



Identifying trends in battery technologies with regard to electric mobility: evidence from patenting activities along and across the battery value chain

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ARTICLE INFO

Article history:

Received 28 July 2014

Received in revised form

25 September 2014

Accepted 13 October 2014

Available online 25 October 2014

Keywords:

Patent analysis

Battery technologies

Electric mobility

Battery value chain

ABSTRACT

Electric mobility is a topic of intense discussions in academia and industry since the stability of future energy supply as well as the associated environmental consequences are uncertain. Therefore, it is necessary to evaluate the research and development status of battery technologies for electric vehicles which are reflecting the interface of the automotive, chemical and electronics sector. The present study applies patent families as technological indicators in order to analyze the research activities of each step of the designed battery value chain individually and in comparison with each other to identify and discuss trends regarding the technologies associated to electric vehicles. By applying this explorative approach to the comparably new field, the study contributes to both the scientific literature on patent analysis as well as on emerging industry and value creation structures related to the electric mobility sector. Although the distribution of patents shows an emphasis on active components, the high number of patents covering more than one value chain step points towards the tendency of considering the whole value chain in systemic research approaches. Furthermore, a detailed analysis of patent assignees reveals insights on the knowledge dissemination across the value chain whereby the major share of industry actors still appears to be focused on their respective core competences but also administers important links to other value chain steps. The increase of collaborative activities across steps further hints towards starting shifts in value creation activities.

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1. Introduction

The limitation of low emission vehicles (LEVs)¹ to niche markets demonstrates that the underlying alternative drive technologies have not yet reached the objectives promoted by governments in response to environmental concerns (Frenken et al., 2004; Oltra and Saint Jean, 2009a). Although technological spillovers between the competing drive technologies emerge (Oltra and Saint Jean, 2009b), battery electric vehicles (BEVs) are currently drawing the highest interest due to their high radical nature and the so far low commercial success (Dijk et al., 2013; Dyerson and Pilkington,

2000; Notter et al., 2010). Thereby, the battery² as the functional unit delivering power to the drivetrain and its production are in the focus as being decisive for introducing electric vehicles (Armand and Tarascon, 2008; Mikkola, 2001). Lithium-based accumulators are primarily suggested as they are characterized by high power and energy density in combination with a high efficiency. However, high costs and technical drawbacks such as a low driving range and safety concerns imply the need for further research in order to increase the competitiveness compared to internal combustion engine vehicles (ICEVs) (Gerssen-Gondelach and Faaij, 2012; Pollet et al., 2012; Scrosati et al., 2011).

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¹ LEVs comprise battery electric vehicles, (plug-in) hybrid electric vehicles and fuel cell vehicles.

² The term *battery* is used ambiguously. In this article, batteries are equal to secondary elements as they are more relevant for applications like electric vehicles (EVs) compared to primary elements or capacitors.

The rising interest in battery research and development (R&D) can for instance be shown by monitoring the development of the number of patent applications in this technological field (von Delft and Leker, 2011), whereby the average annual growth rate of patent families referring to lithium-based batteries amounts to 32% between 2006 and 2010 (Wagner et al., 2013). As the diffusion of electric vehicle technologies proceeds slowly, developments at this stage become rather apparent by means of patent data than from the number of prototypes and production models as e.g. suggested by Bakker (2010) and Sierzechula et al. (2012). Existing literature dealing with R&D in electric mobility thus promotes the use of patents as analysis tool but studies have so far been limited to certain firm samples or applied keyword-based approaches to search for patents on the various alternative propulsion systems (Oltra and Saint Jean, 2009b). Additionally, the analyzed time frame has often been restricted to the time before 2005 and patent data sets have usually been derived from the United States Patent and Trademark Office (USPTO) (Pilkington et al., 2002; van den Hoed, 2005; Wesseling et al., 2014).

The present study aims at contributing to the field of battery technology research by taking into account R&D activities along the battery value chain from single battery components to the integration of the battery in BEVs. An approach which is focusing on the steps of the battery value chain as well as on interactions and interdependencies between these steps is introduced in order to enable a more detailed discussion on trends in battery R&D reflected by patenting activities. For this purpose, relevant International Patent Classification (IPC) codes are assigned to the different value chain steps and used to analyze the worldwide patent developments. By considering the industry affiliations of actors along the chain, the research landscape of battery technologies can be depicted more clearly and particularly shifts in technological competencies as well as overlapping technological activities across value chain steps can be identified. Furthermore, changes within and across value chains potentially resulting from the developments in the field of electric mobility and particularly affecting the automotive, the chemical and the electronics sector, are discussed.

