STRIKING GOLD IN THE VALLEY OF DEATH: IDENTIFYING KEY DRIVERS OF VENTURE CAPITAL INVESTMENT IN EMERGENT SUSTAINABLE TECHNOLOGIES

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Abstract

If we are to avert Climate Change, the world must reduce its net carbon footprint to zero in the coming decades. This will require an unprecedented shift in the technologies relied on in almost every part of the economy. Venture Capital can play a pivotal role in hastening the adoption of new technologies, but for investors to pursue a technology, certain conditions must be met. This research uses the Technological Innovation Systems (TIS) framework to qualitatively explore the nature of these conditions. It does this through a double case study of two technologies at the forefront of the "Climate Tech" investor movement: Electric Cars and Plant-Based Meat Alternatives. Combining literature research with interviews of both investors and people closely involved with these technologies, the research identifies several key building blocks as likely to affect investor interest. These building blocks include Product Quality (the product needs to be competitive on grounds other than its sustainability), Product Price (the product must be able to be sold at an initially significant premium), Production System (product components or materials as well as production capacity should be commoditized), and Customers (the product must be interesting to the mass-market). In both case studies, the ultimately successful companies showed that the existing niche fundamentally misunderstood the market. Through the lens of the TIS, this could be considered an Accident or Event, where a visionary founder challenges existing Knowledge of Application and Market. There is a significant level of overlap between the case studies, suggesting that this might be a key strategy to developing sustainable B2C innovations.

Keywords: Technological Innovation System, Venture Capital, Cleantech, Sustainable Innovation, Battery Electric Vehicles, Plant-Based Meat Alternatives

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Executive Summary

"We have the technology" has often been said about solving Climate Change (Shukla et al. 2022). In fact, many of the technologies have existed for decades. However, many technologies have been or are still outcompeted by technologies not aligned with a net zero future. This report set out to understand the innovation systems surrounding electric cars and plant-based meat alternatives, two sustainable technologies which have rapidly gained popularity and market share over the past two decades. It takes the perspective of the venture capital investor and tries to understand what changed, and how. To do so, it asked and answered the following questions:

1. *How should the innovation system be broken down to best assess changing investor interest?*
2. *How have the innovation systems encompassing battery electric cars and plant-based meat alternatives developed over the past 20 years?*
3. *What developments have proven key to increasing innovation and investment in electric cars and plant-based meat alternatives?*
4. *What are the challenges faced by sustainable deep tech innovators attempting to commercialise their technology?*

Despite existing innovation studies largely focus on analysing systems based on a government perspective, the Technological Innovation System (TIS) of Ortt & Kamp (2022) was considered flexible enough to adapt to an investor perspective. Their TIS assesses a technology's readiness based on seven influencing conditions and the same number of building blocks. A technology is expected to be ready for mainstream adoption when no influencing conditions and building blocks form barriers.

To assess both technologies, an extensive literature research was performed and supplemented with interviews conducted with investors, executives, and third parties active in these technologies during and after their inflection period. Narratives were created for both innovations, elaborating on their transition from niche to mainstream technologies. For plant-based meat alternatives, it focuses on Beyond Meat and Impossible Foods, the ecosystem they helped spur, and also takes a look at the Vegetarian Butcher, which followed a different path. This is summarized in the figures below.

Influencing Conditions	Plant-Based Meat Alternatives	2014		
		1st Gen.	2nd Gen.	2022
Knowledge & Awareness of Technology		🟡	🟡	🟢
Knowledge & Awareness of Application		🟡	🟢	🟢
Natural, Financial, & Human Capital		🟡	🟡	🟢
Competition		🟢	🔴	🟡
Macro-Economic & Strategic Aspects		🔴	🟡	🟢
Socio-Cultural Aspects		🔴	🟡	🟡
Accidents & Events		🟡	🟡	🟢

Building Blocks	Plant-Based Meat Alternatives	2014		
		1st Gen.	2nd Gen.	2022
Product Performance & Quality		🔴	🟡	🟡
Product Price		🟢	🟡	🟡
Production System		🟡	🟡	🟢
Complementary Products & Services		🔴	🟡	🟡
Network Formation & Coordination		🟢	🟡	🟢
Customers		🔴	🟡	🟢
Innovation-Specific Institutions		🟡	🔴	🟡

Figures 4 & 5: The PBMA Technological Innovation System as viewed from 1st and 2nd generation PBMA producers in 2014 and the current state of the TIS for the industry at large. Red implies the influencing condition or building block represents a barrier to large scale adoption, green implies there is no obstacle – yellow implies a transition. For further information see chapter 4.1.

Key for 2nd generation PBMA were improvements in Production System, Product Performance & Quality, Product Price, Knowledge & Awareness of Application (their larger addressable market), and Financial Capital (their VC backing allowing them to spend years in the research phase). Their biggest challenges are Socio-Cultural Aspects and Innovation-Specific Institutions, attributing to the large cultural heritage of meat and its resulting political value.

For electric cars, this spanned from 1990, when the GM Impact Concept Car provoked a regulatory push for electric vehicles, to Tesla's emergence in the early 2000's as auto manufacturers departure from the space created a vacuum. It continues to the current day, denoting the emergence of other start-ups inspired by Tesla's success, and the reluctance of major auto manufacturers to redesign their higher end vehicles until very recently. This is summarized in the figures below.

Influencing Conditions – Electric Cars	2008 Estab.	2008 Tesla	2022
Knowledge & Awareness of Technology	🟡	🟢	🟢
Knowledge & Awareness of Application	🟡	🟢	🟢
Natural, Financial, & Human Capital	🟢	🟡	🟢
Competition	🔴	🟡	🟢
Macro-Economic & Strategic Aspects	🔴	🔴	🟢
Socio-Cultural Aspects	🔴	🟡	🟢
Accidents & Events	🔴	🟡	🟢

Building Blocks – Electric Cars	2008 Estab.	2008 Tesla	2022
Product Performance & Quality	🔴	🟢	🟢
Product Price	🔴	🟡	🟢
Production System	🟡	🟡	🟢
Complementary Products & Services	🔴	🔴	🟢
Network Formation & Coordination	🟡	🔴	🟢
Customers	🟡	🟢	🟢
Innovation-Specific Institutions	🟡	🟡	🟢

Figures 9 & 10: The PBMA Technological Innovation System as viewed from 1st and 2nd generation PBMA producers in 2014 and the current state of the TIS for the industry at large. Red implies the influencing condition or building block represents a barrier to large scale adoption, green implies there is no obstacle – yellow implies a transition. For further information see chapter 4.2.

Key for Tesla's breakthrough were again in Production System, Product Performance & Quality, Product Price, and Knowledge & Awareness of Application (in this case their understanding that Product Price sensitivity was much lower at the high-end). They further benefited from unique advantages regarding Innovation-Specific Institutions, their loyal Customers, and a healthy dose of luck (characterized as Accidents & Events).

Cross-analysing the cases suggests that in both cases the successful VC-backed competing with a less sustainable alternative exhibit the following characteristics.

- Introduction of new ingredients or components relevant to extant niche technology
- Product differentiation using new developments with improved quality and experience
- Strategy to go down segments towards mass-market rather than cater to the existing niche
- Proposed by a visionary with the resources to make it happen

Notable is that the actual sustainability is missing from these characteristics. During the research it became very clear that the actual sustainability of an innovation is much less important than the customer's experience and aspiration towards the product. Returning to Ortt & Kamp (2022)'s framework, this mainly relates to the Production System, Product Quality, Knowledge & Awareness of Application, Product Price, and Customers elements. Furthermore, a visionary founder could be considered to fall under the Accidents & Events category.

Relating this to existing venture capital literature, it is reminiscent of the basics of a good VC investment: high margins, a large total addressable market, a strong founding team, and an unfair advantage. The one place where companies innovating in the studied technologies broke with this classic advice is on scope. Each breakthrough firm saw a significant amount of vertical integration, which it needed to establish itself in a wildly unfriendly market.

Preface

On your screen is the Master's Thesis "Striking Gold in the Valley of Death: Identifying Key Drivers of Venture Capital Investment in Emergent Sustainable Technologies". At its core, this thesis aims to be an exploration of the intersection between the world and study of venture capital on one side, and the study of innovation science on the other, explicitly focused on the importance of both fields for our climate transition. It has been written to fulfil the graduation requirements of the Industrial Ecology Joint Master's Program at Leiden University and the Technological University Delft in the Netherlands. I performed the research and writing for this thesis between September 2021 and May 2022.

The project was undertaken together with Carbon Equity during my internship there. My research question was formulated together with Liza Rubinstein Malamud, my internship supervisor at Carbon Equity. It was further refined with the support of Dr. Hauke Ward from Leiden University and Dr. Roland Ortt from the TU Delft. I am very grateful for their availability, support, and critical eye. As such, I would like to thank them for helping me bring this journey to a successful close.

I would like to thank my interviewees for gracefully providing me with their time, answering questions many of which they have most likely answered many times before. Their insights were invaluable to the success of this research.

Furthermore, I would like to thank the rest of the Carbon Equity team for their patience explaining financial concepts, reading early drafts, and overall support of my research. Carolina, Marco, Jacqueline, Lara, Jeff, Tim, Wiebe, Alexandra, Michael, Bas, & Bas, thank you so much!

Finally, a special thanks to those not yet named who aided me in a myriad of other ways, such as by proofreading sections of this research, helping me refine my thoughts through discussion, lending me your network, or simply being a friendly face when I needed it. This includes my parents, Paul de Ruijter, prof. Linda Kamp, Jonas Tobiassen, and many others. You know who you are.

I hope you learn a thing or two from reading this. I know I did while researching it.

Edward van der Hout

Castricum, May 30th, 2022

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Table of Abbreviations

Abbreviation	Meaning
AP	Alternative Protein
B2B	Business to Business
B2C	Business to Consumer
BEV	Battery Electric Vehicle
CAD	Computer Assisted Drawing
CEO	Chief Executive Officer
CFO	Chief Financial Officer
CNC	Computer Numerical Control
D2C	Direct to Consumer
GFI	Good Food Institute
GM	General Motors
HEV	Hybrid Electric Vehicle
FCEV	Hydrogen Fuel Cell Electric Vehicle
ICEV	Internal Combustion Engine Vehicle
IPO	Initial Public Offering
Li-Ion	Lithium Ion
(U)LEV	(Ultra) Low Emissions Vehicle
PBMA	Plant-Based Meat Alternative
SPAC	Special Purpose Acquisition Vehicle
TAM	Total Addressable Market
TIS	Technological Innovation System
TVP	Textured Vegetable Protein
VoD	Valley of Death
ZEV	Zero Emissions Vehicle

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"Make no little plans; they have no magic to stir men's blood and probably themselves will not be realized. Make big plans; aim high in hope and work."

—Daniel Hudson Burnham, 1910

1 Introduction

1.1 Introduction to the Topic

At the start of the 21st century, "Cleantech" was one of the fastest growing industries in the world, reaching a peak valuation of $284 Billion less than ten years after the term was coined (EarthTalk 2008; Caprotti 2012). Supercharged by venture capital (VC) investment and strengthened by large subsidies and public-private partnerships known as "Green Deals", the sector rapidly expanded throughout 00's (Caprotti 2012). However, this rapid growth unravelled during the 2007-2008 financial crisis, and the sector collapsed in the following years (Giorgis et al. 2021). Compared to other popular VC industries such as biotech and software, profit margins were often too thin, there was too much reliance on subsidies, the capital needed to scale up was too high, and incumbent players showed little interest in buying up-and-coming start-ups like they would in other sectors (Gaddy et al. 2017; Ghosh and Nanda 2012).

Recently, Cleantech has returned under a new moniker: Climate Tech (Herweijer et al. 2020; Giorgis et al. 2021). This time it is backed by a renewed call for action against the "Climate Crisis", lessons from Cleantech's failure, and an ever-growing need for sustainable alternatives to our fossil fuel-based economy (Anon 2020; Fehrenbacher 2020). These statements have a scientific backing through the IPCC's 2021 AR6 report, when it indicated that even its most optimistic projections place us above a 1.5-degree Celsius warming by 2050 and will require a complete transformation of our way of life (IPCC 2021). Just like during the original Cleantech boom, VC investment is heavily focused on scaling up niche technologies previously theorized and invented by academic institutions and government funding (Herweijer et al. 2020; Giorgis et al. 2021). The hope is that the increased social pressure on companies and governments of modern day can help create the environment for climate tech to succeed where Cleantech failed (Kerste et al. 2011, Greenbacks for Greenery 2020; Giorgis et al. 2021).

Nevertheless, climate tech founders and investors face many of the same challenges that held Cleantech back. One of these, or rather the outcome of several of these challenges, is known as the valley of death (Gaddy et al. 2017). The valley of death is a phenomenon where companies working on technologies that have been successfully researched, developed, and demonstrated (RD&D) fail to gain funding when scaling up to the commercialization stage (Beard et al. 2009; Frank et al. 1996). The valley of death played a key role during the Cleantech bust, due to the high focus on renewable energies (RE), which slowly revealed its flaws in its massive scale-up costs, over reliance on government subsidy, and the limited profits in the commodity energy market (Giorgis et al. 2021; Ghosh and Nanda 2012; Hargadon and Kenney 2012). Between these challenges and the 2008 financial crisis, investment in the sector collapsed, taking many of the larger players with it (Gaddy et al. 2017; Giorgis et al. 2021). Climate tech is much broader than Cleantech however, spanning many technologies beyond renewable energy, such as low carbon concrete and steel production, protein substitutes, and electric vehicles (EVs) (Davis et al. 2018; Herweijer et al. 2020). These technologies avoid some of the challenges faced by renewable energy, but there are still many sustainable investment barriers that can hold them back (Hafner et al. 2020).

This research will explore how the technological innovation system can be used to analyse investment interest in start-ups for different sustainable innovations. It will do this through literature review of developments in electric cars and plant-based meat alternatives (PBMA), and interviews with investors in- and representatives of start-ups in these sectors to identify which factors were key in enabling further investment and growth.

1.2 Objective & Questions

1.2.1 Research Objective

This research aims to deepen our understanding of the factors that might lead to investor interest in sustainable innovations.

1.2.2 Research Questions

The main research question is as follows:

How have developments in the surrounding innovation system affected the interest of investors in specific climate technology innovations?

To answer the research question, several sub-questions will be explored.

1. *How should the innovation system be broken down to best assess changing investor interest?*
2. *How have the innovation systems encompassing battery electric cars and plant-based meat alternatives developed over the past 20 years?*
3. *What developments have proven key to increasing innovation and investment in electric cars and plant-based meat alternatives?*
4. *What are the challenges faced by sustainable deep tech innovators attempting to commercialise their technology?*

1.2.3 Brief Results

Investor interest and involvement in the rise of BEVs and PBMA is comparable in some respects, and very different in others. Through interviews and literature research it has been concluded that both industries saw a small number of pioneering companies led by visionaries that reimagined a dormant niche market, relying on product performance to carve out a high-margin section of the mainstream market. In response to the success of these pioneers, a new ecosystem grew, but while this was highly centralized for EVs, it created a wild growth in the case of PBMA. Both benefited strongly from VCs patient capital, although this was a bigger factor for the pioneers in PBMA, and the secondary players in BEVs. Institutions played very different roles for BEVs and PBMA, and the same goes for the socio-cultural aspects and network formation. In both cases, incumbents were laggards, although this is much truer in BEV than PBMA. It seems that PBMA is still where BEV is a few years ago, with its biggest expansion yet to come.

1.3 Scope

The research focuses on the development of two technology areas: battery electric cars and plant-based meat alternatives. As available literature and available interview candidates are limited within this scope, supplementing information is drawn from literature and actors in related spaces, such as hybrid cars, electric mobility, and charging infrastructure for EVs; and plant-based dairy and cultured meats for plant-based meat alternatives.

There is no geographic scope, but due to the topics as well as limitations in the researcher's network, most interviewees are either based in the Netherlands or the US.

The temporary scope is limited to the past fifteen to twenty years, as this is when the first successful seed investments in the studied technologies were done (Zimberoff 2021; Stringham et al. 2015).

1.4 Relevance

1.4.1 Societal Relevance

The recently published IPCC report has stressed that while we have the technologies needed to tackle climate change, many of them are not yet cost competitive, and many more require huge efforts to scale up. According to Kenneth Arrow, who won a Nobel prize for his work detailing why the government needs to invest in early-stage innovation, "venture capital has done much more, I think, to improve efficiency than anything" (Arrow 1995). Combining these two statements, understanding the systemic barriers holding back or even threatening VC investment in these technologies, as well as the mechanisms to overcome these barriers are of incredible importance in humanity's fight against climate change.

1.4.2 Managerial Relevance

Building from the above, the information gained from this research could aid VC investors in analysing and understanding technologies they could potentially invest in. Furthermore, it could also help start-ups frame their innovations to fit with investors' expectations, and governments to identify priority improvements in their innovation systems. With the increasing importance of VC when it comes to financing sustainable innovation ($84Bn of investment between June 2020 and June 2021, with 210% historic year-on-year growth since 2013 (Johnson et al. 2021)) and the tendency of VC-backed companies to dominate the sectors they operate in, deeper understanding of VC in sustainable innovation is key for both start-ups and incumbents in adjacent fields (Lerner and Nanda 2020).

1.5 Outline

The thesis continues with an overview of the scientific background to introduce relevant concepts, including the framework used for the analysis in the next chapter. Chapter 2 then ends with a brief summary of the academic knowledge gap. This is followed by the methods in chapter 3, including the case study approach, the interviews, literature study, and the subsequent analysis, including an overview of the case study report structure. Chapter 4 follows, covering the case study reports as outlined in the chapter before: a narrative exploration of key developments, followed by a more in-depth review of each subcomponent of the used framework for the studied technology, and a deep dive on investor interest, followed by a brief conclusion. Following that, the reports are compared and analysed for key developments, which are identified in the cross-case analysis in chapter 6. Finally, chapter 7 and 8 make up the conclusion and discussion.

The appendices include a brief overview of interviewees, a sample interview request, full-size images of the case study timelines, a table providing sources and context with the visual timelines, and an excerpt from Ortt & Kamp (2022) providing elaboration on the TIS-framework.

2 Scientific Background & Academic Knowledge Gap

2.1 Innovation Sequence

To understand how we might accelerate sustainable innovation, it is good to start with the process of innovation itself. The innovation sequence was first defined by Johnson (1966). According to his analysis, an innovation underwent three distinct phases before reaching mass adoption.

1. Initial development, from the first idea until an "invention"
2. Prototyping and trial production
3. Commercialisation

This perspective on innovation is still relevant today, although more elaborate models have been developed that build on top of Johnson's model, and others have sought to identify the systems at play in each stage of the innovation sequence (Owen et al. 2018; Hendry et al. 2010).

2.2 Niche Strategies as a Pattern of Development and Diffusion

Between the invention and large-scale diffusion of technology, oftentimes a process of development and discovery occurs, in which different "niche strategies" are used to attempt to bring the technology to market (Ortt and Schoormans 2004). These niche strategies might be aimed at specific audiences, markets, or customers. Within these niches, the technology might develop further, making mainstream adoption more likely. If mainstream adoption does not occur, development might fizzle out.

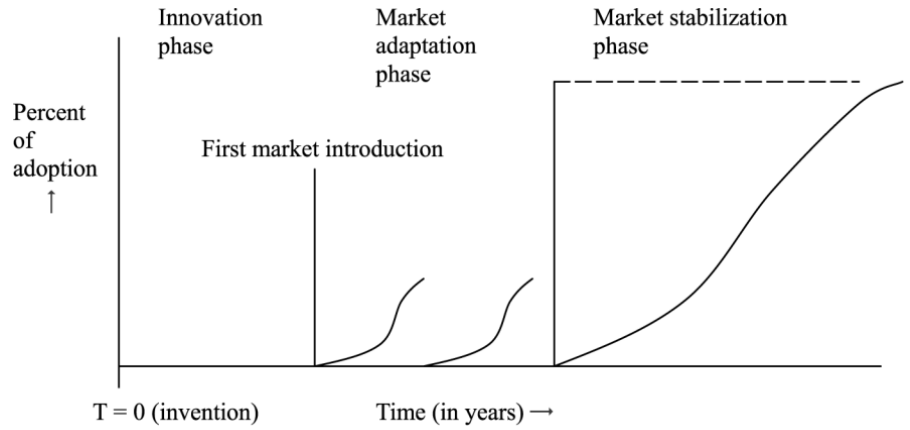


Figure 1: Three phases within the diffusion process (Ortt and Schoormans 2004).

Many governments have programmes aimed at nurturing these niche strategies, using the perspective of strategic niche management (Kemp et al. 1998). In order to assess the performance of these programmes, a wide range of factors have to be assessed: much of the study of innovation revolves around the fact that it rarely if ever happens in isolation. Innovation is as much social and institutional as it is technical, suggesting it should be viewed through a systems lens (Hekkert et al. 2007).

2.3 Innovation Systems

"The concept of innovation systems is a heuristic attempt, developed to analyse all societal subsystems, actors, and institutions contributing in one way or the other, directly or indirectly, intentionally or not, to the emergence or production of innovation." (Hekkert et al. 2007, 414). Because innovation systems are merely a model that cannot fully encompass reality, several such theories exist. On the one hand, innovation systems can be analysed through a geographical lens:

regional and national. This more spatially oriented type of analysis lends itself well to including policy, individual actor relationships and cultural elements (Edquist 1998).

At the same time, there are also approaches to innovation systems that use a specific technology or sector as focal point. These are, predictably, known as sectoral or technological innovation systems (TIS). This type of analysis is less spatially restricted, making it easier to accommodate cross-border innovations and developments (Edquist 1998). As this research focuses on a few specific technologies developed across borders, it will rely on the TIS.

