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Start-ups as technology life cycle indicator for the early stage of application: An analysis of the battery value chain

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A B S T R A C T

Insights from battery research and development (R&D) need to be transferred into industrial application to create innovations and thus foster e.g. electro mobility. In terms of battery technology transfer, the early phase of application is particularly challenging due to the close intertwining between R&D and application. Therefore, the present study introduces start-ups as an additional indicator to capture the transition from science to industry within the technology life cycle. The findings show that despite highly dynamic R&D activities, technology transfer is only taking place on a very limited level. Surprisingly, start-ups focus on incremental improvements of existing technologies instead of introducing radical breakthrough-technologies. An analysis of the battery value chain reveals that opportunities for start-ups are rather located downstream in the value chain when integrating cells to battery systems and developing applications relying on innovative battery technologies. The findings contribute to the area of technology life cycle analysis explicitly using start-up companies as additional indicator for the critical transfer step from R&D to application. In a similar vein, technology forecasting literature, which is to date mainly focused on R&D, is expanded by a more application-centred perspective that allows identifying transfer opportunities along the technology value chain.

1. Introduction

Energy storage devices and particularly batteries are decisive technologies to tackle climate change. Stationary storage opportunities support the extensive use of renewable energies while batteries in electric vehicles (EV) secure individual mobility independent from fossil fuels (Lund et al., 2015; Longo et al., 2014; Kley et al., 2011; Dunn et al., 2011). In order to tackle the grand global challenges and reach ecological and societal goals, improved batteries are needed to successfully enter new markets or for mass-market penetration of EV (Goodenough and Kim, 2011). For this reason, intensive research and development (R&D) activities are going on, resulting in new materials or innovative cell chemistries (Liu, 2010; Scrosati and Garche, 2010). But these R&D insights need to be transferred into industrial application to create innovations and thus foster electro mobility. To date, a lot of attention in literature has been paid to battery R&D, e.g. scientific publication and patent analyses to identify upcoming technologies (Wagner et al., 2013; Golembiewski et al., 2015). However, the transferability and the actual transfer of R&D achievements into practice has only been tackled by a very limited number of studies (Chevrier et al., 2014; Krätzig and Sick, 2017).

To enable a more comprehensive understanding of the transfer process, the current paper proposes a life cycle perspective to capture the whole battery innovation process from basic to applied research and development and particularly reaching until

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commercialization and industrial application. Current indicators to analyse the technology life cycle comprise scientific publications for basic research, patents for applied research and development as well as new product launches for application (Watts and Porter, 1997; Bornkessel et al., 2016). The clear tendency in the structure of these indicators towards R&D activities is particularly helpful for technology forecasting purposes, where early information on new technological developments is crucial. However, new technologies need to be successfully launched into the market to reach their potential and create economic and societal impact, which is especially relevant for technologies facilitating sustainability and energy safety. Since new product launches as an indicator for application might not always be observable yet, an additional indicator reflecting the early phase of application and thus the transition from R&D to application is highly desirable. One way to transfer newly developed, and particularly risky technologies into practice are start-up companies (Swamidass, 2013). Start-ups with their organizational flexibility in comparison with large corporations and at the same time their proximity to research-intensive environments as e.g. university spin-offs are predestined to represent the early phase of application within a technology life cycle (Clarysse and Moray, 2004; Huynh et al., 2017).

Historic as well as recent developments in the battery market underline the need for a thorough analysis of the technology life cycle. It is particularly interesting to note that during the last century, only three batteries, namely, the manganese oxide (MnO_2) primary battery and the secondary batteries of lead-acid or nickel have been in use in mass markets before lithium-ion technology has been introduced in 1991 by Sony. Even more remarkable, no battery technology when successfully introduced into a commercial mass market has been replaced in its applications for many decades. For example, lead-acid batteries, developed more than 100 years ago, are solidly established in their applications and have still one of the biggest market shares globally given by the starter battery application for cars and back-up power in stationary industrial applications. An explanation for this phenomenon might be that each battery technology seems to be particularly designed and adapted to the application and vice versa. In a way, a battery is never an autonomous piece of technology, but rather presents a system solution. Hence, its performance is a result of a negotiation with its application and the system it is built in. Thus, one can observe a high resource complementarity, reflected in a systems approach, where R&D and application are deeply interwoven. For example, despite having more powerful and reliable battery technologies at hand, switching the starter battery technology from lead-acid to lithium-ion did not take place yet, because of costs in this massive market, but also because of the 12 V requirement for which all automotive electronics are built for. Also, the voltage of the mobile phone electronics is adjusted to the voltage of the cell and vice-versa. An exchange of the battery voltage would need significant adjustment of electronics components, which is challenging in times of mass production and high degrees of standardization. Furthermore, when introducing lithium ion batteries into the market, Sony did this with their own camcorders, which were in need of batteries with higher energy content in order to fulfil customer requirements.