The remainder of this article is structured as follows: In the next section, the battery value chain with the corresponding value creating activities focusing on electric mobility is designed based

on a literature review. The third section contains a brief overview concerning the use of patents to identify technological patterns. After introducing the method and database in section four, the findings of studying the developments of patenting activities and patent assignees for every step as well as for combinations along the battery value-added chain are summarized and discussed in section five. The article finishes with concluding remarks and an outlook on future research in section six.

2. The battery value chain with regard to electric mobility

The value chain concept was developed by Porter and Chubin (1985) to explain the process of value creation as a system of sequential, interdependent activities within an organization. A competitive advantage is resulting from providing additional value by adding competencies and services that can be distinguished from other firms (Porter, 2010). This organization specific value chain is embedded in a system of value chains with inter-company or rather inter-value chain relationships with up- and downstream players. This extended concept thus includes all linkages between resources and actors, who can occupy one or more value-adding steps and change their share of value creation (Gereffi et al., 2005; Lazzarini et al., 2001; Zott et al., 2010).

The process of creating value in battery production integrates several steps. The chain starts with the extraction and processing of raw materials to synthesize the cathode, anode, electrolyte, separator and other cell components. Subsequently, the different components are assembled to cells which are then packed to battery stacks which are finally integrated into the vehicle (see Fig. 1) (Majeau-Bettez et al., 2011; Notter et al., 2010). The resulting battery chain underlying our study is aggregated to the four main value-adding steps *raw materials*, *cell components*, *battery system* and *vehicle* (von Delft and Leker, 2011). Although the steps of use, recharging and recycling are of high relevance for the diffusion of electric mobility (Dinger et al., 2010; Lowe et al., 2010), these steps are neglected as they are less crucial for meeting the still existing technological challenges in current battery research.

By designing the chain with regard to applying batteries in electric vehicles, the automotive, specialized battery, chemical and electronics sector seem to be the most involved actors. Different companies from these sectors are active throughout the battery

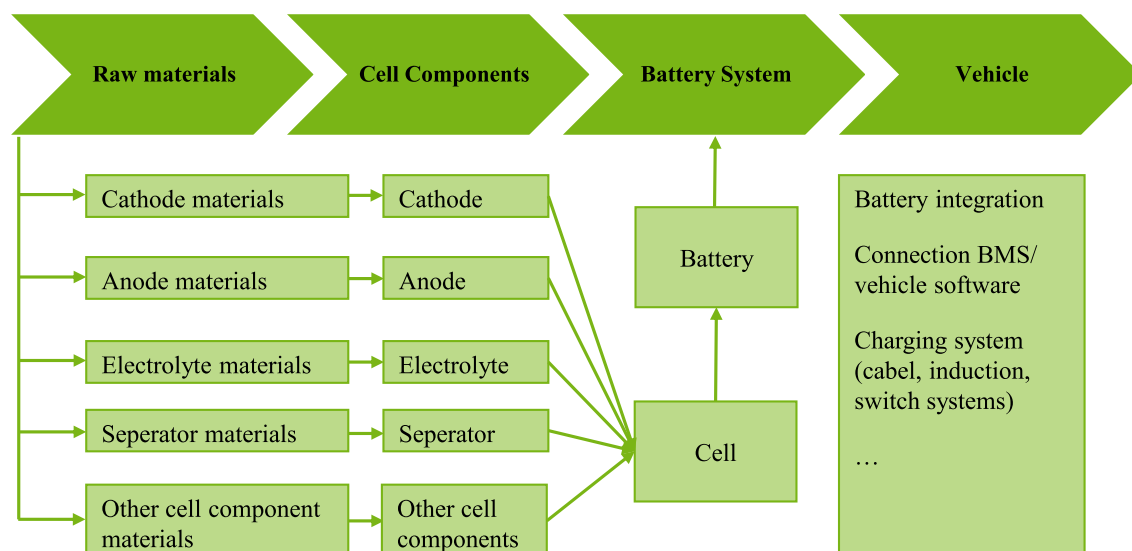


Fig. 1. The battery value chain comprises four major steps from raw materials to the integration in electric vehicles (adapted from von Delft and Leker (2011)).

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