2.4 Technological Innovation Systems Framework

The Technological Innovation Systems (TIS) framework by Ortt & Kamp (2022) is meant to analyse "the situation in which a radically new technological innovation has been demonstrated to work (the invention) and is developed into an innovation that has not started to diffuse on a large scale yet" (Ortt and Kamp 2022, 20). As this research attempts to analyse how certain sustainable technologies made it through this stage, this framework is particularly suited to this research.

The TIS-framework consists of fourteen indicators, split up equally in "building blocks" and "influencing conditions". The building blocks are essential for a functioning TIS, and the influencing conditions influence the formation of the TIS by affecting the different building blocks (Ortt and Kamp 2022). An overview of the building blocks and influencing conditions is given in Figure 1 below.

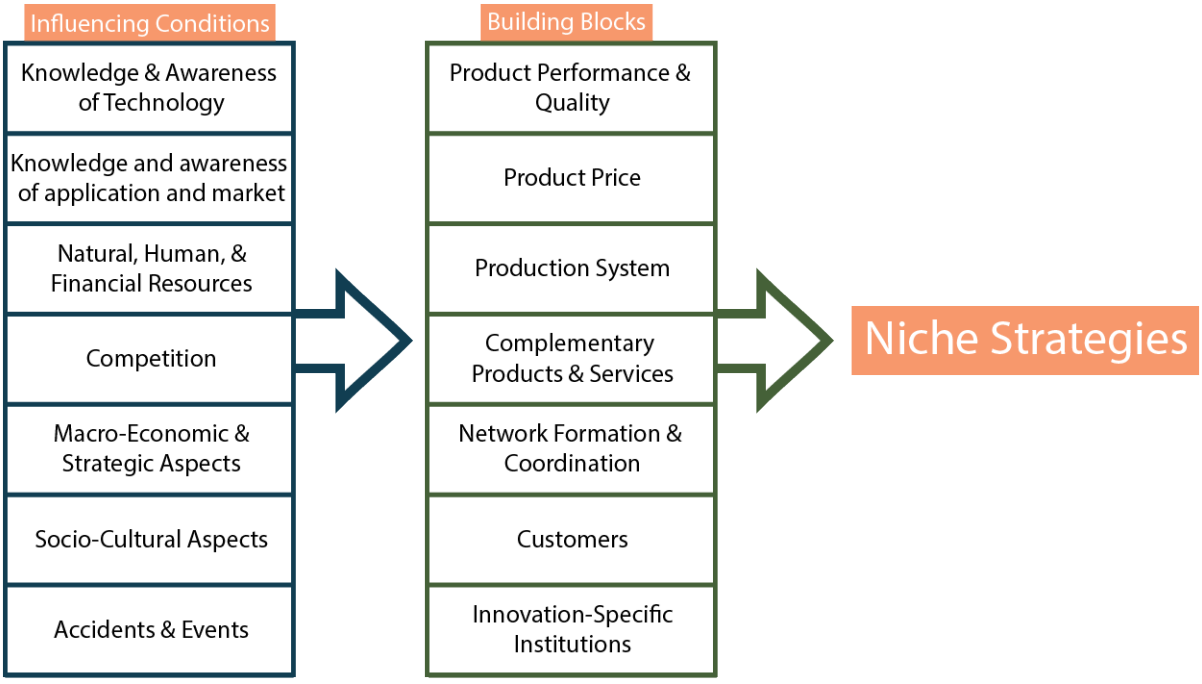


Figure 2: The Technological Innovation System Framework (Ortt and Kamp 2022).

Notable is that the original purpose of the TIS is to help identify and select niche strategies. This research will use the TIS to, instead of identifying whether a specific strategy is valid, dissect sustainable innovation niche strategies that have proven successful. Successful strategies are very rare, as most of them strand somewhere between invention and commercialisation, in what's known as the Valley of Death.

2.5 Valley of Death

For radical innovations, each stage of the innovation sequence sees different funding strategies. Initial funding for basic research is generally provided by the government through (research) grants or might be put up by the innovator themselves or a friendly party (Owen et al. 2018). This funding is high risk: it is highly likely that the research will not work out, or that the results do not result in a viable product. For this and other reasons, such as a fear of creative destruction, the market consistently underinvests in this and the next stage of the innovation sequence, instead relying on the government and academic institutions to back the brunt of research (Arrow 1962).

The market instead prefers to wait for certainty, with especially public companies often stepping in in the commercialisation stage. A very visible example here is the biotech industry: much of Big Pharma's business model relies on identifying individuals or small start-ups developing new technologies or drugs, buying them out once they clear clinical trials, and taking on the work of distribution and marketing.

This leaves the middle stage of the innovation sequence. This is the Valley of Death, existing between established funding sources like grants on one side, and corporate buyouts or bank loans on the other (VoD) (Frank et al. 1996). The traditional VoD occurs because the invention is too far along to be considered research and too elaborate to be self-financed, but too far from commercial viability to be eligible for bank loans or corporate backing (Frank et al. 1996). Companies finding themselves facing the Valley of Death often find themselves drawn to Venture Capital investors (Gompers and Lerner 1999).

2.6 Venture Capitalism

Venture Capitalism (VC) is a private investment strategy focused on early-stage start-up companies with high scalability (Gompers and Lerner 1999). VC funds are often structured as 10-year partnerships, where they will take the first 5 years to invest in several promising start-up companies with large growth potential. In the second half of the partnership, these investments are realized through "exits", as the company is sold or goes public. At this point, successful investments can return many times the original investment (Gompers and Lerner 1999). The large upside in the form of equity growth of successful investments makes it possible for a VC investor to take on more risk than other types of investors and moneylenders (Gompers and Lerner 1999). It is expected and accepted that a significant percentage of investments does not pan out, although where possible a VC will look to liquidate what is left of a company if it seems unlikely that it will be able to attain significant growth (Kupor 2019).

VC fulfils an essential role in the innovation sequence, helping traverse the valley of death between basic research to commercialization (Kortum and Lerner 1998). Besides capital, VC investors often provide many other forms of aid to the companies they are invested in; they are advisors to founders, provide their network to the company, and weigh in on important decisions as board members (Kupor 2019). It is thanks to the combination of these boons that VC-backed companies generally grow much faster than similar companies and dominate their markets: over half of public companies representing two-thirds of US public market capitalization started life as a VC-backed start-up, despite less than one in 200 newly started companies receiving VC backing (Thiel and Masters 2014; Lerner and Nanda 2020).

At the same time, VC is not equally viable for all types of companies. VC's generally look for high scalability, large economies of scale, and high margins (Thiel and Masters 2014; Kupor 2019). Historically, these have been most present in the software and biotech industries; many of the world's largest tech companies and successful medical innovations started life as a venture-backed start-up

(Gompers and Lerner 1999; Thiel and Masters 2014). Early attempts to apply the VC model to sustainable innovation during the Cleantech era have struggled, in a large part because the margins were not high enough support the investment model (Gaddy et al. 2017).[*] In the modern day, VC's have become de facto gatekeepers of innovation, increasingly focusing on the innovations and niche strategies that best suit their business model (Lerner and Nanda 2020). Lerner and Nanda (2020), for example note that "the top ten patent classes using the US Cooperative Patent Classification (CPC) system represented 48 percent of all venture capital patents filed over the 2008–2017 period, as compared to 24 percent for the top ten patent classes for patents not filed by venture capital–backed firms."

2.7 Valley of Death Revisited

This narrow focus of VC's has fragmented the VoD—while some innovations (mostly software-based) are nearly unaffected by the VoD, it is a key issue for many others, especially sustainable technologies (Johnson et al. 2021). Several causes for VoD's in Cleantech are identified in literature:

- Thin margins. A major problem for early Cleantech renewable energy start-ups was that they struggled to differentiate their final products enough. Instead, they had to compete in commodity energy markets. This meant resulted in them being unable to provide the 10x returns required for VC-style investment, while they were considered too risky for other types of finance (Gaddy et al. 2017; Giorgis et al. 2021).
- Profitability is too far off. Likely one of the most common causes for the valley of death in new or underdeveloped innovations. Most VC funds last for about ten years, and some technologies simply need longer time horizons to attain profitability (Owen et al. 2018; Marcus et al. 2013).
- Capital intensity is too high. On top of the obvious link to thin margins, VC funds are limited, and for their investment strategy to pay off it is key to spread their investments and limit the size of individual investments. At the same time, they like to have a significant share of the company, to be able to steer important decisions. Balancing these factors, each fund has a limit to the amount they are willing to invest. If by the time that money runs out incumbents or banks are unwilling to risk their capital scaling up the invention, the VC is left holding the bag (Polzin et al. 2021; Ghosh and Nanda 2012; Giorgis et al. 2021).
- Lack of exit opportunities. In software and biotech, a strong symbiotic ecosystem exists. While most innovations come from scrappy start-ups, Big Pharma actively supports incubators and innovation, and acquires these start-ups once they show promise. On the other hand, Big Energy has traditionally acquired very few start-ups, as they often compete with their own fossil-fuel based products (Gaddy et al. 2017; Ghosh and Nanda 2012; Hargadon and Kenney 2012).

Interacting with the above reasons is the theory that the valley of death is caused by a glut in early-stage start-ups due to an overabundance of government grants and financing (Beard et al. 2009). From this perspective, the valley of death is nothing but a natural "culling" of unviable ideas and initiatives when they are looked at through a lens of profitability rather than social- or environmental impact, research, or simple interest.

[*] Notably, during the interviews a second reason came up for Cleantech's struggle: investors were unable to "Exit" their companies because of a lack of acquisition culture among incumbents and overall hesitation of investors during the financial crisis.

Finally, it must be remembered that "some start-ups just fail". While not directly related to the Valley of Death, a non-insignificant number of start-ups that might seem to be in the Valley of Death from the outside, might suffer from other issues such as incompetent leadership or a lack of good business model (Bocken 2015; Kupor 2019).

2.8 Three Valleys

This fragmentation can be temporally divided into three different Valleys of Death: the Technology Valley of Death, the Commercialization Valley of Death, and the Market Expansion Valley of Death (Jenkins and Mansur 2011; Denney 2018; Moore 2014; Beard et al. 2009).

- Technology Valley of Death. This is the "classic" VoD, where a company struggles to find investors or loans after developing past the academic stage. The key challenge here is often time, with profitability being too far off, and investors not convinced there will be a market for the product, or that they will be able to recoup their investment when they need it back.
- Commercialization Valley of Death. Moving from prototype to initial production is another step where many companies stumble. Capital intensity and thin margins are key challenges here. Building a first production facility and producing the initial units can be very expensive, and margins have to be large enough to recoup the risk-adjusted cost.
- Market Expansion Valley of Death. The final third Valley of Death is about scaling from a local initiative to a large company or even an international behemoth, or from a niche to a mass-market product, like Tesla did with the Roadster and Model S. As explored in Moore's (2014) *Crossing the Chasm*, companies often struggle to adapt to new markets, and these can be "risk the company" level bets due to investments in production and distribution networks. Financiers willing to back these ventures require high levels of certainty or high profits, as the investments at this level can be truly staggering.

All three of these VoDs played a major role during the first sustainable innovation crash during 2008-12, and lessons from the failures of this period are expected to be key during the current push for sustainable innovation.

2.9 Deep Technology Innovation

"Deep Technology" investment is the most troubled field of innovation. Ghosh and Nanda (2012) classify it as combining high uncertainty with high capital costs, placing it squarely in their view of the VoD. Looking at some of the technologies in this quarter of the technology matrix (Figure 3 below), several of the theories behind the VoD seem applicable. Most of the technologies are—or were at the time of Ghosh and Nanda's writing—low margin technologies positioned towards commodity markets, suffering from high capital intensity and long development times. On top of this, many of these technologies are aimed at the conservative energy sector, limiting exit opportunities.

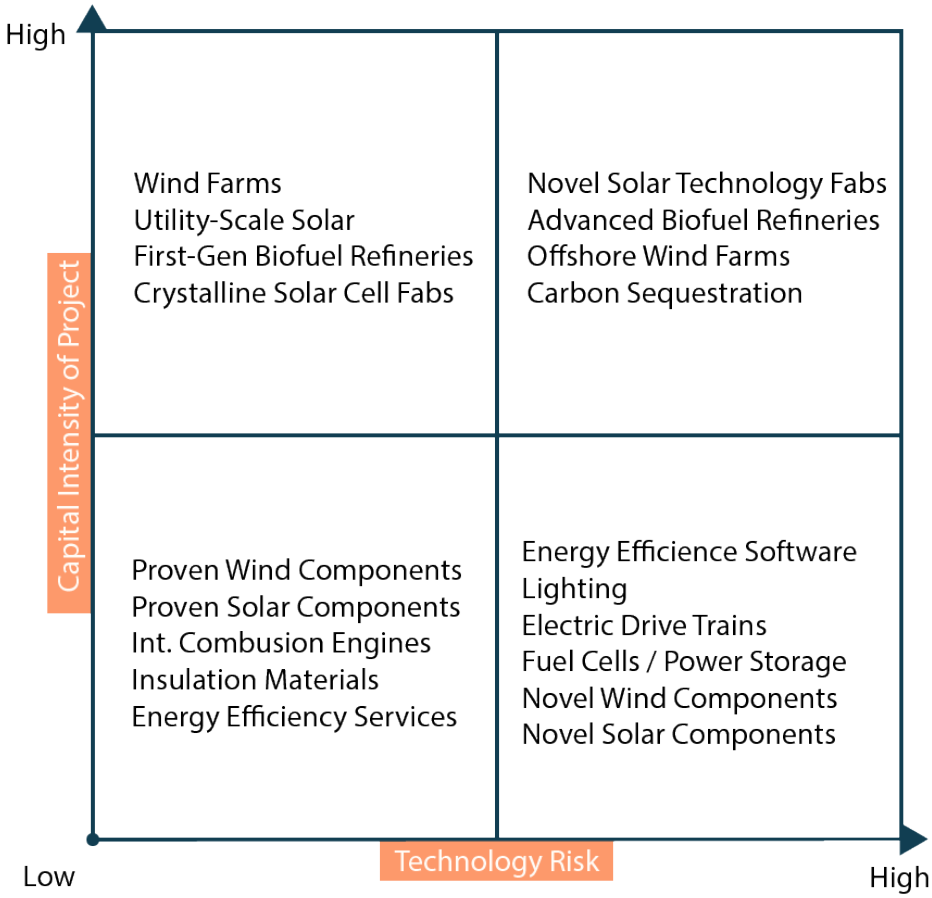


Figure 3: Different sustainable technologies and their relative capital intensity and technology risk.[*]

Notable is the placement of electric drive trains in the bottom right, resulting in an implied position of electric cars as a whole in the top right. While introducing drive trains to slot into the existing automobile industry could be considered capital-light, this simply cannot be considered true for anyone building a global car company from scratch.

2.10 Sustainable Innovation

Sustainable Innovation has seen several waves, most (in)famous of which Cleantech. Coined by VCs that were hoping to "save the world", it represented the boom and subsequent bust of investment in sustainable technology in the first decade of the 21st century (Caprotti 2012). This era instigated the rise of large scale commercial solar and wind power, as well as some other technologies such as smart thermostats with Nest, and the start of BEVs with Tesla (Gaddy et al. 2017; Stringham et al. 2015). The

[*] VC investment mostly exists in the bottom right, and the valley of death most occurs in the top right (Ghosh and Nanda 2012).

Cleantech boom went bust during the 2007-2008 financial crisis, suffering from systemic problems related to the nature of deep technology innovation such as profitability and exit opportunities lasting through 2012 (Giorgis et al. 2021). Notably, some have recently argued investors pulled out too early, and if they had been more patient, they would have reaped massive gains rather than the billions of losses (Mount 2021). Nevertheless, the name has gradually fallen out of favour between 2013 and 2018, due to associations with bad investments.

Climate Tech is a more recent but similar investment movement. The rebrand can largely be attributed to the bad associations with Cleantech's bust, but it also comes with different investment theses (Fehrenbacher 2020). Rather than the "indefinite optimism" of Cleantech, climate tech is explicitly focused on emerging technologies that can create value and have a reasonable route to "10X, or even 100X" (Herweijer et al. 2020; Thiel and Masters 2014; Giorgis et al. 2021). This could be seen as a kind opportunism, but as Thiel and Masters (2014) indicated, a successful start-up needs these kinds of returns to succeed, and not putting enough focus on this was a major reason why Cleantech went bust (Giorgis et al. 2021). Climate tech draws inspiration from success stories originating from the Cleantech era, such as Tesla and Beyond Meat, which successfully navigated the VoDs, and has already far surpassed Cleantech in financial size and scope (Herweijer et al. 2020; Gaddy et al. 2017; Stringham et al. 2015).

Finally, Greentech is an uncommon and mostly historical name for sustainable technologies (Caprotti 2012). It was the prevailing term before the emergence of Cleantech and is occasionally used as a non-era-specific term. It is generally associated with renewable energy, clean water, or pollution removal, and will not be mentioned further in this research (Kenton 2020; Dikeman 2015).

2.11 Academic Knowledge Gap

As outlined in the scientific background above, while a considerable amount of research has been done on innovation and innovation systems, the vast majority of research on this topic has focused on government action and influence to stimulate and protect new niche strategies through policies, budgets, and agencies. Elaborate studies of VC are limited in innovation studies, and those that exist generally focus on the role of VC inside National Systems of Innovation, rather than the role of VC within specific Technological Innovation Systems (Keller and Block 2013; Hargadon and Kenney 2012).[*]

Moving outside innovation science to business, historic papers such as Frank et al. (1996) showed that government efforts were enough to let software and biotech innovation flourish in the VC sphere. However, a more recent paper by Gaddy et al. (2017) showed that this went awry for Cleantech. Cleantech saw investors lose money and bail on the technologies as the subsidies and policies they relied on dried up in the wake of the financial crisis. Business literature carefully dissects firm performance and investor focus, but rarely expands to socio-technical aspects.

When exploring the Nanda and Ghosh's 2012 matrix in chapter 2.9 above, it is interesting to see that the Electric Car, a technology now hailed as exemplary, started life as a VoD technology.[†] It should have been far more attractive to investors to focus on drivetrains alone. Combining this with recent business literature identifying VCs as gatekeepers of innovation, this research finds several gaps in the literature (Lerner and Nanda 2020).

Primarily, there is a gap between business innovation and innovation literature; whereas business innovation lacks the tools to analyse innovations on a socio-technical systems level, innovation systems science could be considered to underestimate the influence of VC investors. This research attempts to close this gap by exploring the relationship between a technological innovation system and investor interest and activity in this technology.

A second but related gap is identified when it comes to understanding the changes that lead to individual technologies passing "the gatekeepers" after failing to do so before. Sustainable technologies are a key example here because they are distinct technologies that are relatively well-documented *and* because understanding how we can accelerate sustainable innovation is so societally relevant.

Next to the academic gaps indicated, the research also finds academic relevance by studying the currently ongoing Climate Tech investment boom, on which to date very little has been written.

[*] A search for "Technological Innovation System" + "Venture Capital" returned no papers that focus on Venture Capital but use Technological Innovation Systems in the first 10 pages on Google Scholar.

[†] Tesla is considered a top-right type of investment, as rather than "simply" producing an electric drivetrain such as initially pursued by Atieva (bottom right), they chose to create a vertically integrated BEV company from the bottom up, which is far more capital intense.

3 Methods

3.1 Research Design

3.1.1 Multiple Case Study

This research analyses two different case studies. Because Climate Tech is a very broad subject encompassing the entire economy, a single case study is not enough (Herweijer et al. 2020; Sovacool et al. 2018). Instead, by picking two very distinct case studies, that have both already overcome the valley of death, this research aims to identify the shared and different roads towards success, which will be more robust through the multiple case study approach (Sovacool et al. 2018; Yin 2003). Each case study is broken down into influencing conditions and building blocks, and it is explored how these have affected the interest of investors as well as overall adoption. This was first done through a literature review, after which expert interviews were held with investors and start-up founders or representatives, to confirm and elaborate on the literature review.

3.1.2 Case Study Selection

The two case studies identified are EVs, and plant-based meat alternatives. These are two of the most funded sustainable industries within separate climate verticals, together accounting for approximately $21 Billion (34% of all) in VC funding[*] in 2019 (Herweijer et al. 2020). Sustainable energy technologies are not included, because their problems are relatively well explored and documented, and investment in them has long peaked (Mazzucato and Semieniuk 2018; Bürer and Wüstenhagen 2009; Gaddy et al. 2017). This only leaves smart energy technologies (Nest and related companies) as an alternative case study, but this technology's more natural positioning as an evolution of the existing technology made it a less representative case study (Gaddy et al. 2017).

These case studies work well because plant-based meat replacements and BEVs are very different technologies: for example, due to the possibility to produce at a small scale and lack of need for a network, plant-based meat alternatives have a lower capital intensity (Zimberoff 2021). On the other hand, high unit prices for mass-producible items mean BEV companies can realize very high revenues compared to most start-ups, and growing interest has led to significant exit opportunities (Tesla 2021; Meyer 2021b). Beyond the above, there are significant differences in needs for specialized infrastructure (plant-based burgers do not need to charge), purchase frequency, and regulatory environment and challenges.

3.2 Case Study Protocol

3.2.1 Overview

The case study protocol is established to increase reliability of the research (Yin 2003). The case study protocol includes the data collection procedures, the case study questions and a guide for the case study report.

3.2.2 Data Collection Procedures

3.2.2.1 Literature Review

Several searches were performed using Google Scholar. First, a search was performed to identify other systemic literature reviews of electric cars and plant-based proteins. For the following terms, the first 10 pages of Google Scholar results were considered.

- literature review plant based "meat alternative" OR protein

[*] The split here is 19.5 Bn to BEVs, and 1.2 Bn to APs. Mobility dwarfs all other climate investments (Herweijer et al. 2020)

- literature review EVs OR cars

The same was done for searches looking to identify key papers regarding the establishment of these sectors, homing in on transition and investment perspectives.

