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UNLOCKING THE POTENTIAL OF CLEAN ENERGY STARTUPS: COMMERCIALIZING SCIENTIFIC BREAKTHROUGHS TO SOLVE HUMANITY'S GRAND CHALLENGES

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Overview

The term "deep tech" was originally coined by Chaturvedi (2015) to refer to significant breakthroughs that address urgent societal and environmental challenges. These game-changing innovations have the potential to transform existing industries and create new markets. However, their development requires substantial funding, specialized expertise and infrastructure, and the time to market can be lengthy. As a result, deep tech startups face significant technological and market risks, as well as complex production and material processing challenges that can hinder the commercialization of their innovations.

In recent years, venture capital investment has concentrated disproportionately on creating short-term returns, with the academic and media spotlight dominated by consumer-focused digital unicorns. However, deep technologies that have seen relatively little investment in the past are now attracting increasing interest from venture capitalists and innovation policy makers, as they are seen as a potential source of future growth. This increasing attention should also be taken up in academia to scientifically explore the potential role of deep tech startups in solving complex societal challenges such as climate change and global energy crises. This study therefore aims to draw conclusions for clean energy startups whose technologies often meet the deep tech criteria and are critical to facilitating the energy transition and reducing carbon emissions.

In this work I build on the technology lifecycle model developed by Gruebler (1997) and the more specific deep tech startup lifecycle model from Schuh et al. (2022) to examine the commercialization of deep technologies transitioning from the research and development stage to the growth stage. It aims to identify key success factors and scale-up patterns across deep tech startups from various industries. Such early phases are generally considered critical for technologies, as there is a risk of failing to translate research know-how on one side into commercial know-how on the other - often referred to as the "valley of death". It was studied in depth, with a focus on funding and external support programs such as technology transfer offices and incubation support to overcome this phase. Due to the technology risk in deep tech startups, the research and development stage concludes with a relatively binary answer as to whether or not the technology is viable. In parallel, deep tech startups must prepare for the growth stage by building production capacity, supply chains, and a network of partnerships to realize their technology and create the exponentially growing demand needed to demonstrate the marketability of their product.

Therefore, this study proposes an analysis of entering the growth stage from the perspective of deep tech startups from different industries, applying historic technology diffusion and ramp-up patterns in technologies as theoretical context. It fills the research gap identified in (Romasanta et al. 2021) regarding how to approach early market validation and lays the foundation for developing growth metrics tailored to deep and clean tech startups by answering the following research question: *How do deep tech startups approach commercializing and scaling their technology, and what can be learned for clean energy startups?*

Methods

To address the research question, an exploratory, inductive qualitative study is conducted through multiple cases. This approach is expected to be best suited to examine the new phenomenon of scaling up deep tech startups and develop novel theory routed in practical observations. Moreover, this design allows to answer the "how" question of the study in direct conversation with the interviewees including decision makers in prioritized startups, industry, and academic experts as well as investors.

Studied cases are selected based on achieving remarkable scientific breakthroughs in various industries, including energy, healthcare, and aerospace. They represent industries typical of deep tech and meet the deep tech criteria of technological innovation, manufacturing and long and resource-rich development combining both Schuh et al. (2022) and Romasanta et al. (2021). Having successfully navigated the challenging phase of commercializing their technologies and being currently in the growth stage of industrialization, the cases are suitable for replicating theoretical foundations. This theoretical sampling strategy allows me to focus on the phenomenon of commercialization and scale up by excluding unsystematic heterogeneities. Based on the historically observed patterns of technology diffusion, which offer potential for cross-industrial learning, the distinct industrial backgrounds are chosen as systematic difference between the selected cases. This approach contributes generalizable insights and enhances the existing deep tech startup lifecycle framework. Beyond the qualitative interviews, quantitative data is collected including duration from invention to first commercialization, doubling of capacity in the period thereafter, number of patents, publications and other company growth metrics such as revenue and number of employees. This combination of qualitative and quantitative data points increases the universal validity of identified growth patterns and success factors by allowing evidence from multiple sources to be triangulated as suggested by Eisenhardt (1989).

Results

My study demonstrates that deep tech startups across industries share similar growth patterns and success factors in technology commercialization. They initially focus on proving the performance advantage and achieving short time-to-market in niche markets, while later stages prioritize product reliability and quality, as well as driving down costs in line with historic technology diffusion patterns. Startups benefit from high degrees of vertical integration in early stages to maintain independence, flexibility, IP ownership and process control – despite the high resource requirements of developing and manufacturing in house. As they approach growth phases, partnership networks become essential to leverage industrialization expertise. Changing product specifications due to customization, intellectual property sharing, and startups' lack of experience make relationship building a lengthy process which is why successful deep tech startups start preparing for the growth phase through industrial partnerships many years in advance. The process from minimum viable product to first product sales appears to be pivotal. Joint development with customers and the need to secure sales for the company's own financing and investor confidence extend the timeframe for customer-specific products with limited standardization well into the growth phase. Confirming the role of a sense of urgency in historic technology diffusion patterns, deep tech startups benefit from an active leadership team that shapes public perception and creates awareness both with policy makers as well as society.

Conclusions

This analysis contributes to the emerging body of research on deep tech startups, addressing the call for research in (Romasanta et al. 2021). It provides a stronger understanding of the success factors in commercializing and scaling up technologies, as well as guidance for managing technology and market risks typical for deep tech startups. Historically observed patterns such as the initial importance of technology performance over cost, the need to work closely with customers, and the importance of managing public perception are confirmed. Other success factors identified in this work include the changing role of vertical integration and industrial partnerships as startups enter the growth phase. The deep tech startup lifecycle theory is extended by uncovering the drivers prevalent in the research, development, and growth phases, suggesting a more pivotal structure and a less linear process than described in (Schuh et al. 2022). Practical implications include providing a framework suitable for strategic decision making for early-stage startups in the clean energy space, as well as a set of evaluation criteria to help investors and policymakers assess growth potential of emerging clean technologies. Furthermore, the potential of analyzing quantitative growth patterns for deep and clean tech startups in future research is highlighted.

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