Although battery R&D is closely intertwined with its respective applications, the focus of current research has been set on R&D, widely neglecting application and particularly the transfer from R&D to industrial application. But to fully grasp technological developments in the battery field, the whole technology life cycle needs to be taken into consideration. The study at hand aims to close this gap by scrutinizing the specifics of the battery technology life cycle and how the transfer from R&D to application and thus the early phase of industrial application can be analysed in more detail. For this purpose, technology life cycle indicators are used, i.e. scientific publications, patents and new product launches as indicators for basic research, applied research and development as well as application (Watts and Porter, 1997). Considering the transfer from R&D to application, the study strives to extend the approach developed by Bornkessel et al. (2016) and introduce start-up companies as an additional indicator to capture the early phase of application. The subsequent analysis of opportunities and barriers for start-up companies along the battery value chain provides detailed insights on where and how start-ups can be used best to foster technology transfer.

The contributions of the present study to the technology forecasting literature are twofold. First, the study adds to technology life cycle analysis explicitly using start-up companies as additional indicator for the transfer step from R&D to application. Thereby, a contribution is made to the development of technology life cycle indicators, which, yet, have focused on publications and patents for R&D as well as new product launches for application (Bornkessel et al., 2016). Start-ups as additional application-oriented indicator allow detailed insights into the early phase of application, where product launches might not yet be observable. This is not only relevant for batteries, but holds true for all sustainable technology-driven environments, where technology transfer is often hindered by established, more cost efficient technologies and is largely dependent on policy measures such as subsidies or quotas. This is due to path dependencies causing a sailing ship effect, whereby the emergence of a new technology temporarily leads to an increase in investment and innovation effort in the established technology (Sick et al., 2016). Insights into opportunities and barriers for start-ups could guide the way for more effective policy measures and thus technology transfer for sustainable technologies. Second, and based on this new approach, technology forecasting literature, which is to date mainly focused on R&D, is expanded by a more application-centred perspective that allows identifying transfer opportunities along the technology value chain. This is particularly valuable for technological fields, where R&D and application are closely intertwined. In these cases, early information on possible and upcoming application fields is critical to successfully bring new technologies into the market.

The remainder of this article is organized as follows. Section 2 presents theoretical background on technology life cycle analysis. Subsequently, Section 3 elaborates on the databases and search strings used to obtain the respective data in section three, while Section 4 encompasses analyses and discussion. The work is concluded in Section 5 with a short summary of the main results as well as implications and avenues for further research.

2. Technology life cycle indicators

Referring to the concept of product life cycles (Brockhoff, 1967; Day, 1981; Midgley, 1981; Easingwood, 1988), technology life cycles depict the development over time for the different stages of technological change (Ernst, 1997). This can be traced to the relationship between technological performance and cumulative R&D expenditure, which follow an S-shaped course (Merino, 1990). To describe the technology life cycle, the analysis draws on the indicators developed by Watts and Porter (1997) and adapted by Bornkessel et al. (2016) (Fig. 1). Thereby, the focus is on the R&D profile of the technology life cycle from basic and applied research to development and application (Watts and Porter, 1997). The initial phase of the technology life cycle, basic research, is represented by scientific publications drawn from general databases such as Scopus, Science Citation Index or discipline-specific databases such as Chemical Abstracts Service. The next phase, applied research and development, can be captured using patents from either databases