- plant based "meat alternative" OR protein "innovation system"
- plant based "meat alternative" OR protein drivers funding OR investment
- plant based "meat alternative" OR protein system transition
- EVs OR cars "innovation system"
- EVs OR cars drivers funding OR investment
- EVs OR cars system transition

A total of 800 papers was reviewed based on title. In total, 190 papers (130 BEV, 60 PBMA) were downloaded for further analysis. After dropping duplicates and non-peer reviewed papers, as well as reading abstracts, 82 papers (60 BEV, 22 PBMA) were read and coded according to the TIS.

For specific elements of the innovation system and other questions that arose during research, targeted searches were performed to supplement the lessons from the systemic literature review, to make sure that every influencing condition or building block was correctly assessed.

3.2.2.2 Interviews

Purpose of Interviews

As the focus of existing literature is squarely on government action, technical innovations, or customer acceptance, it quickly became clear that primary research would be required to fill out the TIS framework. As Cleantech and later Climate Tech VC has been a rather exclusive market, featuring a small number of long-term players each of which has unique experiences and insights, semi-structured expert interviews were the most applicable form of information gathering. These would help identify the barriers to financing green innovations as seen through the eyes of investors and founders, discovering which of the influencing conditions and building blocks were most key to these investors.

Interviewee Selection

Interviewees were selected based on opportunity. The researcher used their professional network and that of Carbon Equity to approach VC investors, founders, and very early employees in either of the technologies studied, or one closely related to it. To improve the sample size, online research was performed to identify funds that were early investors in either technology or are niche funds focusing on the sectors encompassing these technologies (mobility / alternative proteins (AP)). Experienced investors at these funds were approached through a personalized message over LinkedIn, relying on the Sales Navigator functionality. A template for such a request can be found in the appendix. Finally, several high-level executives at established companies in these spaces were approached.

Interview Structure

Due to the unique situation and experiences of each interviewee, as well as the need to aggregate and intercompare results, semi-structured interviews were deemed to be the most suitable. The semi-structured interviews used the following high-level structure:

For investors:

- The interviewee was asked to introduce themselves and explain how they first got involved in sustainable investing.

- The interviewee was asked to give some background on how they and their firm invested (in what stage of company growth, which technologies).
- The interviewee was then asked to elaborate on their investments in the studied technologies. This included elaborating why they invested, why they might have not invested in other companies pursuing the same technology, and how their opinion had developed over time.
- The interviewee was further asked for their opinion on this technology, and how it developed over time.
- The interviewee was asked what they thought were/are the biggest hurdles for companies trying to find funding for this technology, and how it has developed over time.
- The interviewee was then asked what they thought about the amount of money being invested in these technologies.
- The interviewee was finally asked about the topic of the valley of death. If necessary, it was quickly introduced. They were then asked what they thought about the valley in relation to the technology being discussed.

For founders / employees:

- The interviewee was asked to introduce themselves and explain how they first got involved with the technology.
- The interviewee was asked to introduce the company.
- The interviewee was asked for their opinion on this technology, and how it developed over time.
- The interviewee was asked about the biggest hurdles for companies trying to pioneer these technologies, and how it has developed over time.
- The interviewee was asked what they thought were/are the biggest hurdles for companies trying to find funding for this technology, and how it has developed over time.
- The interviewee was finally asked about the topic of the valley of death. If necessary, it was quickly introduced. They were then asked what they thought about the valley in relation to the technology being discussed.

Interview Recording

When possible, interviewees were asked to take an hour for the interview, in which they were asked about several key topics. In several cases however, less time was available. All interviews were conducted by the researcher themselves through videoconferencing software: depending on the interviewee's preference either Zoom, Google Meet, or Microsoft Teams. If agreed to by the interviewee, interviews were recorded and transcribed using Microsoft's Azure Cloud services. If not agreed to, the interviewer made shorthand notes during the interview, and expanded to the best of their memory afterwards.

Interview Analysis Approach

Based on transcripts and shorthand notes, interviews were coded along the 14 dimensions of the TIS-framework. Themes were identified for each of the influencing conditions and building blocks. Where applicable, themes were fed back into future interviews for confirmation. As the number of interviewees was limited and their profiles were very heterogenous, no statistical or otherwise quantitative analyses were performed on the outcomes.

3.2.3 Case Study Report Outline

Both case studies are built up following the outline in Table 1 below.

Table 1: Sections of the Case Study Report

Section	Comments
1. Introduction	An introduction to the history of the technology. The case studies focus on recent developments (developments leading up to and following the emergence of a now-leading start-up). This section introduces what happened before and gives the larger picture history of the technology.
2. Case Narrative	Following the introduction, the modern history of the technology as found through the literature review and interviews is elaborated. In this section, no analysis is performed.
3. Influencing conditions*	Based on the narrative, the development of each influencing condition is briefly elaborated. This is based on a red-yellow-green system of colours, as well as the main developments leading to a change in colours.
4. Building Blocks*	Based on the narrative, the development of each building block is briefly elaborated. This is based on a red-yellow-green system of colours, as well as the main developments leading to a change in colours.
5. Development of Investor Interest	Based on the narrative, the chronological development of investor interest is briefly elaborated. This "breaks out" the focal influencing condition (financial resources) to highlight feedback loops and explore the thesis's research goals
6. Conclusions	Based on sections 3 and 4, answers to RQ 3 and 4 are formulated that are specific to this case study.

3.2.4 Case Study Questions

Several questions are used to validate the relevance of the case study and ensure completeness. These questions are featured in Table 2 on the next page.

* For the subchapters and dashboards exploring the development of influencing conditions and building blocks, the order proposed by Ortt & Kamp (2022) is maintained to make comparison between case studies easier. As such, no particular value should be ascribed to the order of the influencing conditions and building blocks.

Table 2: Guiding Questions for Case Studies.[*]

Questions per Section	Comments
1. Introduction	
A. Define the technology, i.e., the functionality it provides, the technical foundation behind it, as well as subsystems or directly related technologies.	A clear definition is key to formalizing research scope and boundaries.
B. Describe the prior strategic niches and niche strategies	A brief history of prior generations and corresponding strategic niches and niche strategies is provided here for context.
C. Identify and describe the commencement of the studied "technology generation"	Like a technology definition, it is important to formalize the research period.
2. Case Narrative	
A. Chronologically describe the socio-technological developments with regards to the technology	A complete narrative built from literature review and interviews is established. At this stage the goal is to give a full and complete overview of the TIS to help with context.
B. Describe the interest of investors during the series of niche applications	In the overview it is important that next to the developments regarding the technology, the development of investor interest is properly captured.
3. Sequence of Influencing conditions	
A. Chronologically describe the development of influencing conditions affecting the technology	Breaking out the influencing conditions separately makes it possible to analyse their development and the way they affected the building blocks and investor interest.
4. Sequence of Building Blocks	
A. Chronologically describe the development of building blocks affecting the technology	Breaking out the building blocks separately makes it possible to analyse their development and the way they affected the influencing conditions and investor interest.
5. Development of Investor Interest	
A. Chronologically describe how investor interest developed	Breaking out the investor impact separately makes it possible to see how it has been affected by the development of other influencing conditions and building blocks.
6. Conclusions	
A. Identify the key developments that drove increased investment in the technology	Drawing from the previous three sections, the key influencing conditions and building blocks driving investor interest are identified.
B. Identify the challenges that remain despite increased access to funding	Based on the status of different influencing conditions and building blocks, certain remaining challenges are identified. Consider whether these factors can also be considered non-essential when stimulating investor interest.

[*] Inspired by Vintila (2015).

4 Case Study Reports

4.1 Plant-Based Meat Alternatives

4.1.1 Overview

This chapter contains the full case study report on PBMA. It starts with a graphic overview of the TIS, before giving some background and a narrative of the case, which is accompanied by a graphical timeline. After the general narrative is established, individual influencing conditions and building blocks are further described. Impact on investor interest is summarized at the end, together with a more general lookback on the development of the case study.

Graphic Overview

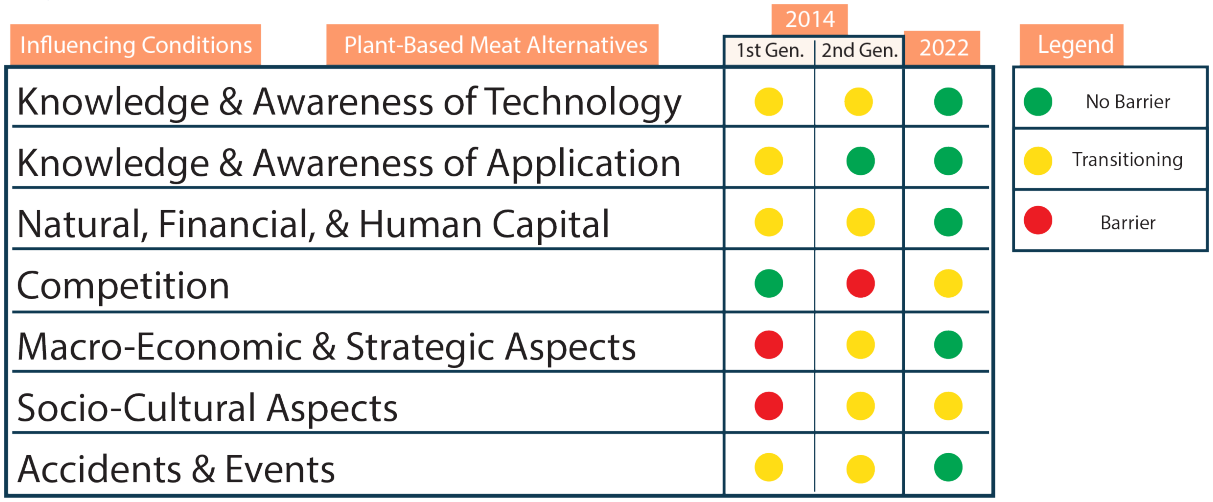


Figure 4: A high-level overview of the development of influencing conditions in the PBMA TIS between 2014 and the present.[*,†]

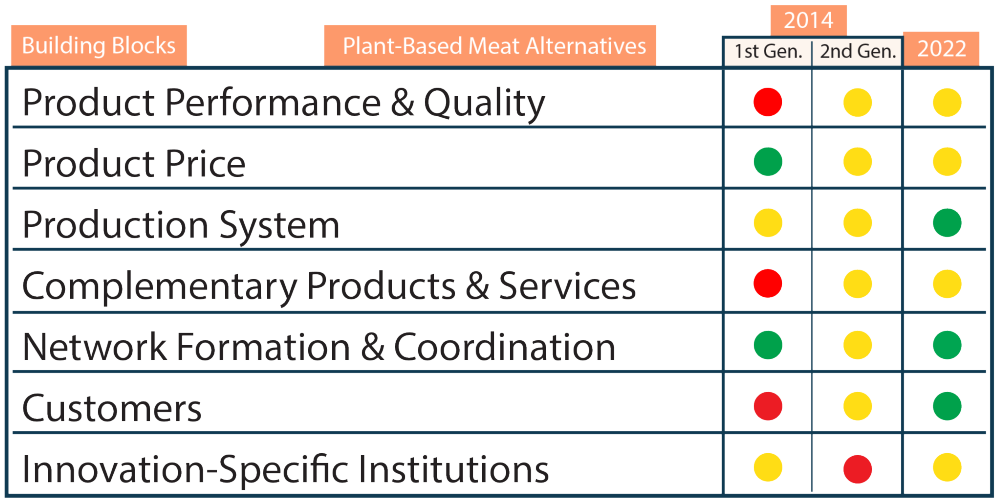


Figure 5: A high-level overview of the development of building blocks in the PBMA TIS between 2014 and the present.[5,6]

[*] 2014 was chosen as a starting year as this is when the Impossible Burger was first sold, signalling the start of the "2nd Generation" of PBMA.

[†] Note that there are two separate perspectives on the TIS at the starting period. The first is for the existing niche of "1st Generation" PBMA, and the second for the newcomer "2nd Generation".

4.1.2 Introduction

To produce PBMA, protein crops are processed into isolates and concentrates. Using low temperature extrusion technologies, an intermediary product known as textured vegetable protein (TVP) is created. This TVP is used as the basis to create any number of different end-products (Asgar et al. 2010).

PBMA are separate from the more traditional "meat replacements", referring to tofu, tempeh, and seitan (Wild et al. 2014). These have been around much longer, with tofu and tempeh going back thousands of years, and the Indonesian wheat-based protein being invented somewhere in the 16th century. These products were never intended to be true meat replacements, until adopted as such by the Western world in the mid-20th century (Singh et al. 2021).

Around the same time, the first renditions of modern PBMA were introduced when food processing company Archer Daniels Midland invented TVP in the 1960's (Mistry et al. 2020). These first products weren't great; while the texture was acceptable, they came with the aftertaste and smell associated with soy products (Interviews 11 and 14). The products were mainly bought by those that did not eat meat for moral or dietary reasons but weren't widespread. Next to TVP-based products, other early-stage meat alternatives were Quorn (mycoprotein-based), and Valess (milk-based). Each of these struggled with at least one factor of taste, smell, texture, or looks, and general interest remained low. Throughout the 90's and early 2000's, several projects, such as the PROFETAS project in the Netherlands was launched, focusing on improving these products and making them interesting for a larger audience (Dagevos et al. 2018).

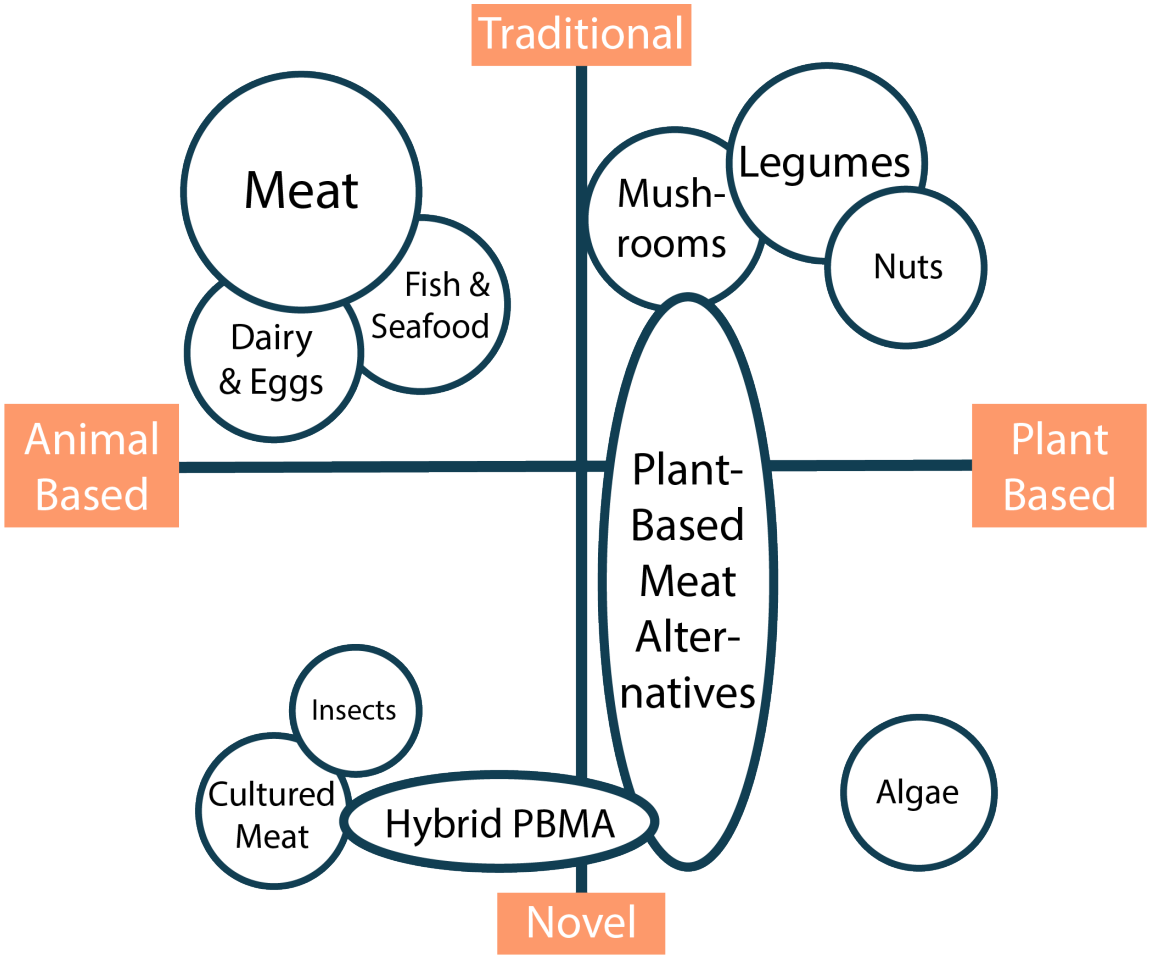


Figure 6: An overview of different protein sources. Based on Dagevos et al. (2018).

The second generation of modern PBMA started with three companies founded about twelve years ago: Beyond Meat (then known as Savage River) (2009), The Vegetarian Butcher (2010), and Impossible Foods (2011). Using novel ingredients such as pea protein, innovative recipes and techniques, and a mindset to sell to "flexitarians", these companies set out to create a new market. Rather than sell something like meat to those that didn't eat meat, they sought to replace it for those who would otherwise eat meat (He et al., 2020, Interview 11 and 17).

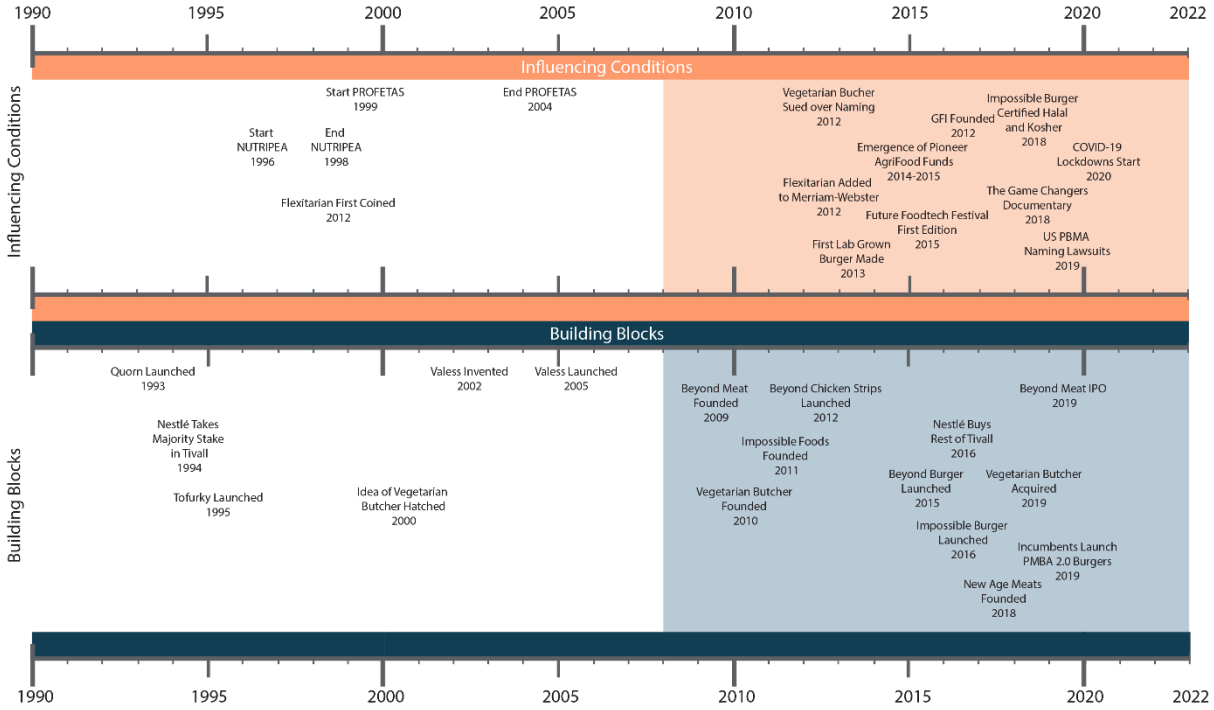


Figure 7: Timeline of key developments in the PBMA TIS between 1990 and 2022.[*]

4.1.3 Case Narrative

Of the three brands, the Vegetarian Butcher was first to market, opening its doors to the public in 2010, after working on products since 2000 (de Vegetarische Slager 2020). Beyond Meat followed in 2012, bringing out their Chicken-Free Strips after licensing technology from two professors from the University of Missouri that had been working on this for a similar length of time (Andrews 2019). While the Chicken Strips didn't last, they followed with the Beyond Burger in 2015 (Andrews 2019). Impossible was the last of the three, only launching its first product—the Impossible Burger—in 2016, after working on the technology for nearly 5 years (Impossible Foods).

The three companies are united in that they explicitly focus on displacing animal products rather than cater to the existing vegan or vegetarian populace: this is clear through aggressive naming and imitation. The Vegetarian Butcher was caught in hot water shortly after with regards to the way they named their products, opting to move to intentional (archaic) "miss"-spellings in 2012 (de Vegetarische Slager 2020). This mentality of animal product displacement is corroborated by interviewees (12, 14, 17). One said: "Animal welfare is where plant-based really got started: the environment was always important, but that was more of an intellectual argument. Killing pigs to produce meat was something very visual. Back in 2010 we didn't care about the climate in the same

[*] The shaded area indicates the period covered by the case narrative. Please note that this timeline only covers events. Changes over time are not included to preserve readability. For a full-page version of the timeline, see Appendix II-A. For sources regarding event dating, see Appendix III-A.

way." Over time, this priority has changed. Sustainability has slowly emerged as a more and more important driver of new (and old) start-up companies trying to challenge the meat industry, even more so than animal welfare, which is mainly popular with true vegetarians (de Boer et al., 2017, Interview 14). A third driver for consumer interest is health, although opinions on the healthiness of PBMA vary (Boukid 2021; Zimberoff 2021; Sexton et al. 2019).

