OEMs such as BYD.

In addition, some European and Asian TIER 1 suppliers accelerated their research and development based filing activities for electric vehicles in this period. The major increases in the number of patent applications for electric vehicles were made under the Japanese TIER 1 suppliers by Hitachi, Denso, Aisin, Sanyo and LG and under the European TIER 1 suppliers by Bosch, Siemens and Michelin (figure 14).

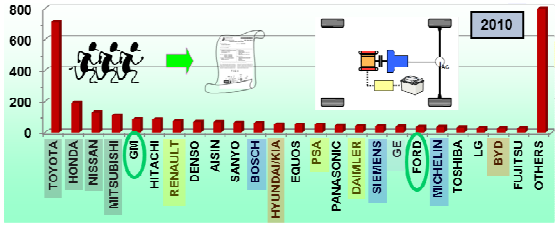

Figure 14: Applicant specific filings of patent applications for electric vehicles in 1998 and 2010 [5]

5 Conclusion

With the significant improvement of electric storage and automotive production technologies as well as of vehicle electric and control systems in the last 15 years, electric vehicles were developed for the mass market at first in the USA and later also in Japan, Europe and China.

For the purposes of predicting innovation trends for battery/capacitor electric, extended range electric and fuel cell vehicles, some specific trends on first and second filing of patent applications, particular drive train architectures, countries and applicants have been calculated based on the EPODOC database of the European Patent Office (EPO). This database contains currently more than 74 000 entries for electric vehicles and serves therefore as reliable basis for statistical analysis. For the calculation of technology trends only published patent documents and their publication dates have been considered.

The results of the statistical analysis confirm the increasing complexity, interdisciplinary nature and relevance of control units and methods in electric vehicles. The trends show an explosive development of inventions for electric vehicles in Japan and China. Furthermore, they indicate that some European and Chinese applicants have already made up an initial shortfall in R&D

activities for electric vehicles compared to Japanese and American applicants.

Additionally, successive changes in R&D and filing strategies from OEMs to TIER 1 suppliers are identified. Due to the enormous growth of the Chinese R&D activities for electric vehicles during the last few years, Chinese applicants have already closed the gap with Japanese and American applicants in the field of electric vehicles.

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