Two of the three (Beyond and Impossible) can be considered VC-backed companies—unlike the other two the Vegetarian Butcher only raised external capital once (de Vegetarische Slager 2020). Beyond and Impossible both raised over $100 million in VC funding over their lifetimes (Crunchbase, 2022b, 2022a, 2022a). This is also visible in the approach: the Vegetarian Butcher started out as just that, a vegetarian butcher shop (de Vegetarische Slager 2020). They used the shop to experiment and gain recognition, from where they could naturally grow into partnerships once products were ready to be scaled up (Tziva et al. 2020). On the other hand, Beyond Meat took two years from founding the company to develop their first product, and Impossible five (Zimberoff 2021).

This is also visible in the product: while the Vegetarian Butcher's products made leaps in texture and taste, they remained like the first generation PBMA in many ways (Tziva et al. 2020). On the other hand, Impossible and Beyond Meat's patience and capital led to them much more complex products, even so far as developing proprietary solutions for their burgers, such as Impossible's plant-based haemoglobin, colloquially known as heme (Zimberoff 2021).

All these companies were met with great enthusiasm, and interest immediately far outstripped supply. "A shop would purchase what they thought would be a month's supply, and they'd sell out in hours" one interviewee who was involved with a PBMA company recalled (Interview 11). "And then they'd ask for more, but production just couldn't keep up."

It is around this time, 2014-2016, that some of the earlier food-focused VC funds started to show up (L. Johnson et al., 2021, Interviews 2, 12-17). Often built out of the portfolio and expertise of angel investors, or a more specialized offshoot of AgriFood funds, these were true niche investors (Zimberoff 2021). This includes investments in related markets, such as cultured meat (Mosa Meat) and milk (Perfect Day). At this point, few incumbent players took the innovation seriously: one interviewee working for an animal feed company that set up a corporate VC fund around this time mentioned that "[the other executives] thought it was a waste of time." But others believed. Tyson Foods and Cargill made their first small investments around this time, including a 5% stake for Tyson in Beyond Meat (Mouat and Prince 2018). Next to these established players, one stranger also made a move: after being one of their earlier investors, Google tried to fully acquire Impossible Foods in 2015 for a sum of $300 Million (Clements 2015).

In 2015, the Vegetarian Butcher completed its one and only fundraise, raising 2.5 million (the maximum allowed within their legal construction under Dutch law) through crowdfunding, combined with funds from one of the earliest vegetarian-VCs (de Vegetarische Slager, 2020, Interview 12). All this funding was spent on a factory, which they completed in 2017, to allow them to supply other retailers more effectively, such as Albert Heijn.

2017-2019 is when investor interest really began to pick up. Interviewees point to the growth of Impossible and Beyond Meat's valuations (together raising over $300 million in 2017-2018), a foreshadowing of Beyond Meat's IPO, and a maturing of the space in general (Crunchbase 2022b, 2022c; Mouat and Prince 2018, Interviews 1-2, 7, 12, 14-17). "Overnight the dynamic changed: I went from being one of maybe twenty investors globally to being just one of many", a Netherlands based investor said about the effects of the sale of the Vegetarian Butcher and Beyond Meat's IPO. "A VC is

an insider, you know these things are going to happen", a US-based investor said when he put the inflection point slightly earlier. At the end of 2018, Unilever bought out the Vegetarian Butcher for an undisclosed sum, proving that there was a market for mature plant-based companies (Tziva et al. 2020). Not long after, Beyond Meat went public with an IPO in 2019, seeing the largest price surge on the first day of trading for a major company since the dot-com boom (Murphy 2019). The next year, investment in plant-based start-ups tripled (Gaan 2021).

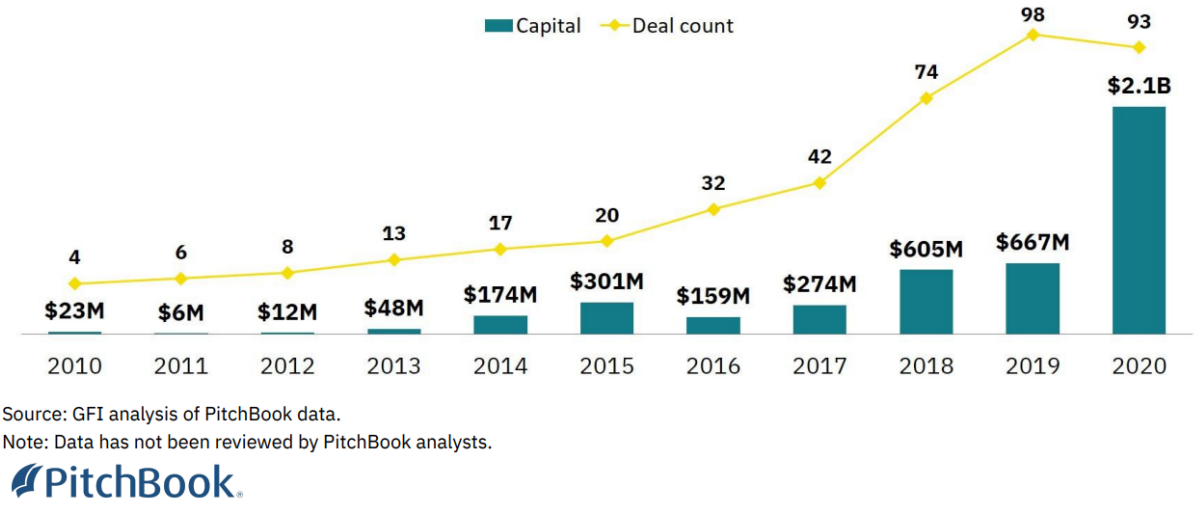


Figure 8: VC Funding of Plant-Based Companies over time (Gaan 2021)

An ecosystem had started to emerge: the number of companies and investors active in the space was growing steadily. Dedicated conferences had started to pop up since 2015, and attendance went up every time they came back around (Rethink Events 2022; Zimberoff 2021). Notably, while the number of investors skyrocketed, the number of start-ups grew far more slowly (Johnson et al. 2021). This resulted an upward trend of start-up valuations, as VCs started to compete for those that were left. Interviewees speak of "dumb money" entering the industry—pointing to those with less knowledge or connections to the industry, but equal or deeper pockets—investing in start-ups that might not have been funded in the past (4, 7, 14, 17). Several interviewees indicated having to give up on attractive companies, or even being priced out of the market altogether, stating that "valuations and expectations [were] too high, even as early as Series A."

As anywhere, the COVID-19 pandemic had an impact on PBMA. While the majority of distribution channels pre-pandemic were fast-food and other chain restaurants, this shifted overnight to retail (Interviews 15-16). Sales were buoyed by a combination of factors, including a distrust of animal products stemming from the pandemic's origin, and a belief that plant-based diets might boost the immune system (Attwood and Hajat 2020; Zhao et al. 2022). Finally, logistics might also have given PBMA an advantage: plant-based meats have improved shelf-life when compared to normal meats, because they can be shipped frozen, making it easier for a store to keep the product available during supply chain issues (Interview 16). It wasn't the first time that public perception of the traditional meat industry strengthened interest in PBMA (Attwood and Hajat 2020). This was corroborated by interviewees, who repeatedly named Netflix documentaries such as Gamechangers and SeaSpiracy as sources of consumer interest and an inspiration for start-ups (5, 7-8, 14-17).

As the pandemic continued, publicly disclosed PBMA sales saw a reduction for the first time since the boom started in Q3 of 2021 (Watson 2021). This has led to depressed public valuations of Beyond Meat and Oatly in early 2021, when compared to 2020. Simultaneously, overall investment in plant-

based innovation remains high, and growth compared to 2019 is still up significantly, making it hard to give a longer-term perspective (Johnson et al. 2021).

4.1.4 Sequence of Influencing conditions

4.1.4.1 Knowledge and awareness of technology

2014 | Gen. 1 🟡 | Gen. 2 🟡 | 2022 🟢

Literature identifies two "generations" of PBMA, preceded by traditional soy (tofu/tempeh) or wheat (seitan) based meat alternatives (Tziva et al. 2020; He et al. 2020). Compared to the first generation, the second generation was more complex, and was significantly boosted by the emergence of pea protein as an ingredient to displace soy (Interview 11). Lessons from other sectors were introduced, and new techniques such as high-moisture cooking extrusion were introduced. This allowed for more attention for features such as taste and texture (Tziva et al. 2020). Further improvements focused on improving the way meat is mimicked, such as Impossible Foods' "Burger that Bleeds" using plant-based heme iron (Choudhury et al. 2020).

4.1.4.2 Knowledge and awareness of application and market

2014 | Gen. 1 🟡 | Gen. 2 🟢 | 2022 🟢

Instead of focusing on vegetarians, the second generation of PBMA explicitly focused on "flexitarians" and the general population (Dagevos et al. 2018; Broad 2020). This development was key to expanding the product from the niche to a more mainstream phenomenon—part of a larger trend also enveloping organic and free-range foods (Gravely and Fraser 2018). This in turn increased the total addressable market significantly, but also required significantly more product development, as rather than catering to those who ate no meat, the plant-based industry started seriously competing with the meat industry for the first time (Dagevos et al. 2018).

4.1.4.3 Natural, human, and financial resources[*]

2014 | Gen. 1 🟡 | Gen. 2 🟡 | 2022 🟢

There is little focus on these resources in most literature. Out of the three types, financial resources are most touched upon, especially by Dagevos et al. (2018) which follows the development of PBMA market in the Netherlands. It identifies that the Dutch market especially struggles with finding funding. It highlights the few examples where this did occur, as well as the Vegetarian Butcher's crowdfunding campaign, but notes that most product development is self-funded, with occasional government support through research project grants. Of note is that Dagevos et al. state that this is unique to the Dutch landscape, showing that in other places there is far more comingling of PBMA and traditional foods companies. The latter is backed up by other papers, such as Broad (2020) and Choudhury (2020), which confirm that large food retailers and conglomerates have recently started to buy PBMA start-ups to strengthen and revitalize their own portfolio.

Right after Dagevos et al. (2018) was published the same happened in the Netherlands, with Unilever acquiring the Vegetarian Butcher in December 2018 for an undisclosed sum (Tziva et al. 2020).

4.1.4.4 Competition

2014 | Gen. 1 🟢 | Gen. 2 🔴 | 2022 🟡

There are two types of competition in the PBMA space. First is PBMA's struggle against the meat-based regime, and second is internal competition between different PBMA brands (Dagevos et al. 2018). It is mainly the few large players (Beyond Meat, Impossible Foods) that compete directly against the meat-based regime (Choudhury et al. 2020).

Smaller players mainly compete for niches or are absorbed by incumbents. In the Netherlands, for example, Unilever ended up buying the Vegetarian Butcher (Dagevos et al. 2018; Tziva et al. 2020).

[*] VC as a Financial Resource is broken out as a separate topic in 4.2.6 Development of Investor Interest

As PBMA gained popularity among non-vegetarians and vegans, incumbent food companies have started innovating and creating their own vegetarian brands, and older more traditional PBMA companies have seen a growth in popularity (Choudhury et al. 2020; Dagevos et al. 2018).

4.1.4.5 *Macro-economic and strategic aspects*

Impossible Foods and Beyond Meat were both founded near the tail end of the Cleantech bust. This is surprising, as a downturn is usually not when VCs are looking for new investments, instead focusing on preserving their existing companies. Nevertheless, neither company seems to have suffered from it, and it put them on course to grow strongly as the economy rebounded (Interview 17).

Several papers observe that governments' climate targets can play a significant role in adopting plant-based diets (Singh et al. 2021; Aschemann-Witzel et al. 2020). Simultaneously, it is also identified that plant-based diets are systematically undervalued as climate action, likely due to socio-cultural aspects—only very recently have countries started to adopt plant-based national diets (see next point) (Beverland 2014; Malek et al. 2019).

4.1.4.6 *Socio-cultural aspects*

Socio-cultural aspects are key in both the strength of the incumbent meat industry, and the transition to more plant-based diets. Many papers identify the importance of meat in culture, status, and identity (Beverland 2014; Weinrich 2019; Aschemann-Witzel et al. 2020; Malek et al. 2019; Dagevos et al. 2018; Broad 2020). Vegetarianism and veganism are associated with femininity or regarded as deviant (Beverland 2014; Aschemann-Witzel et al. 2020). On the other hand, meat, and especially large cuts such as steak, are associated with power and masculinity (Stibbe 2004). This relates to why, according to interviewees, starting with a burger made so much sense. "Burgers are already somewhat questionable", one said. "Once you add in ketchup, mayo, the taste doesn't matter that much as long as the texture is right and it looks the same", another added (Interviews 11, 14, and 17).

Despite the above, worries about climate and animal welfare are slowly changing the landscape. Numbers of vegetarians and vegans are on the rise, many people identify as "flexitarians"—flexible vegetarians (Beverland 2014; Tziva et al. 2020; Saari et al. 2021).

Finally, there are significant differences between acceptance of PBMA in the Western world and the non-Western world. Especially South-East Asian cultures have a long history with vegetarianism in general (He et al. 2020). This results in higher acceptance rates of PBMA, despite most of the companies manufacturing these products originating from Western countries (Choudhury et al. 2020; He et al. 2020).

4.1.4.7 *Accidents and Events*

Beyond Meat, and later Impossible Food's, decision to explicitly market towards non-vegetarians/non-vegans was a turning point in the plant-based space (Broad 2020). Before this decision, there was little chance the market would grow naturally (Broad 2020). When they were proven right, through adoption and championing of major retailers and celebrity chefs, they reaped significant rewards (Choudhury et al. 2020). In turn, their successes proved to others that it could be done, and that there was room for plant-based innovation in the mass-market (Choudhury et al. 2020).

Tziva et al. (2020) mention that for the Netherlands the rise of the Party for the Animals, featuring a documentary about animal wellness in factory farming also positively affected the place of PBMA. This was corroborated by interviewees, who mentioned documentaries such as Gamechangers as an

important aspect of the popular perception of the meat (and alt-meat) industries (Interviews 8, 12, 14, 17).

4.1.5 Sequence of Building Blocks

4.1.5.1 Product Performance and Quality

Food neophobia is a recurring issue in the literature. PBMA is identified as tasteless, or customers find it difficult to structure meals around these (Weinrich 2019). This is a big obstacle for PBMA, as in the pursuit of being more meat-like they often become more complex and processed. This in turn nets them the nickname of being overprocessed "Frankenfoods", where the healthiness of the product is put into question (Aschemann-Witzel et al. 2020; Broad 2020).

In recent years, overall knowledge, and awareness of technology of PBMA is steadily improving, but acceptance stays low, in part due to factors such as price (Aschemann-Witzel et al. 2020). Other roads to improve awareness are partnerships with restaurants and fast-food chains (Singh et al. 2021).

4.1.5.2 Product price

Several papers identify perceived high price as a significant barrier for consumers to switch to more plant-based diets (Dagevos et al. 2018; He et al. 2020) This is despite a willingness from consumers to pay more for PBMA (Vatansever et al. 2020).

The main hurdle for PBMA is that most producers operate at vastly different scales than the incumbent meat industry. Partnerships with incumbents, as well as steady growth help bring down these costs (Cohen 2021). Since releasing their burgers, Impossible and Beyond have reduced prices several times (Cohen 2021; Zhao et al. 2022). In this same period, meat prices have gone up for several reasons, further aiding the market position of PBMA.

4.1.5.3 Production system

Making early breakthroughs possible was the scalability of PBMA production. Rather than needing to immediately build a plant after the lab, small scale batches could be made in a garage. Beyond that, co-manufacturing could be a bridge. In this, an existing plant rents out manufacturing capacity to the emerging start-up (Interviews 2, 11 and 17).

Key developments are extruder technologies (from single to twin screw and shear extrusion) (Choudhury et al. 2020; He et al. 2020). These types of developments improve the final product and make it easier to create more complex types of PBMA. This is a hot area of research, with several start-ups and incubators focusing on just this stage of the production system (Tziva et al. 2020). At the same time, much of what is done today was already possible with older extruder systems (Interview 11).

Rather than extruder technologies, ingredient developments really helped propel PBMA forward. The emergence of peas as a base helped improve texture and flavour. Further development into other protein sources is still ongoing, and many start-ups are trying to find the next best thing (He et al. 2020, Interview 1).

4.1.5.4 Complementary products and services

PBMA is mostly a stand-alone technology. Notable is the usage of hybrid-foods—foods in which meat is partially substituted by PBMA (Vatansever et al. 2020). This can be a gateway towards making PBMA more mainstream or help increase production levels to reduce the cost of true plant-based meat alternatives. Similarly non-plant-based animal meat alternatives, such as dairy- or cell-based ones can help nurture interest in animal-free consumption: getting people to give meat alternatives an initial try is one of the largest hurdles in adoption (Dagevos et al. 2018). Investors often spoke of

"synergies" or a belief in "system change" when asked why they invested multiple companies focusing on meat alternatives.

4.1.5.5 Network formation and coordination

2014 | Gen. 1 🟢 | Gen. 2 🟡 | 2022 🟢

Only Dagevos (2018) really zooms in on the process of network formation, doing so briefly for the Netherlands. They mention several government-led sectoral research projects, bringing different players together. Many of these predate the current wave of PBMA.

Looking more concretely at network organizations and the like, the majority of PBMA companies are based in Europe or America, where there are several start-up incubators (Choudhury et al. 2020). Tziva et al. (2020) mention a Dutch industry association, and similar associations exist in other countries. Notably, the Good Food Institute (GFI) has emerged in 2016 as a US-based but internationally active non-profit advocacy for "clean meat", including but not limited to plant-based meats (Sexton et al. 2019). In the same year, the Plant-Based Foods Institute also saw the light of day, and the first industry conferences got off to a humble start (Zimberoff 2021).

4.1.5.6 Customers

2014 | Gen. 1 🔴 | Gen. 2 🟡 | 2022 🟢

As indicated, a breakthrough is the marketing of PBMA to "all" customers, rather than just vegetarian or vegan ones (He et al. 2020). For this to succeed, taste, texture, and looks are key factors (Banovic et al. 2022). From literature emerge two separate themes when it comes to adopting PBMA: a cognitive interest (focused on health, animal welfare, climate), and a more primal experience (focused on taste, texture, and looks). Cognitive interest drives people to try PBMA, whereas satisfaction with factors like taste and texture solidifies the interest. Currently, many consumers are looking for meat alternatives, but are not happy enough with the available offerings to convert to fully plant-based diets (Weinrich 2019; Gravely and Fraser 2018; Choudhury et al. 2020). Finally, price also plays a role, with even a 10% price premium significantly hurting interest in PBMA.

Despite these hurdles, time is a big asset in favour of PBMA. Familiarity has been considered a key driver of the adoption of new foods, and as plant-based products have conquered a space in the super-market, they are likely to become more commonplace and less foreign (Onwezen et al. 2021). Every year, consumer acceptance towards meat alternatives grows (Bryant and Sanctorum 2021).

4.1.5.7 Innovation-specific institutions

2014 | Gen. 1 🟡 | Gen. 2 🔴 | 2022 🟡

There are several innovation-specific institutions that presented problems for the fledgling companies. Notable is Impossible Foods' market entry stumbles due to usage of its GMO soy-based heme. In the US, it needed to go through a lengthy trial to prove that it is safe for human consumption, and the burger is still banned in Europe due to its usage of GMOs (Choudhury et al. 2020). In several places there have also been lawsuits regarding the usage of the word "burger" or other meat-related terms to refer to PBMA (Tziva et al. 2020).

Next to these, there are also incumbent institutions that favour meat production. This includes agricultural policy and nationally recommended diets. Agricultural policy often features significant subsidies for animal meats that are not received by producers of PBMA (Aschemann-Witzel et al. 2020). Nationally recommended diets are slowly converting to be more plant-based, but in many countries, this is something of the last few years (Beverland 2014; Saari et al. 2021; Aschemann-Witzel et al. 2020).

4.1.6 Development of Investor Interest

Both Impossible and Beyond were founded to combat climate change (Bronner 2018; Kaul and Stebbings 2020). Despite this, their original pitch to VCs was, according to interviews, heavily animal welfare oriented. It was not the right time for a climate focus, and the saving the animals story was

more emotional (Interview 11, 14). At the same time, long-time Cleantech investors also played a major role in backing these companies, so this point could be disputed (Kaul and Stebbings 2020).

For new companies, inspired by Impossible and Beyond Meat's successes, an AP investing community slowly emerged from about 2014-2015 onwards. The investing community and start-ups developed together, until the run up to Beyond Meat's IPO sent especially the investing side into overdrive (Gaan 2021). Since then, it has greatly expanded, and the space has become "too hot" according to some, with interviewees noting that "we'd love to have Dutch investors, but the US can offer us so much more" (Interviews 1, 5). Similarly, interviewed Dutch investors noted being priced out of the market (Interviews 7, 8). interest in the more mature market has mostly shifted from building a new vertical powerhouse to focusing on companies that are taking a specific next step, either through making a new plant-based product or optimizing some step in the supply chain (Gaan 2021). The one exception here is the Live Kindly collective, which is a more platform-approach to plant-based innovation (Gaan, 2021, Interviews 16 and 17).

4.1.7 Conclusions

Next Generation PBMA was founded for environmental reasons, but opinions vary on the importance of animal welfare and human health as ancillary reasons to invest. Key PBMA companies were backed from the start by large VC firms, which allowed them to work for several years towards a breakthrough product. These breakthrough products repositioned the market for their PBMA to include everyone, massively increasing the addressable market, even if their initial price was higher (to provide the margins needed for a VC-style business). While the cultural and social values regarding meat remain a tough nut to crack for PBMA, this new generation's much closer resemblance has helped bridge the gap to some extent. A large focus on restaurant-first releases, the plant-based burger as an experience, and changing zeitgeist further boosted PBMA 2.0. Regulation was mostly a negative influence, but it did not prevent the establishment of Beyond or Impossible, and the emergence of lobby-organizations and company networks has helped solidify the position of PBMA.

Looking at the Ortt & Kamp (2022) framework, this translates to the following influencing conditions as key differentiators: *Knowledge and Awareness of Application and Market*, and Natural, Financial and Human Capital, with the greatest challenges in *Socio-Cultural Aspects*. Regarding building blocks, this meant: *Product Performance and Quality*, *Product Price*, and *Customers*. Since VC investment exploded, *Network Formation and Coordination* has played a key role in furthering the ecosystem, whereas *Innovation-Specific Institutions* continue to challenge them.

On the investor side, as the market emerged, a completely new investment and start-up ecosystem emerged, focusing not just on PBMA but on animal free and more sustainable "alternative" proteins. This ecosystem has expanded to creating new vertical companies in these AP spaces and innovating individual processes and products in the PBMA space. It has especially been present in the US and Israel, with the Netherlands (as one of the original hotbeds of PBMA) somewhat falling behind.

4.2 Electric Cars

4.2.1 Overview

This chapter contains the full case study report on Electric Cars. Just like the chapter on PBMA, it starts with a graphic overview of the TIS, before giving some background and a narrative of the case. After the general narrative is established, individual influencing conditions and building blocks are further described. Impact on investor interest is summarized at the end, together with a more general lookback on the development of the case study.

Graphic Overview

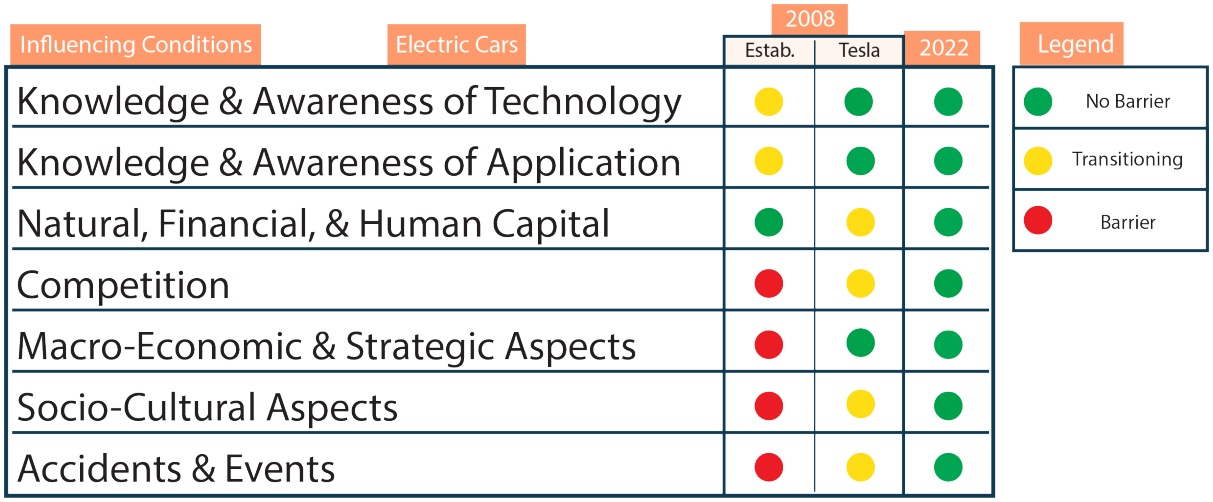


Figure 9: A high-level overview of the development of influencing conditions in the BEV TIS between 2008 and the present.[*]

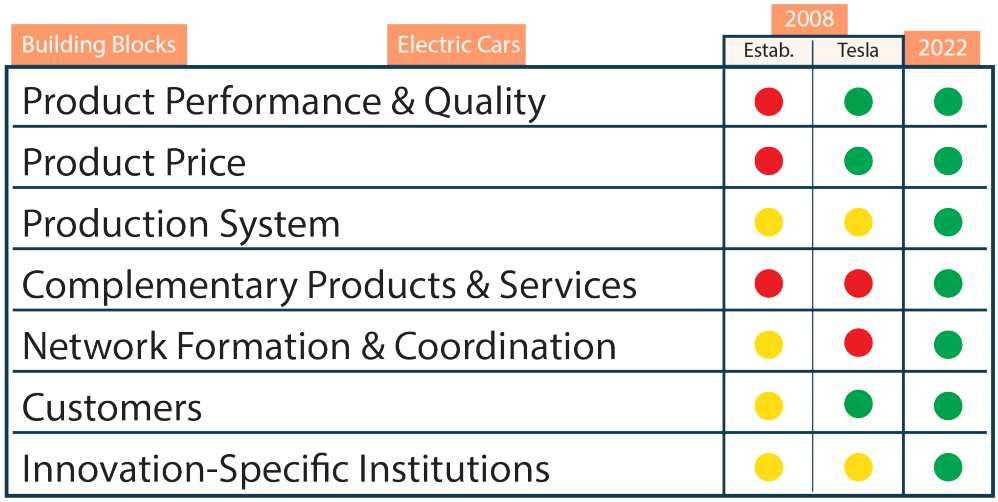


Figure 10: A high-level overview of the development of building blocks in the BEV TIS between 2014 and the present.[*]

[*] 2008 was chosen as a starting year as this is when the Tesla Roadster was first sold, signalling the start of the modern electric car. Again, note that there are two separate perspectives on the TIS at the starting period. The first is for the existing niche of low-end electric cars (such as the scrapped GMC EV1), and the second for Tesla, who reimagined the market.

4.2.2 Introduction

For this research, the term *electric car* or *battery electric vehicle* refers to light vehicles solely propelled by one or more electric motors drawing power from an on-board battery. This is different from Hydrogen Fuel-Cell EVs (FCEV), which rely on a liquid hydrogen fuel to generate electric current from a fuel cell; any type of Hybrid EV (HEV), which pairs the electric motor with a fossil-fuel engine for auxiliary power or electric generation; or heavy duty full BEVs such as vans or trucks (Bitsche and Gutmann 2004).

Electric cars predate the first internal combustion engine vehicle (ICE), the Benz Patent Motor Car, by about four years, being introduced in 1881 (Høyer 2008). But while the ICE garnered mainstream popularity in the early 1900s, BEVs slowly fell out of favour, due to their comparatively high up-front costs, low range, and long recharge times. As gas stations started to become commonplace, ICEs cemented their advantage in extra-urban travel, and the gap increased (Høyer 2008). All these challenges continued to foil several more attempts to popularize BEVs for the next century, which cropped up whenever and wherever oil became scarce or electricity uncommonly cheap, such as during the OPEC crises of the 1970's, and in areas with high amounts of hydropower (Haley 2015; Høyer 2008).

The series of events that have led up to the current wave of BEVs can be traced back to GM's Impact Concept Car. Supposedly, the presentation of this car at the 1990 LA Auto Show led non-technical California lawmakers to believe that BEVs were close to being commercially viable (Kemp 2005; Collantes and Sperling 2008). Based on this misconception, these lawmakers amended the 1990 Clean Air Act to include a requirement for the seven big auto manufacturers to make 2% of the cars they produced Zero Emissions Vehicles (ZEVs) by 1998, if they wanted to market their cars in the state (Kemp 2005; Collantes and Sperling 2008).

In response to this, GM started work on the EV1, the production version of the Impact concept car. Despite positive customer response, the EV1 never broke through to be a success. In fact, as the cars were only ever available as special "live testing" leases, GM took the cars back and ended up scrapping most of them, despite enthusiastic customers pleading to keep the cars (Li et al. 2017). Reasons for the discontinuation of the model included GM's negative view of the BEV market as an unprofitable niche, and the successful lobbying of the auto manufacturing industry against the ZEV stipulations (Lin 2011; Thomas and Maine 2019).

GM's EV1 was not the only response to California's ZEV regulations: other cars that went through similar trial releases around the turn of the century included the Honda EVPlus, Nissan Hypermini and R'Nessa, Toyota RAV4 EV, Chevrolet S-10, Chrysler TEVan, and Ford Ranger BEV. Most of these were similarly recalled and scrapped as the ZEV regulation was successfully lobbied against (Nieuwenhuis 2018; Dijk et al. 2013).

The one single success story from the ZEV era was not the electric car. Instead, the Toyota Prius' hybrid design leveraged the strengths of BEVs of the time, such a low emissions, fast acceleration, and regenerative braking, while using a fossil fuel engine to offset challenges such as range and power, (Zapata and Nieuwenhuis 2010). Relying on a lower-powered electric drivetrain and small batteries also limited the cost of EV-related components. Launched in the US in 2000, the Prius managed to ride the lines both between increased up-front costs for the extra hardware and reduced fuel consumption, and between familiarity and novelty so well, that Toyota dominated the low emissions vehicle (LEV) category for the next decade (Calantone et al. 2006; Zapata and Nieuwenhuis 2010; Pohl and Yarime 2012).

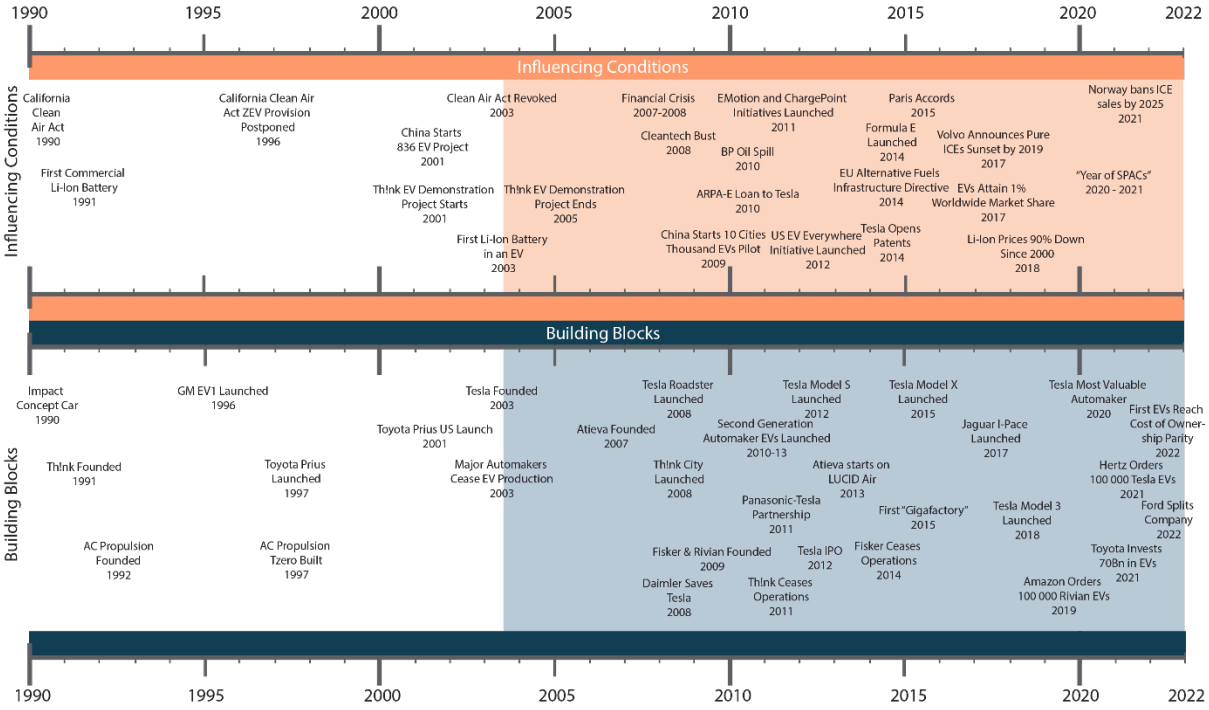


Figure 11: Timeline of key developments in the BEV TIS between 1990 and 2022.[*]

4.2.3 Case Narrative

Returning to the cancellation of the GM EV1, Elon Musk has tweeted that Tesla was founded "[…] when GM forcibly recalled all electric cars from customers in 2003 & then crushed them in a junkyard" (elonmusk 2017). Interviews did not directly confirm this, but an interviewee involved with a BEV company did note that the major automakers intentionally leaving the space presented a golden opportunity, which Tesla (and later others) eagerly jumped into (Interview 18).

In tandem with incumbents' efforts to develop EVs, Alan Cocconi, the GM Impact Development lead, founded AC Propulsion and built the tzero, the first attempt at a BEV sports car. A prototype, the tzero was a one-off hand-built car that wasn't enough convince Silicon Valley's investors. "Nothing was about the tzero was scalable" one interviewee said (Interview 18). Another noted that building a complete car seemed too big a challenge at a time (Interview 9). It did however inspire Martin Eberhard and Marc Tarpenning, two Silicon Valley entrepreneurs, to fund AC Propulsion to replace the lead-acid batteries with lithium-ion, giving the tzero a significant range (300 miles) and an acceleration boost (Chow 2003).

[*] The shaded area indicates the period covered by the case narrative. Please note that this timeline only covers events. Changes over time are not included to preserve readability. For a full-page version of the timeline, see Appendix II-B. For sources regarding event dating, see Appendix III-B.

Figure 12: A studio image of the AC Propulsion tzero for the 1999 World Fair[*]

The performance of this upgraded tzero gave Eberhard and Marc Tarpenning enough confidence that a productionized sportscar with the same technology was possible (Interview 18). They founded Tesla and started work on the Roadster. Disagreement with AC Propulsion on the approach meant that while Tesla licensed technology, there was no further partnership (Thomas and Maine 2019). Instead, AC Propulsion focused on converting the Scion xB hatchback to an electrified version and positioning itself as a supplier of technology to OEMs interested in pursuing BEVs (Thomas and Maine 2019).

When Cocconi was once again urged to turn the tzero into a production car by Elon Musk, he brought Eberhard in contact with Musk (Interviews 9 and 18). Musk ended up leading Tesla's series A investment round and joined the company's board (Thomas and Maine 2019).

Over the next few years (2003-2008) BEV production was almost non-existent. Next to Tesla, only Th!nk, a Norway based company was working on a BEV production car, which also launched in 2008. Unlike Tesla, Th!nk pursued the low-end market, with its Th!nk City being a smart-like city car (Interview 10). According to one interviewee (Interview 9), at the time there were three strategies considered feasible to bring BEVs to market. First, there was the high-end approach, which Tesla pioneered, compared to the low-end market approach followed by Th!nk in Europe and BYD in China. The third approach was a fleet-based approach, which depending on the target market could be both high- and low end oriented. On the lower end were pilot programmes such as those tried in Swiss Mendriso, and China's Ten Cities, Ten Thousand Vehicles plan (Dijk et al. 2013; She et al. 2017). On the high end, Lucid's original thesis was to create a limousine to replace the Chinese government's fleet of Audi A6L cars (Interview 9).

In the US, Tesla's approach had several key advantages over the one chosen by Th!nk and automobile OEMs (Stringham et al. 2015). Being smaller companies, all of them paid a premium on mass-market parts bought from suppliers, and every EV-specific component would be expensive, as it was novel and nonstandard (Thomas and Maine 2019). No matter how low-end the vehicle would be, these factors would greatly inflate the unit price (Thomas and Maine 2019). The Th!nk City ended up

[*]Tom Gage, AC Propulsion 1999.

costing $36 495, whereas the Smart Forfour, a comparable ICE car started at just $13 980 (Gilboy 2019; Cars-Data.com). In comparison, the Tesla Roadster released at a price of $110 000 in a market that was far less price sensitive: technical specifications such as top speed and acceleration let it compete with Ferrari and Lamborghini cars that cost far more (Thomas and Maine 2019).

Figure 13: A studio image of the Th!nk City[*]

As the Roadster went into production, Tesla started development on the Model S, a premium Sedan and its first true production car, built in their own factory rather than contract-manufactured by Lotus or another third party. Trying to transition to the Model S nearly bankrupted Tesla several times over (Cao 2021). Between struggles to finalize the Roadster production line, internal volatility (Tesla went through four CEOs in 2008), and the financial crisis, their Series E round collapsed (Stringham et al., 2015, Interviews 9, 10, and 18). With days left before bankruptcy it was an automaker, Daimler, that provided the cash that let Tesla continue (Stringham et al. 2015). Out of this investment came a minor partnership, with Daimler relying on Tesla to supply the drivetrains needed for their electric Smart Fortwo while they developed their own.[†] Daimler ended up scrapping their BEV project (both drivetrain and cars) as soon as regulation allowed them to, and all sold Fortwo's were equipped with Tesla drivetrains (Interview 18).

More meaningful partnerships followed, including one with Panasonic focused on battery development, which continues to this day; and one with Toyota, which resulted in the transfer of Toyota's Fremont NUMMI plant (an old GM partnership that weighed on Toyota after GM went bankrupt) to Tesla in return for equity (Stringham et al., 2015, Interview 18).

As development of the Roadster wrapped up, other contenders started emerging. Fisker, LUCID, and Rivian were all founded in the 2007-2009 period. LUCID, then known as Atieva, and Rivian both struggled to find funding in the US: Atieva found as single US investor and raised the rest of its capital from China and Japan, while Rivian was funded primarily by a private investor based in Saudi Arabia.

[*] Car Magazine 2009: https://www.carmagazine.co.uk/car-reviews/think/thnk-city-2009-electric-review/

[†] According to an interview with an ex-EV company executive, Daimler only pursued the BEV Fortwo to comply with Canadian law (Interview 18).

One interviewee stated that "Funds did not know how to assess the risk or help the company. So, they waited. This was a common pattern in early-stage venture capital." (Interview 9, corroborated by 10). Fisker, focusing on more established hybrid vehicles rather than full electric, did find funding from heavyweight Kleiner Perkins as they considered the hybrid technology more feasible (dougdirac 2011).

Figure 14: A studio image of the 2008 Tesla Roadster from autovehicle.info[*]

In 2010, the landscape changed. Under the Obama administration, ARPA-E—a US government initiative focused on accelerating sustainable innovation modelled after DARPA—provided both Tesla and Fisker with loans of respectively $465 and $539 million to build factories (Hargadon and Kenney 2012). Tesla used this loan to build out the factory they purchased with Toyota in preparation of the Model S launch, about which Peter Thiel later said, "There was only one moment where that was possible, and Tesla played it perfectly" (Thiel and Masters 2014, p. 167). Once public, Tesla repaid the loan in 2013, ten years ahead of schedule. Fisker went bankrupt a few years later despite the loan (Giorgis et al. 2021).

Around the same time, incumbents started releasing a new generation of BEVs (Nieuwenhuis 2018). This included the Nissan Leaf, Chevy Volt, and BMW i3. Notable about these vehicles is that they targeted a very different market than the start-ups. Thomas and Maine (2019) quoted Martin Eberhard as saying: "The i3 was designed so as to not cannibalize their profitable lines at all." Each of these cars was in the lower end, but, like the Th!nk City, still commanded a high up-front price. This combination meant that while the cars found success among environmentalists and city drivers, if these could secure subsidies, and had perceived access to fast-charging infrastructure (Ingeborgrud and Ryghaug 2019; Mersky et al. 2016; She et al. 2017).

Fast-charging infrastructure played a critical role in the further introduction of especially lower-range BEV companies (Ingeborgrud and Ryghaug 2019). Even if many riders do not use these fast

[*] Autovehicle.Info: http://www.autovehicle.info/tesla-roadster/detay/tesla-roadster---darkstar-2008-2012-6640.html

chargers regularly or at all, "Range Anxiety" is a significant barrier to purchasing a BBEV.[*] The emergence of BEV-charging companies such as Newmotion, FastNed, and others from about 2009 onwards is no coincidence. As BEV markets shaped up, governments expanded their incentives, and a significant amount of money was spent on these systems (Schroeder and Traber 2012; Chen et al. 2020). They were joined by investments from BEV manufacturers who saw the need of charging stations to increase interest in the cars (Chen and Perez 2018).[†] Some other attempts to improve range-capabilities were also pursued, including battery-swapping, both by start-up Better Place, and Tesla themselves, but this was far more costly and less efficient than expected (Noel and Sovacool 2016). Better Place folded by 2013, and Tesla's pilot lasted just over a year (Noel and Sovacool 2016). Battery swapping technologies ended up making a comeback in the electric bike and scooter (sharing) space a few years later.

From 2010 until 2018, Tesla was the sole option in the high-end BEV market. On the side of major automobile manufacturers, it was mainly low- to mid-end BEVs that multiplied, as the Nissan Leaf continued to be the #1 selling BEV in Europe, and the newer Renault Zoe did similarly well (Kapustin and Grushevenko 2020). Nissan-Renault seemed the only major automobile manufacturer to take the market serious, and they did not operate in the higher segments. By 2017, due to high oil prices and OEMs managing to bring down prices BEVs were first considered cost-competitive with ICEs in specific markets, although they still lagged ICEs when it came to performance (Maciejewska et al. 2019; Glitman et al. 2019).

At the same time, Tesla worked down the segments, releasing the Model S sports car in 2012, and Model X SUV in 2015. During this time, Tesla managed to build a cult-like following for its BEVs. Speaking about them, one interviewee said: "They made BEVs their Religion. They were all in—and that's the mindset that was needed make good BEVs. Larger companies were trying to see BEVs as part of a portfolio, but their branding was all over place" (Interview 9). Tesla's lower end cars still boasted the performance of their higher-end brethren as well as unrivalled safety ratings (Chen and Perez 2018). The problem was availability. Demand for Tesla cars outstripped supply at every turn, with waiting times going over a year by the time the Model X released. By the time the Model 3, Tesla's first "affordable" car released in 2017, there were nearly half a million outstanding reservations, and daily new signups were almost double the initial production capacity of 5000 cars per week. It took Tesla up to 2020 to produce the first 500 000 vehicles (Tesla Inc. 2020).

In 2017, Tesla's dominance was put into question. The competition finally shaped up: Jaguar released the I-Pace, the first high-end electric car from an established automaker, which would soon be followed by the Porsche Taycan. On the start-up side, Atieva (by then rebranded to Lucid) raised 1 billion from the Saudi Public Investment Fund to build a factory, finalize design, and start production on the Air, a high-end sedan, and Rivian raised similar amounts in the US to build their factory and produce an SUV and a pick-up truck (Crunchbase 2022d, 2022e).

[*] Range Anxiety refers to the fear that a BEVs battery is insufficient to reach one's destination. As charging stations were few and far between, and BEV range was short compared to ICEs the risk theoretically existed that one ended up too far from a charger. The perception of this problem was far larger than real-world experience showed (Noel and Sovacool 2016).

[†] Tesla themselves did originally not intend to build fast chargers. They expected that the Roadster would not be a grand tourer, but customers almost immediately took the cars on cross country trips. Tesla realized it could be a good way to advertise the car, and much of the cost could be subsidized by strategically locating the chargers at locations such as malls that would benefit from a captive audience (Interview 18).

While the competition increased, Tesla was struggling. Ramping up production of the Model 3 as well as building out several "Gigafactories" in the US and Shanghai stretched the company thin, and they were often mere weeks from bankruptcy throughout the production ramp up (Kolodny 2020b). This was reminiscent of the problems Tesla faced in 2008 through 2012, when they were working up towards producing the Model S (Rosenbaum, 2018, Interviews).

Despite the challenges, Tesla started to stabilize and posted a profitable quarter in July 2019. The stock rallied, and Tesla overtook Toyota (the world's most valuable automaker) in early 2020. After posting four profitable quarters in row, it was included in the S&P 500 index by mid-2020, leading to a further rally, and peaking at a $1 Trillion Market Cap in 2021 (Bursztynsky 2021). Tesla's success created a friendly climate for other BEV start-ups to go public, which they did mostly through the rise of SPAC's* over the course of 2021, resulting in very high valuations for these companies as they rode the wave of interest of retail investors (Saengchote 2021).

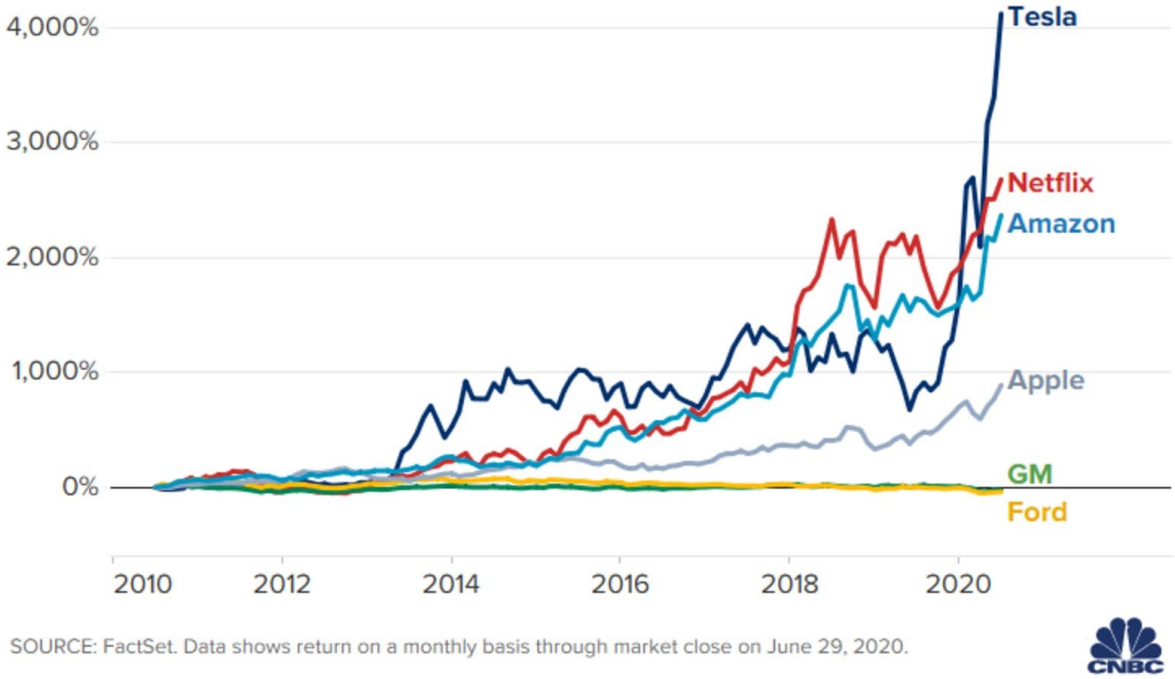


Figure 15: Tesla Stock growth between its IPO and 2020 peak (Kolodny 2020a)

At the same time, the regulatory push first instigated by the CARB in 1991 was finally making a comeback as governments started to set net zero targets (Stokes and Breetz 2018). The first serious commitments were made through the 30@30 programme, encouraging governments to aim for 30% of new cars being BEVs by 2030 (Clean Energy Ministerial and Electric Vehicles Initiative 2021). These were further emboldened in 2021 when the EU proposed its Fit for 55 strategy, which upped the target in Europe to be 55% by 2030, and 100% by 2035 (European Environment Agency 2021).

This mix of regulation, customer interest, and investor appetite for BEVs inspired traditional automakers, with more and more of them launching newer and more competitive midsegment EVs, such as KIA's BEV line-up and Hyundai's Ioniq. In May of 2021, Ford launched pre-orders for the F-150

* SPAC stands for Special-Purpose Acquisition Company. In the financial world, SPACs are empty companies listed on a stock exchange with the sole purpose of merging with a private company, after which the SPAC dissolves and the private company is now listed on the exchange. This process is often cheaper, easier, and faster than an Initial Public Offering (IPO) (Young 2022).

Lightning, an all-electric version of the US's highest-selling, to start production in 2022, aimed at a modest 15,000 units in the first year. In the first 48 hours, Ford received 45,000 pre-orders, going up to 200,00 before the end of 2021. In response to this overwhelming customer interest, Ford massively moved up production timelines, quadrupling them to be at 150,000 by 2023, and even going as far as splitting the company into "traditional" and electric businesses at the start of 2022 (Doll 2022; Mullaney 2022). In November of 2021, six of the seven largest automobile manufacturers entered an agreement to phase out fossil fuelled cars by 2040, which Toyota—the world's leading manufacturer and original LEV pioneer—declined to join. A month later, the company partially u-turned when it announced that its premium Lexus brand would move to be fully electric by 2035 as part of a $70 billion investment in EVs(Reuters 2021).

4.2.4 Sequence of Influencing conditions

4.2.4.1 Knowledge and awareness of technology

2008 | Estab. ● | Tesla ● | 2022 ●

Like PBMA, there have been several attempts at popularizing BEVs. The most recent wave started in the 90's (Köhler et al. 2013). Since this period, there has been a rapid increase in patenting activity, especially in recent times (Köhler et al. 2013). This was mainly through small scale local research stimulated by government research in different countries (Doufene et al. 2019; Pohl and Yarime 2012; Nykvist and Nilsson 2015). This research was varied, and for a long time it was uncertain which technology would be the way forward, between FCEVs and BEVs (Pohl and Yarime 2012; Köhler et al. 2013). This small-scale research was broken through first by the success of Hybrid EVs(HEVs), and specifically the Prius. BEVs themselves only truly shone through after Tesla pioneered lithium-ion batteries and focused on the luxury segment. Some Asian carmakers followed in the volume segment, but it took a long time for other manufacturers to take BEVs seriously (Nieuwenhuis 2018; Sun et al. 2019; Magnusson and Rickne 2010).

4.2.4.2 Knowledge and awareness of application and market

2008 | Estab. ● | Tesla ● | 2022 ●

The BEV market has made several surprising developments. Initial interest in the technology was focused on sharing systems (Skjølsvold and Ryghaug 2020; Haley 2015). Technological limitations prevented this from being a success though, and the next evolution was low speed BEVs by local innovators. This was a very limited market, and the first real breakthrough was the onset of HBEVs (Hosseinpour et al. 2015). The next development was Tesla's entry into the luxury vehicle space, which was the one vehicle category that could subsidize the high cost of batteries (Nykvist and Nilsson 2015). Slowly, more affordable BEVs entered the space, but their limited range kept them from becoming mainstream, tempering faith in EVs, with several brands having little exposure to the market as recent as 2016 (Nilsson and Nykvist 2016). This reached a tipping point in the past few years, with mid- and low-end BEVs gaining ground as technology improved (Skjølsvold and Ryghaug 2020; Morgan 2020).

Next to the market for personal BEVs created by Tesla, there remains strong interest in electric (autonomous) shared vehicles. This is seen as an ideal use-case for EVs, as their operating costs are much lower than ICEs. Taxi systems were a key early market for BEVs (Li et al. 2016)

4.2.4.3 Natural, human, and financial resources[*]

2008 | Estab. ● | Tesla ● | 2022 ●

Despite the automobile industry being one of the largest in the world, much of BEV development took place on the government's dime (Magnusson and Rickne 2010). Governments have sponsored these programmes with large amounts of money, with China committing the equivalent of 140 million USD to BEVs as early as 2001, and billions more down the line (Li et al. 2016). Similarly, the US government guaranteed a loan of nearly half a billion dollars for Tesla's first factory alone, as part of

[*] VC as a Financial Resource is broken out as a separate topic in 4.2.6 Development of Investor Interest

a 14-billion-dollar automotive innovation programme (Berkeley et al. 2018). On top of direct aid, many government programmes build or subsidize chargers and subsidize the purchase of BEVs.

Individual start-ups saw an influx of cash during the Cleantech era, but US VC interest was muted. Most of the start-ups that would later be successful (apart from Tesla) had to go abroad, ultimately finding funding in China and later Saudi Arabia (Crunchbase, 2022c; Seetharaman & Lienert, 2013, Interviews). "Only a single Cleantech investor dared to invest in [Lucid]", one interviewee said. "They would rather wait and see than invest in EVs". Tesla on the other hand was always ahead of the pack, and relied on investors outside the Cleantech world, relying on their founders' established network from previous ventures (Interviews 9 and 18).

Human capital developed differently. As a pioneer, Tesla attracted many of the people interested in EVs and helped them develop their skills. As people moved on from the company, they founded competitors: so much that they were even dubbed the "Tesla Mafia", after Peter Thiel's famous PayPal Mafia (Ohnsman 2021; Ludlow and Hull 2021). One US-based investor confirmed this during an interview, naming "Tesla talent" a key asset to Lucid's success (Interview 9, corroborated by 19).

4.2.4.4 Competition

2008 | Estab. 🔴 | Tesla 🟡 | 2022 🟢

As mentioned, uncertainty regarding the dominant ZEV technology hampered all of them (Köhler et al. 2013). Once it was clear that BEVs would be the dominant strategy, this largely cleared up: after 2012 very little support for FCEVs remained outside Japan (Nilsson and Nykvist 2016).

Initially, there was little competition within the BEV space—with only the BMW i3 globally available, there were many separate markets catering to their own niches at different price points. Even as availability picked up, a few key models made up most of the market, with many more models existing in local niches (Berkeley et al. 2018; Morgan 2020; Richter 2019). Since taking the spot from Nissan in 2015, Tesla has held the largest share of the BEV market. The BEV market itself has also seen huge growth, with total new car registrations growing by double digits almost every single year since 2010 (IEA 2022).

4.2.4.5 Macro-economic and strategic aspects

2008 | Estab. 🔴 | Tesla 🟢 | 2022 🟢

Development of BEVs has historically occurred in lockstep with shocks to the oil price. For example, the start of research into modern BEVs can be traced back to the 70's oil crises (Doufene et al. 2019; Pelegov and Pontes 2018). Furthermore, these types of shocks meant BEV programmes were often local affairs and seen as strategic developments by governments. This manifested in significant protectionism and sponsoring (Li et al. 2016; Zhang et al. 2014). On a smaller scale, this manifests in increased consumer interest in BEVs when the oil (gas) prices are high (Hanke et al. 2014).

While BEVs avoid being reliant on oil for fuel, it faces similar challenges regarding materials. Lithium, as well as rare earth metals are required to produce BEVs and naturally occur in few countries, and the ethical and moral dimensions of the mines sourcing these materials are often put into question (Hanke et al. 2014). See the figure below exploring the price of battery packs using this material over time – they dropped 97% since their introduction in 1991.

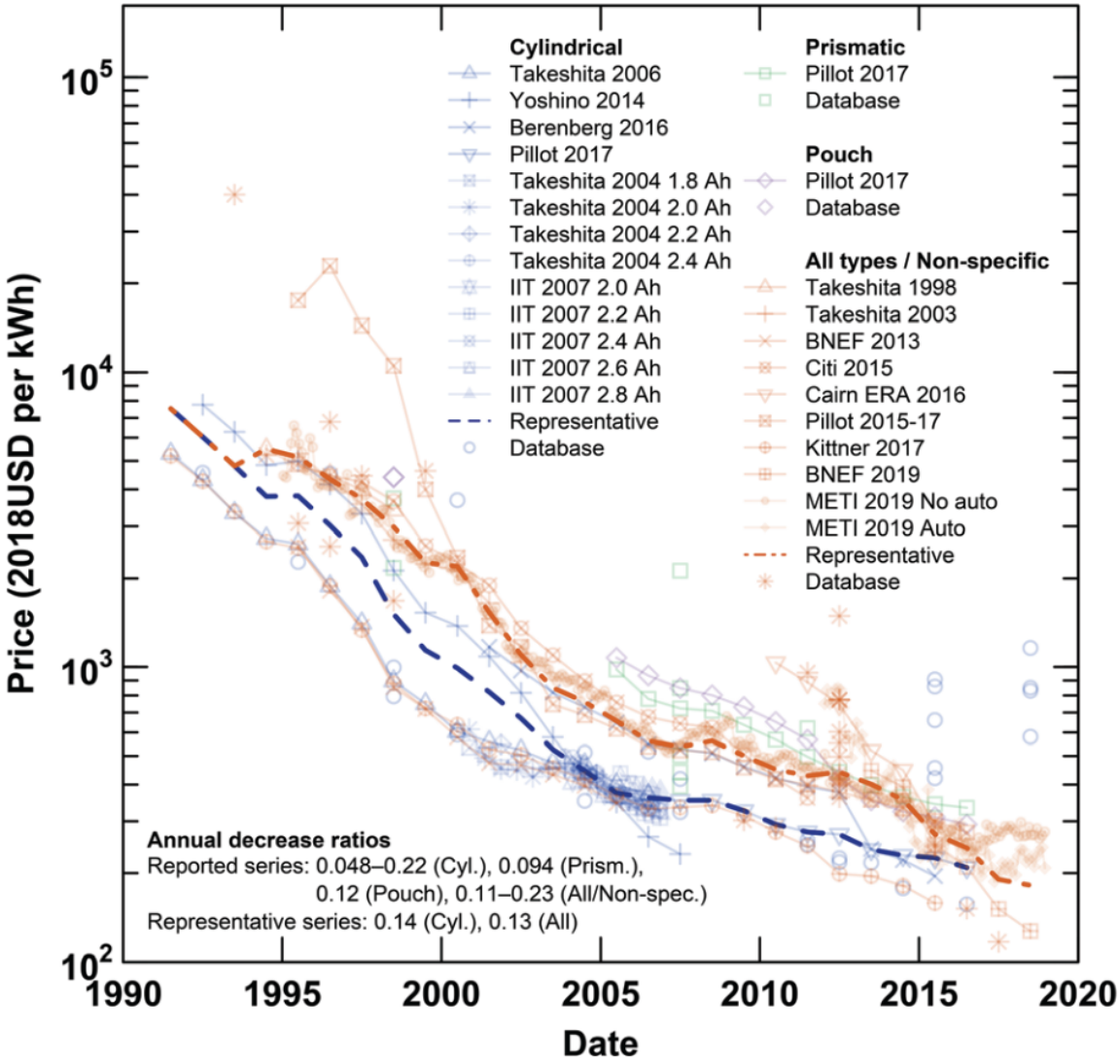


Figure 16: Cost of Lithium-Ion (Ziegler and Trancik 2021)

Next to the strategic interests, the BEV is one of the main technologies in a transition towards a carbon neutral future (Köhler et al. 2013). This is good for the development of the technology, as it makes it more attractive from an environmentalist perspective, but of limited value for the market without a government push towards this future (Zhang et al. 2014).

4.2.4.6 Socio-cultural aspects

2008 | Estab. ● | Tesla ● | 2022 ●

For the second half of the 20th century, and the first years of the 21st, the car was one of the defining symbols of modern society (Köhler et al. 2013). This is slowly changing, especially in youth, who are more open to the idea of sharing or flexible mobility (Köhler et al. 2013).

However, many of those who like cars reject BEVs as being not the same. To some regard, this is due to physical objections such as limited range or lack of towing hooks, but also due to less tangible aspects: people consider BEVs to be “soulless” (Nykvist and Nilsson 2015; Berkeley et al. 2018).

Simultaneously, as early as the first Prius, sustainable cars have been in fashion in certain wealthy circles, relying on the ability to broadcast a consumerist version of environmental awareness (earning it the moniker “Pious” (Interview 9)). Tesla leaned on this need to position its Roadster and Model S vehicles, creating a “Cult-like following” (Interview 9). This following combined with its performance

meant that Tesla was less reliant on subsidies than the competition; Hardman et al. (2017) state in an analysis of the data of (Vergis and Chen 2015) that "Further analysis of their data revealed that for non-Tesla BEVs (e.g., Nissan Leaf) the incentive is important. For the purchase of a Tesla BEV, they found that purchase incentives were not important." (p. 1103).

4.2.4.7 Accidents and Events

2008 | Estab. 🔴 | Tesla 🟡 | 2022 🟢

California's Clean Air regulations from 1990 is consistently considered the single most important regulation in support of BEVs and other low emissions vehicles (Pelegov and Pontes 2018; Haley 2015; Sovacool and Hirsh 2009). This can be traced back to a non-technical lawmaker being impressed by GM's 1990 BEV concept car, introducing the idea of a zero-emissions vehicle to the regulation (Stokes and Breetz 2018).

Other key developments were the popularity of the Toyota Prius showing that reducing fuel usage could be popular with consumers, which inspired other automakers (Magnusson and Rickne 2010). It was then Tesla's release of the Roadster in 2008, and subsequent government supports that brought BEVs to the spotlight (Haley 2015; Hardman et al. 2017). Tesla has also often been criticized as held together by sheer luck, the company more than once teetering on bankruptcy (Kolodny 2020b; Rosenbaum 2018).

Finally, as mentioned previously, oil-related accidents and shocks play a significant role. This includes the oil crises in the 70's, and the Deepwater Horizon spill (Pohl and Yarime 2012; Pelegov and Pontes 2018).

4.2.5 Sequence of Building Blocks

4.2.5.1 Product Performance and Quality

2008 | Estab. 🔴 | Tesla 🟢 | 2022 🟢

Initially, more basic factors speed or even the number of seats were problems for early EVs, but this can be considered solved (Nykvist and Nilsson 2015). A larger struggle for BEVs has been to compete with ICEs on range and charging time (Masiero et al. 2016). The Tesla Roadster popularized BEVs by tackling most of these issues bar the charging time, albeit at a high price tag. It also leveraged EVs' immediately available torque to beat much more expensive sportscars on popular metrics related to acceleration (Stringham et al. 2015). This put BEVs on the map.

Range and charging time have steadily improved since the introduction of this generation of BEVs in 2008, but even today action radius is a major problem with lower end BEVs (Masiero et al. 2016; Nykvist and Nilsson 2015; Krause et al. 2013; Haddadian et al. 2015). Action radius is mainly linked to battery technology, which has seen massive improvements in the past 12 years, often so rapidly that scholarly articles cannot properly capture it (Nykvist and Nilsson 2015; Masiero et al. 2016; Coffman et al. 2017).

4.2.5.2 Product price

2008 | Estab. 🔴 | Tesla 🟡 | 2022 🟢

There is a direct trade-off between price and performance for EVs, due to their reliance on batteries. Batteries that are good enough for long-range BEVs are available, however they are too expensive to be put in lower-end vehicles (Nykvist and Nilsson 2015; Berkeley et al. 2018).

It is for this reason that Tesla's high-end roaster and Model S were such a masterstroke, because for a more expensive car the batteries made up a smaller part of the total price, and at higher price points, price sensitivity of customers was much lower (Nieuwenhuis 2018; Masiero et al. 2016). Since the release of the Roadster, battery prices have declined significantly, making BEVs more cost-competitive over time (Henze 2021). This has seen Tesla move down segments, whereas most incumbents have improved the performance of their BEV offerings, afraid of cannibalizing their high margin products until recently (Interviews 9 and 19).

4.2.5.3 *Production system*

2008 | Estab. 🟡 | Tesla 🟡 | 2022 🟢

The transition from ICEV to BEV is not as simple as merely dropping an electric motor in an existing model (Nieuwenhuis 2018). The automobile industry is one of the most complex and optimized supply chains in the world (Köhler et al. 2013). This has also meant that uncertainty regarding the optimal future technology caused considerable lag in the response of the larger OEMs (Köhler et al. 2013; Bakker et al. 2014). This is visible with Toyota, who held on to FCEVs much longer than all others, because they were such an early mover and so far along in this technology (Köhler et al. 2013; Pohl and Yarime 2012). It also explains why BYD and Tesla, relative newcomers to the automobile sector were able to penetrate. Coming from electric, or even nothing, was easier than shifting complex existing production systems into uncertainty. Once the decision had been made however, OEMs shifted remarkably quickly (Doll 2022; Reuters 2021).

4.2.5.4 *Complementary products and services*

2008 | Estab. 🔴 | Tesla 🔴 | 2022 🟢

A global network of charging infrastructure is key to the successful rollout of BEVs. This is because of the concept of "range anxiety"—due to the relative short and long recharge of EVs, consumers are terrified of being stuck without electricity (Nykvist and Nilsson 2015). This was made more complicated by the high up-front costs and long repayment times of this technology (Schroeder and Traber 2012; Kley et al. 2011). This was part of the reason there was so much interest in sharing business models, where it would be easier to have people pay into a system for more than just charging, which was often done very inefficiently (Ajanovic and Haas 2016; Kley et al. 2011).

In the end, it has largely been government (as part of support for BEV rollout), BEV manufacturers (as cost of doing business), and locations themselves that have funded public charging infrastructure (Robinson et al. 2014; Li et al. 2016).

4.2.5.5 *Network formation and coordination*

2008 | Estab. 🟡 | Tesla 🔴 | 2022 🟢

Over time, many different networks have developed in the BEV or even automobile space. Some notable partnerships include the Toyota-Panasonic battery backing almost all HEVs, and the Tesla and Lotus joint venture to build the first Roadster (Li et al. 2016; Pohl and Yarime 2012). BEVs were of high strategic importance to battery manufacturers: without BEVs most customers would only possess approximately 7 Li-Ion cells, but a single BEV used thousands (Tarpenning 2021). This helps contextualize why A123 Systems, the troubled battery start-up, was one of Th!nks last backers.

4.2.5.6 *Customers*

2008 | Estab. 🟡 | Tesla 🟢 | 2022 🟢

For a long time, the BEV market was niche with a small but devoted community (Skjølsvold and Ryghaug 2020). It took many incentives and developments to get the average consumer to consider purchasing a BEV (Krause et al. 2013). Consumers expect the same range and refuelling conveniences that an ICE offers. This has made it hard for BEVs to gain a foothold and spin the wheel of innovation (Hosseinpour et al. 2015). Key customers then were public organizations doing large scale BEV acquisitions. These types of purchases made it safer to innovate, as there was a guaranteed market (Doufene et al. 2019; Masiero et al. 2016).

It is also observed that consumers are largely unaware of developments with regards to BEVs. Their perceptions regarding range and performance are often outdated, which hinders adoption (Berkeley et al. 2018; Krause et al. 2013; Bunce et al. 2014).

This has slowly started to shift as BEVs started to enter the mainstream. Market share hit 1% in 2017, and rapidly picked up from there, as seen in the graph below.

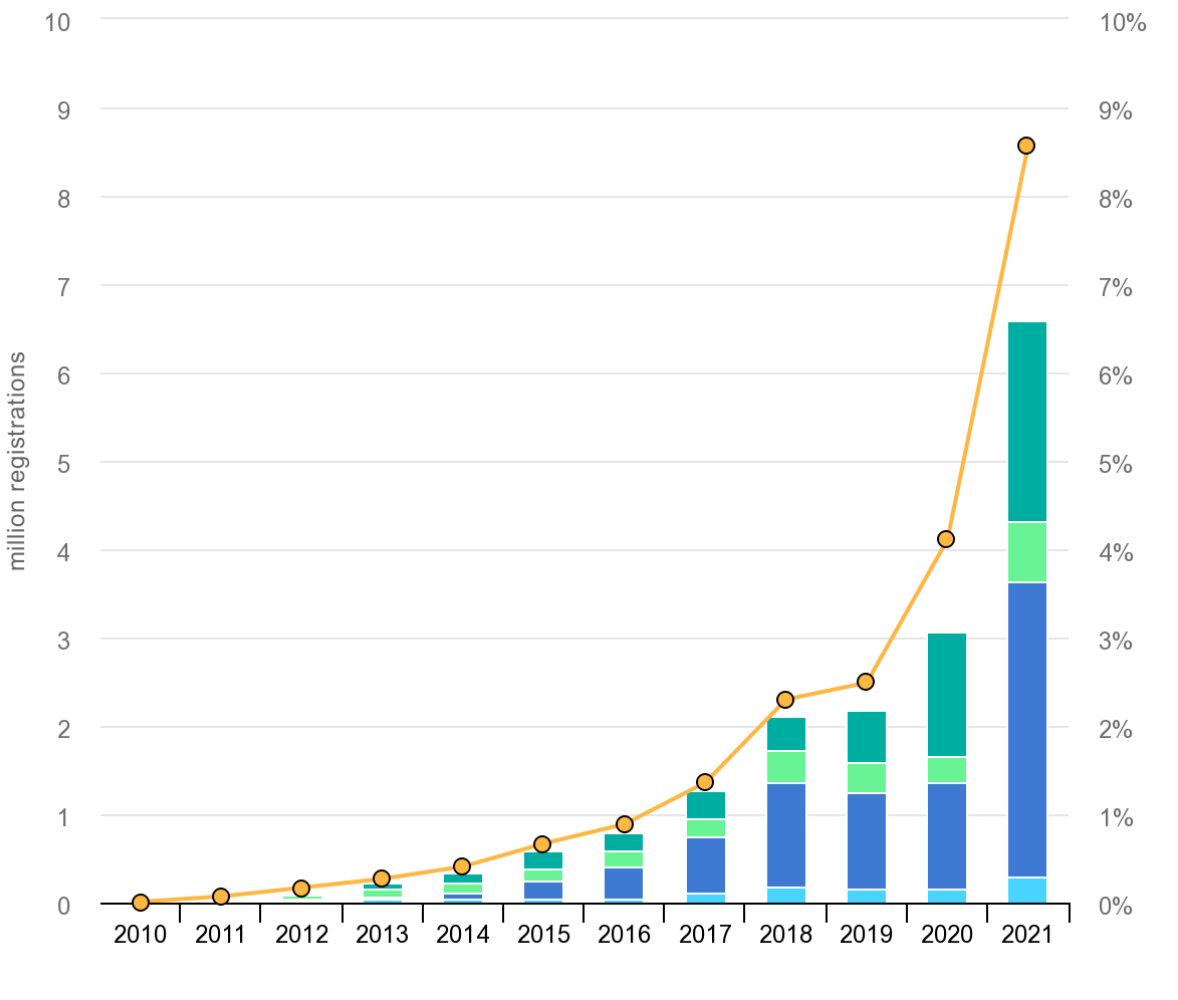


Figure 17: Market Share of BEV Registrations 2010-2021 (IEA 2022).

4.2.5.7 *Innovation-specific institutions*

2008 | Estab. | Tesla | 2022

After renewable energy, BEVs are probably the most visible and developed sustainable technology. Governments have long pushed for the technology, so much that most innovation only happened because of government push. Li et al. (2016) goes as far as stating: "In this sense, deploying BEVs is not a market-driven technology diffusion, but a government-dominated political target" (p. 373). This was in reference to the Chinese market, but much of it transfers to other markets, such as the Swedish or American ones (Magnusson and Rickne 2010; Pohl and Yarime 2012; Li et al. 2016). Each of these governments has spent billions supporting nascent industries with tax breaks, building charging infrastructure, or giving consumers direct discounts on the cars (Masiero et al. 2016; Hardman et al. 2017).

Furthermore, Tesla greatly benefited from tax credits in the EU's ETS. At its peak, this represented about 12% of Tesla's revenue—essentially representing a subsidy paid to them by other companies. "The Tesla business model, however, also benefits from other revenue streams, such as the income Tesla obtains selling zero emission credits to others (at one stage amounting to 12% of revenues)" (Nieuwenhuis 2012, p. 42).

4.2.6 Development of Investor Interest

AC Propulsion initially tried to raise money with their tzero concept in the early 2000's. Between their "hobbyist" approach and an industry coming freshly of the internet bubble bursting, investors

were unwilling to bite (Interview 9). The only people interested were Marc Tarpenning and Martin Eberhard. They gave AC Propulsion some cash to retrofit the tzero, with lithium-ion, greatly enhancing its performance, but even that was not enough to convince other investors on the company (Interview 9). The problem was "everything was one off. It showed that it could work, but there was no way it was manufacturable." Auto manufacturers were also out: 2002 saw a GM-led suit of auto manufacturers trying to kill the ZEV regulation and already winding down their BEV programs (O'Dell 2003; Kemp 2005).

Due to their network and experiences from previous ventures, Martin Eberhard and Marc Tarpenning had more success raising seed money from "Friends, Family, and Fools", as well as two smaller VCs that wrote seed checks. From the get-go their aim was to "only spend venture money on the novel stuff. The drivetrain, the batteries, and the like." Everything else they would get from a contract manufacturer, trying to stay as little capital intensive as possible. Even so, this hurdle was the main reason they got turned down by many investors. Elon Musk joined as an investor in the Series A and led the round. The Series B was mostly just follow-on investment as the company reached its targets.

By their series C in 2006, things became easier. They had finished the first engineering prototypes, making it possible to show investors what they were investing in. "The cars were a little rough, CNC'd, not finished, but it was something. Every VC has a sports car, and they could see themselves drive them." That was key, according to an interviewee that experienced the start-up first hand (Interview 9). "A VC does not have that much imagination. They couldn't sell them on revenue because there wasn't any. But they could show them something that they wanted, or they could see someone else might want."

Tesla's challenges arose when they started the transition from the niche Roadster towards the more mainstream market Model S in late 2007. Disagreements at the board level led to a year of four CEO's, which was a death knell for their planned Series E round (Interviews 9 and 18). It is uncertain what the impact was of the Cleantech bubble. "None of Tesla's investors were traditional Cleantech investors." One interviewee said. "Whether that was for better or worse I don't know." For Atieva, the second BEV that ended up being successful—and the first to be positioned in the Cleantech space—it meant struggling to find investors in the US (Interviews 9 and 10). This aligns with literature: during financial hardship, VCs will first halt investing in new start-ups, focusing on preserving their existing investments (Howell et al. 2020).

At this point, Tesla was seriously struggling for cash. Elon Musk invested most of his remaining capital, and they still came within days of bankruptcy before the Daimler investment came through (Stringham et al. 2015). As Tesla started delivering Roadsters, cashflow stabilized somewhat but they were a long way off the model S. They drew up plans to go public and raise funding to build an Arizona or New Mexico manufacturing facility, but it would be a tough battle. The ARPA-E loan and the Toyota factory made it significantly easier for Tesla to "cross the gap", with one interviewee stating that "it might not have been as good of a story otherwise, but there was a plan."

It was not as good of a story for the competition. Fisker and Th!nk folded in this period, as investors lost faith, the Cleantech bust bankrupted A123 Batteries, a key supplier and backer, and initial product sales were not enough to buoy the companies (Interview 10). The smaller companies, Rivian and Atieva, leaned on their initial and largely foreign investors to come through and back them (Crunchbase 2022e, 2022d). It would take until 2017 for investor interest to start heating up, as the signs of a mass market started to appear: the Model 3's "affordable car" positioning, Amazon's promise to buy 100.000 Rivian delivery vehicles, and early signs that major automobile manufacturers

were starting to take the market more seriously (L. Johnson et al., 2021, Interview 19). This led to massive investments from a small number of players: the Saudi Investment Fund investing $1 Billion in Lucid, and 10.5 billion mostly from Amazon, Ford, and T. Row Price in Rivian (Crunchbase 2022d, 2022e).

Tesla stock started a meteoric rise starting in early 2020, which accelerated BEV start-ups' plans to go public, releasing these companies on the public markets (Saengchote 2021; Giorgis et al. 2021). As the new regime formed, private investors shifted focus to developing battery and other production system companies, which will be key in the further adoption of the technology (Johnson et al. 2021). One notable exception to this is Lightyear, a Dutch company that focuses on developing a "Solar Car" rather than a plug-in BEV(Lightyear). While the company has grown fast, it has not seen the explosive growth of other BEV companies, nor has it pursued a SPAC (Crunchbase 2022f). Interviewees note that fundraising for, or even starting a company like Lightyear is much easier than it was in the past (Interviews 3, 6).

4.2.7 Conclusions

Tesla successfully created a market where there was none by using product performance and customers' sensitivity to brand to subsidize novel technologies, making them profitable through a high product price. Investors backing Tesla did not primarily care about the environmental benefits, and neither was it the main driver for its customers. This greatly increased the addressable market when compared to prior efforts, which had a more environmental focus and took a lower-cost approach. At the same time, significant government subsidies aimed at these environmental impacts sweetened the deal and were key to Tesla's continued growth. Tesla's success inspired a few deeply funded copycats, but the plurality of start-up activity was in charging and complementary products.

Looking at the Ortt & Kamp (2022) framework, this translates to the following influencing conditions*: Knowledge and Awareness of Technology*, *Knowledge and Awareness of Application and Market*, *Competition*, and *Socio-Cultural Aspects*. Regarding building blocks, this meant: *Product Performance and Quality*, *Product Price*, and *Customers*. *Accidents and Events* deserves an honourable mention but is harder to pin down than the other influencing conditions.

When considering the investor landscape, the complexity of the automotive industry meant that start-up efforts in full BEV innovation was for the most part highly centralized in a small number of companies, which saw extremely high amounts of investment from a few large, non-specialized players. These companies went public en masse when Tesla's performance on the stock market provided an opportunity.

5 Cross Case Analysis

5.1 Overview

5.1.1 Similarities

The cases of PBMA and BEV show many similarities. Both innovations were championed by companies that reimagined a niche sustainability-focused product into a great product that happened to be sustainable, enabled by championing a new component (lithium-ion batteries) or novel ingredient (pea protein powder). These companies challenged a highly optimized and embedded regime which considered the niche they operated in small and unviable. They were led by visionaries that saw an opportunity which others did not and managed to raise funding from investors not typically active in these industries.

To exploit the niche involved major re-engineering based on a prototype or lab product created by a specialist that was not yet suitable for mass-production. Initial products (Roadster, Beyond Chicken Strips) were VC backed and relied on (relatively) small scale production at a premium price, serving to build a brand and as a learning experience towards a second product. These first products greatly benefitted from the outsourcing and offshoring trends that dominated major industries in the 70's and 80's. Off-the shelf availability of many components and ingredients reduced barriers of entry and made it possible for a small entrant to compete with behemoth incumbents.

The second products (Model S and Beyond Burger) were the true breakthroughs, as initial success enabled fundraising for real manufacturing equipment and expanded hiring. Initial success also served as validation point for possible competitors (Lucid/Rivian, Impossible), enabling them to raise more funds. Competitors followed a different trajectory from the market creator—whereas market creators were also the first ones to go public, competitors stayed private for longer and were more heavily funded by investors, focused on leapfrogging towards large scale production of a single or small number of core products with distinguishing features (Lucid's focus on a luxury experience, Rivian's pick-up, Impossible's heme).

In both cases, a Europe-based competitor that was earlier to market (Th!nk, Vegetarian Butcher) found some success, but did not scale nearly as hard as the US-based competition. This was due to a combination of factors including but not limited to lower funding opportunities and the more fragmented European market.

5.1.2 Differences

The PBMA market developed quite different from the BEV market. Some differences that might have been in favour of PBMA:

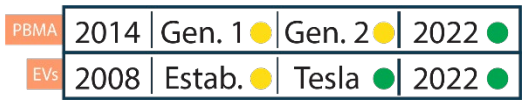
- The nature of the product: it is simpler, easier for customers to try, and relatively cheap to rent manufacturing capacity for, all lowering the barriers to entry
- Existence of already developed players in this and related niches, which benefitted from the renewed interest
- Quick emergence of a dedicated investing ecosystem, with food-focused angels and funds popping up as early as 2014, in turn helping nurture new start-ups
- A stronger social stigma on the incumbent industry, pushed through social media and viral documentaries
- An existing customer base from PBMA 1.0 products
- The early acquisition of the Vegetarian Butcher by Unilever signalling incumbent interest, and the much larger and publicized IPO of Beyond Meat in comparison to Tesla

- Both industries saw the brunt of their growth after the financial crisis—PBMA emerged during the tail end of the crisis, whereas BEVs had already gone to market
- While Beyond and Impossible were generally welcomed by retailers and restaurants alike, BEV start-ups were shunned by the existing dealerships, leading to them vertically integrating the sales process

At the same time, literature and interviews identified several challenges PBMA faced but BEVs did not. This included:

- Visible political opposition, including legal challenges on the naming of PBMA products. On the other hand, BEVs have received billions in government subsidies, tax breaks and other benefit
- Branding ability and network effects. Purchasing a BEV is a very visible statement towards others, whereas one's food choices are less vocal. At the same time, Beyond and Impossible relied on this very strongly for their debuts
- Product positioning. PBMA has been unable to shed its "alternative" moniker, whereas BEVs are already considered to be "the future" by a large part of the customer base
- Cultural and traditional values. While "petrolheads" are a non-marginal group, the cultural importance of ICEs is minor compared to that of meat

5.2 Comparison per Influencing Condition



5.2.1 Knowledge and awareness of technology

Both PBMA and BEVs go back much further than their recent history. For the longest of time, both innovations operated in the margin for specific niche groups. In both cases, it was visionary start-ups that identified the modern opportunity of this technology, rather than incumbents. But where research institutes were the driving forces behind PBMA, it was the existing industry which pioneered much of the technology in BEVs (albeit heavily financed by governments).

Within EVs, Tesla took an unprecedented step to make all their patents open source, which helped the development of the technology for other players. Development in PBMA is less cooperative: many products rely on distinctive features to stand out of the crowded space, for example see Impossible's "Burger that Bleeds!"

Finally, the shift towards new proteins has been more complex than the shift to lithium-ion batteries. It is somewhat reminiscent of the uncertainty between FCEVs and BEVs of the 00's, but unlike that debate, it is easier to pursue both technologies, as network effects through complimentary products (chargers, hydrogen refuelling) are not as strong in PBMA.

5.2.2 Knowledge and awareness of application and market

The breakthrough moment was in both innovations a repositioning of the technology towards a new market. Rather than focus on low-end products for niche markets, they shifted focus to a high-end product for the mainstream market. The total addressable market massively expanded overnight, encouraging investment and development.

5.2.3 Natural, human, and financial resources

While both BEVs and PBMA saw significant government investment in academic research on the development of new technologies, the story is very different for business development in in the two industries. BEVs benefitted from a combination of corporate benefits such as tax credits and loan guarantees, as well as personal benefits for consumers, including non-financial ones such as HOV-lane

access or free parking, and financial benefits such as tax credits, discounts, and rebates. On the other hand, there has been little specific government aid towards the expansion of PBMA innovations, and the little that has come has been very recent (Fortowsky 2020).

When considering private financial resources, BEV is similarly advantaged. While PBMA is one of the largest Climate Tech investment verticals, investments are dwarfed by those in BEVs and mobility (Johnson et al. 2021). One advantage for PBMA so far has been that incumbent food giants have been more interested in acquiring PBMA companies than their automobile industry brethren.

On the topic of human resources, not that much information is available on either case. In both cases, a lack of trained workers exists. The people founding the pioneering companies came from outside the space. These pioneering companies were later the source of many spinoff companies.

5.2.4 Competition

On the point of competition, the experiences of PBMA and BEVs both do and do not significantly differ. BEVs had a much longer period during which pioneer Tesla had little to no serious competition. This was true on different levels: in comparison to the existing niche, the regime, and later entrants.

In comparison to the existing niche, the product performance difference between a Tesla Roadster and a Th!nk or EV1 was like the difference between PBMA 2.0's Beyond Burger, and PBMA 1.0's Tofurkey burger. The intended customers of the emerging products and these customers' reasons for purchasing the products were very different from those in the existing niches.

Simultaneously, the immediate response from incumbent players in the PBMA space has been much more adequate than in the BEV space. The larger players have spent considerable resources buying themselves in or developing their own PBMA, whereas most automobile incumbents continued to downplay BEVs until the very last moment.

Finally, the automobile industry longer development timelines meant that spinoffs from Tesla—or would-be competitors inspired by the Roadster—took much longer to form a competition. The first Lucid Air cars were only delivered in late 2021, despite development starting back in 2013. When comparing this to PBMA, the response from new entrants was much more adequate, and could be split in three categories:

- On one side, a few brand-based start-ups posed a more immediate competition. These relied heavily on minor recipe changes and coproduction, resulting in companies such as Heura Foods launching and producing as early as 2017.
- PBMA start-ups focusing on further evolution of the plant-based space, such as Juicy Marbles' plant-based steaks and Redefine Meat's whole cuts have taken longer to develop but have recently started to sell their products after launching in 2019 and 2018. There are also players such as Plantible, which are looking for the next protein source.
- Impossible and Beyond Meat's success in part also lead to significant development in the broader alternative meat space. Mycotechnology and cultured meat are both still heavily in development but have already raised significant investment. The first products (Nature's Fynd's Fynd Protein-based meats and Eat Just's Cultured Chicken) reached shelves in 2021, with significant growth expected in 2022.

Most of BEV competition exists in the first two of these three perspectives. For EVs, the broadening of the ZEV space would mainly refer to hydrogen. However, hydrogen light vehicle development has stalled, with incumbents selling less than 40.000 cars sold across just two models by 2021. Some

interest remains, mainly in the heavy-duty truck market, with the prime start-up contender being Nikola.

5.2.5 Macro-economic and strategic aspects

While the start-ups that championed both technologies were first developed during the Cleantech era, neither of them truly benefitted from (or was harmed by) the rise and fall in related investment. “Tesla was never backed by Cleantech funds, whether for better or for worse we will never know”, one interviewee noted (Interview 18, corroborated by interview 9). Similarly, while Beyond and Impossible were backed in part by Cleantech investors, there was seemingly enough distance between them and the failed solar and biofuels investments that they felt they were given a chance.

The same could not be said about some of the other competitors in the BEV space. Fisker and Th!nk both folded in part due to the financial crisis, and Lucid first struggled to find initial investors in 2009 and was later forced to seek investment outside the classic US VC industry.

Another difference stems from the strategic importance of car manufacturing. This helped US and China-based BEV start-ups court government backing. No such equivalent exists in the PBMA space.

Finally, both technologies are aligned (by definition) under the pursuit of a net-zero future. In practice however, there is significantly more government stimulation of BEV than PBMA.

5.2.6 Socio-cultural aspects

This is another influencing condition that significantly differs between the two case studies. While automobiles hold significant cultural value, modern BEVs have been successfully positioned to be on equal footing or better than ICEs for most people. Even “car people” like BEVs for their fast acceleration and high top-speed. “Feeling soulless”, is the one criticism people sometimes have of BEVs.

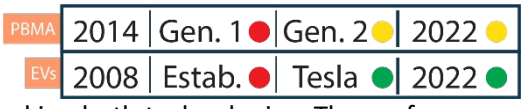
The story of meat is very different. Meat consumption is a status symbol and cultural significant tradition across the world, and PBMA has been unable to challenge this for the most part. Instead, it’s gained some traction as an “now and then option” and eased the transition towards flexitarianism or vegetarianism for those already interested, or less enamoured with meat or specific meat products.

5.2.7 Accidents and Events

For both technologies, the emergence of key visionaries (Martin Eberhard & Elon Musk for Tesla, Ethan Brown & Patrick Brown for Beyond and Impossible) played a major role. Their decision to take on a completely different market than existing players was key to breaking through.

Other accidents and events are mostly technology-specific, with little topical overlap or generalizability.

5.3 Comparison per Building Block



5.3.1 Product Performance and Quality

Product performance was a key building block in unlocking both technologies. The performance difference with previous generations of these technologies is what allowed a reimagining of the market by the visionaries mentioned above.

The start-ups that became market leaders valued product performance over anything, which ended up driving much of their advantage. Simultaneously, existing niche players were unable to attain the same level of performance, and incumbents systematically crippled product performance in fear of cannibalizing their existing markets.

5.3.2 Product price

Both technologies relied on a high-end market entry strategy. This meant higher prices, but considering the higher quality, customers often considered their products a better deal. From here, the companies worked to lower their prices, either by offering differentiated products (Tesla) or by lowering the prices of their flagship products as scale (and competition) increased (Beyond, Impossible). This is where incumbents are regaining some advantage, because of their huge established production capacity makes it easier for them to compete as they commit to the new technologies and product performance differences start to slink (Trainer 2020; Reuters 2021; Doll 2022).

5.3.3 Production system

Both early PBMA and BEV companies are relatively highly vertically integrated. This is in line with Christensen's (2001) views on new technologies: "Vertical integration is an advantage when a company is competing for the business of customers whose needs have not yet been satisfied by the functionality of available products" (Christensen 2001, 108). These companies had to supply much of their core technologies themselves and create their own demand. "It wasn't possible to build a large company that built BEV drivetrains in 2009", one interviewee said of Lucid (Interview 9, corroborated by 19). "That's why they ended up focusing on creating their own car in 2013".

The story for plant-based is similar. While pea protein was available for other uses, if incumbents did not believe in a mainstream market for PBMA, there was no point for Beyond or Impossible to not control the full supply chain.

Despite their own high level of vertical integration, offshoring and specialization within incumbent industries aided these companies in gaining their initial foothold. Off-the shelf parts or ingredients made it easy to experiment and build products, and reduced overhead as the companies were growing. "Originally, Ford made everything themselves. By the time Tesla got started you could just order a windshield, wipers, and rear-view mirror, all from different specialized vendors". One interviewee noted (Interview 6, corroborated by 9). "If they had to make all those kinds of parts from scratch too, it would have been much harder." The same goes for PBMA companies, which could buy most of the non-specific raw resources in bulk rather than having to grow them themselves, letting them focus on specific ingredients such as Impossible's heme (Interview 11).

This control of the supply chain extended to distribution for both companies. Tesla has always controlled its own distribution, breaking from the dealer model that dominated the auto industry. This was less true for the PBMA space, who relied heavily on professional chefs and restaurants to push their product.

More recently, other interviewees (3, 6) pointed to technological innovations such as CAD and 3D-printing as other examples of barrier-lowering developments in the BEV space. SaaS and other technological developments have in general made it easier than ever for small companies to challenge the status quo (Chen and Wu 2013).

As both technologies have become more ubiquitous, production systems have sprung up, with among others next-generation battery and plant-based protein material producers emerging.

5.3.4 Complementary products and services

There is little similarity regarding the development of this building block. As they started producing, BEV manufacturers learned that they weren't just the "extra car", but that people intended to do everything with their BEVs. This started the BEV fast charger industry, which mostly developed in tandem with the BEV industry. Aside from this, BEVs have been mostly standalone products.

On the other hand, PBMA has developed in tandem with several other vegetarian and vegan technologies. Cultured meat and plant-based milks have helped solidify the concepts of vegans, vegetarians, and flexitarians in the zeitgeist. At the same time, few start-ups have dabbled in more than one technology. Investors have been more varied, with two AgriFood VCs mentioning separately that "If you believe in systems change, it only makes sense to back a sector rather than a single company."

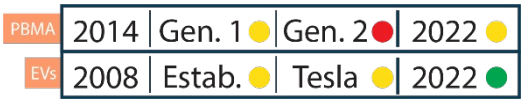
5.3.5 Network formation and coordination

This building block was much more present for PBMA than for BEVs. For the longest time, Tesla was alone in the high-end EVs, bar a lucky partnership in Toyota and a strong symbiotic one in Panasonic.

On the other hand, much of PBMA has been network based. PBMA could draw on existing vegetarian and vegan movement and set the stage for a broader APs innovation system. This meant that later PBMA companies could leverage the GFI and similar organizations, as well as strong university ties based on earlier research projects such as NUTRIPEA and PROFETAS.

5.3.6 Customers

PBMA and BEVs have many similarities when it comes to target customers. Both aimed at higher-end customer segments with high brand-sensitivity, using the premium experience to create a margin that enables the innovation. "It had to be a premium experience", one interviewee (9) said about the Tesla Roadster. "It had to be perfect, or the chance would be ruined." Similarly, Beyond and Impossible's burgers were initially restricted to restaurants. This offered a curated initial experience, to improve reception of the product and build hype.



5.3.7 Innovation-specific institutions

Innovation-specific institutions paint two starkly different pictures. Whereas governments strongly supported BEVs with subsidies, special policies, and grants, PBMA have seen significant resistance, both through legal battles on product naming (initiated by regulators) and because of strict ingredient regulation.

At the same time, both industries struggled with having to enter a market where incumbents strongly benefitted from existing institutions, and successfully managed to establish themselves despite many of these institutional challenges continuing to this day.

5.4 Investor Interest

In both industries, initial investors were atypical, and there was limited interest from incumbent players to support the eventual pioneers. But where Tesla was mainly supported by investors outside Cleantech, it was some of the largest names in the space (Kleiner Perkins, Khosla) that were early supporters of the companies that would pioneer PBMA. These larger VCs did get involved in ZEVs, but bet on other horses, investing in low-end BEV Th!nk and hybrid Fisker (Kleiner Perkins), or pursued

efficiency and biofuels (Khosla). Investor interest in both technologies was spurred by the huge addressable market: transforming the industries would surely reap large rewards.

Both industries suffered limited setbacks from the Cleantech bubble collapsing. Several companies collapsed because of it, and others nearly did as they struggled to raise funds. As the first products went to market, the response was very different. Reactions to Tesla were muted: in part due to the crisis there were few copy-cats or related start-ups, incumbents showed little interest or competition at the high-end, and once public the company sat stably on the stock market for years before serious competition arose. On the other hand, when Beyond Meat and Impossible Foods proved general consumer interest for PBMA, this signalled the start of the AP investment and start-up movement, and when Beyond Meat went public it immediately shot up. The explosion took far longer to arrive, and only occurred in the public markets.

These differences seem largely a result of the natures of the products: it is much simpler to bring a new recipe to market than it is to create a new car company. Investments needed were smaller, allowing for niche firms to flourish. A big question that remains is whether more PBMA companies will go public, and when they do how this will compare to the explosion of 2021 EV SPACs. So far, it can be argued that PBMA, or the larger AP market, still hasn't "crossed the chasm" (Moore, 2014, Interview 19).

5.5 Regime Comparison

5.5.1 Influencing Conditions

Directly comparing the dashboards of both case studies shows both differences and similarities. Regarding influencing conditions, pioneer companies challenged what we knew about the technology, its application, and the market. Especially Knowledge & Awareness of Application and Market and the resulting product repositioning was their key breakthrough of the seven influencing conditions. It was heavily intertwined by expanding Knowledge & Awareness of Technology: there was a lot left to learn about the technologies, but this only became possible after repositioning them. Also in both cases, incumbents had far greater Natural, Financial, and Human Capital at their disposal, although VC backing of PBMA was relatively much better early on than that of BEVs.

Competition is the first influencing condition where the case studies diverge. PBMA's position was much worse than that of Tesla's – it mostly relied on hype and customers being willing to change their diets. They were more expensive, not qualitatively better than the animal-based opposition, and didn't manage to capture their audience to the same degree. And unlike the first generation, second generation PBMA explicitly planned to outgrow the existing vegetarian and vegan market.

When it comes to Macro-Economic & Strategic Aspects as well as Socio-Cultural Aspects, both technologies played into higher level trends. Sustainability was slowly becoming a mainstream topic by the time PBMA 2.0 released, and even though Tesla released their Roadster in the midst of a Financial and Cleantech bust, they were uniquely set up for success as a company. In the words of Peter Thiel: "*Tesla CEO Elon Musk rightly saw a one-time-only opportunity. In January 2010—about a year and a half before Solyndra imploded under the Obama administration and politicized the subsidy question—Tesla secured a $465 million loan from the U.S. Department of Energy. A half-billion-dollar subsidy was unthinkable in the mid-2000s. It's unthinkable today. There was only one moment where that was possible, and Tesla played it perfectly." (Thiel & Masters 2014, p. 167).*

Accidents and Events are hard to categorize here. Successes can be described as visionaries finding their path and the right people at the right time, as well as viral events related to documentaries or accidents affecting incumbents. Negatives include lawsuits and legal challenges.

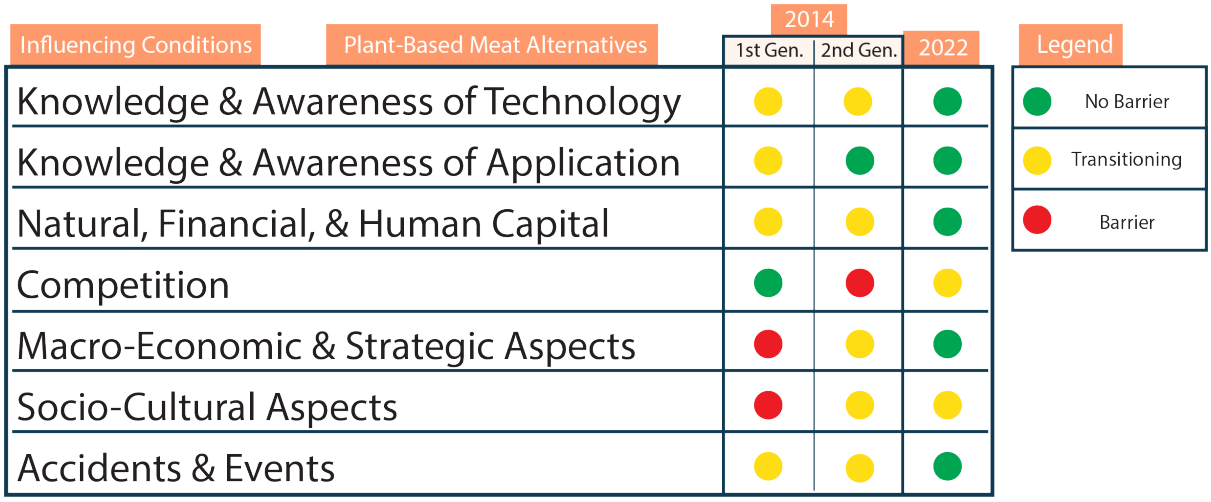


Figure 18: A high-level overview of the development of influencing conditions in the PBMA TIS between 2014 and the present

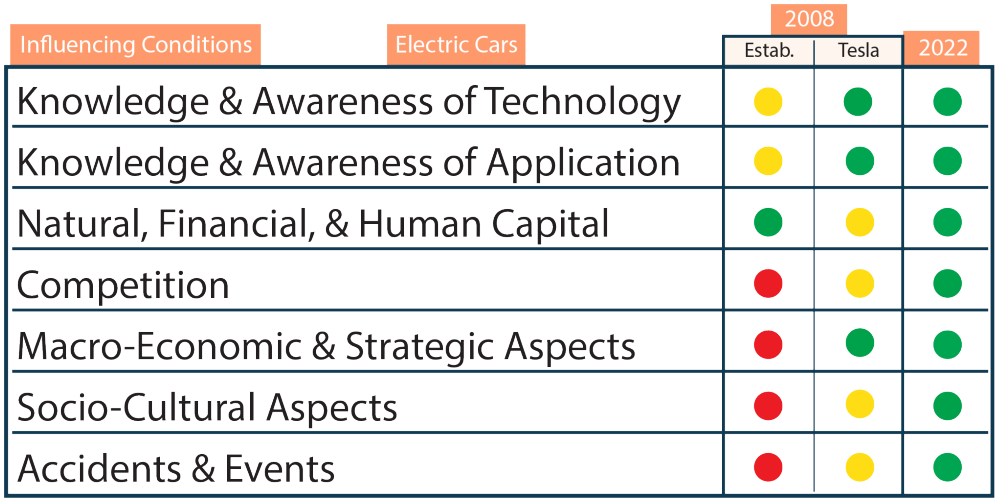


Figure 19: A high-level overview of the development of influencing conditions in the BEV TIS between 2008 and the present

5.5.2 Building Blocks

When it comes to Building Blocks, the breakthrough in both cases was Product Performance & Quality. The resulting was price was higher than existing players in the market, but the market of those that could afford it was enough to sustain investment. Importantly, this meant a higher margin.

In both cases, the Production System was not necessarily a barrier, but pioneer companies approached production very differently than incumbents. They relied on co-producers and manufacturers, availability of half products and off-the shelf components. Meanwhile the incumbents often had plenty of manufacturing capabilities but struggled to realize the processes needed – often due to internal struggles.

A difference emerges regarding Complementary Products. BEVs were shunned by the industry for a long time, forcing Tesla to set up its own chargers and sales points, only really backed by other start-ups and the government. Meanwhile, the food industry didn't necessarily embrace PBMA, but it made a splash in restaurants, and meatpackers were significant early investors. This is also true for Network Formation & Coordination, which was much stronger in PBMA. On the BEV side, it was mainly battery players (Panasonic, A123) that played a coordinating role, whereas the automotive companies largely went their own way outside one-on-one partnerships. In PBMA, the much larger number of

organizations of varying sizes, as well as organization like the GFI and theme investors helped create networks.

In both cases, Customers were much more interested in the pioneer companies' products than incumbents. Improved quality, marketing, and mission all played a role.

Finally, Innovation-Specific Institutions were much more in favour of BEVs than of PBMA. PBMA largely faced legal challenges and little support; BEVs collected billions in subsidies and benefited from other perks such as free charging, HOV- and bus lane access, and public support. At the same time, in both cases, these institutions were relatively consistent, unlike renewable energies, which suffered a lot from inconsistent or unpredictable regulation.

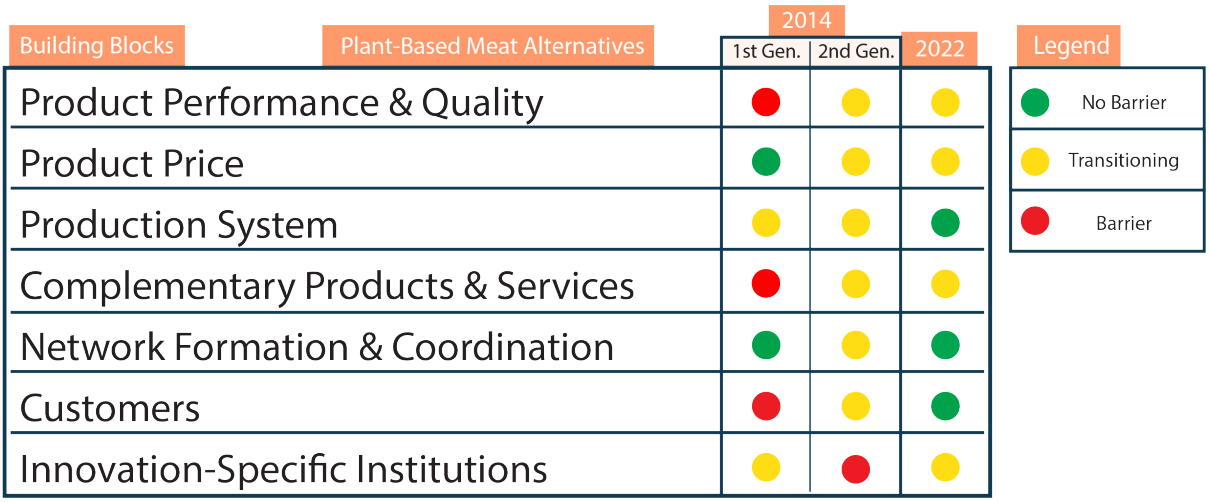


Figure 20: A high-level overview of the development of building blocks in the PBMA TIS between 2014 and the present

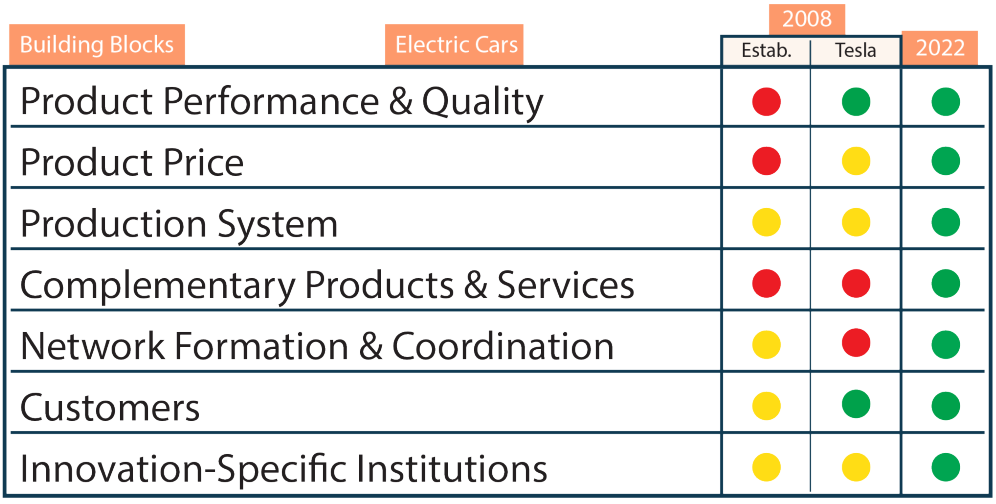


Figure 21: A high-level overview of the development of building blocks in the BEV TIS between 2008 and the present

5.5.3 Regime Level Conclusions

In both case studies, the emergent actors came out into a transitioning innovation system. With the benefit of hindsight, few influencing conditions or building blocks could be considered barriers, and the few that were, were surmountable. Notably, all barriers remaining when the first products were released relate to the ecosystem, not to the companies themselves. This relates to Complementary Products & Services and Network Formation & Coordination for EVs, and Competition

and Innovation-Specific Institutions for PBMA. These challenges could largely be overcome through the network and capital provided by investors, non-traditional strategies, and a bit of luck.

For Tesla, this meant building chargers themselves, sharing the cost with the locations they were building, an online ordering flow in a time that dealers still reigned supreme, and finding partnerships where they could, such as the Fremont NUMMI deal with Toyota falling into their lap and convincing the battery industry to support them (Tarpenning 2021, Interview 18).

For the PBMA companies, it was hostile Innovation-Specific Institutions and Competition. The long road to GRAS-certification and its EU-equivalent that could have killed Impossible and Beyond was held at bay with large amounts of venture money. Similarly, a restaurant-first marketing strategy made it hard for retailers and meatpackers to keep these products out of customers' mind.

PBMA has since developed faster than EVs, but also hit its limits faster, as certain barriers such as socio-cultural factors are hard to truly overcome this quickly. Similarly, the product seems more room for improvement left, as showed by the hundreds of start-ups still emerging.

6 Answers to the Research Questions

This research set out to answer the following question: *How have developments in the surrounding innovation system affected the interest of investors in specific climate technology innovations?*

To do so, a number of sub-questions was asked and answered. In answer to sub question 1, "*How should the innovation system be broken down to best assess changing investor interest?"*, the TIS framework was chosen at the end of Chapter 2 based on existing literature in regarding innovation sciences, the broadness of the studied sustainable innovations, and their international nature.

This was an expansion of the framework's intended use-case: it had previously only been used to understand and inform government policy (Ortt & Kamp 2022). This expansion is not perfect: while the framework was very useful to capture how certain companies reimagined an innovation, and what that meant for the technology's positioning, the framework does not translate 1:1 to the factors that play a role in the investment process, and from the framework's perspective, new technologies often took steps back regarding certain influencing conditions or building blocks, even if these were improvements from an investor's perspective. Chapter 3 expanded on how this was realized in the research and case studies.

Chapter 4 then answered the second sub question: *How have the innovation systems encompassing battery electric cars and plant-based meat alternatives developed over the past 20 years?* It did this through narratives exploring the history of these technologies in recent years, mostly looking at the rise of pioneer companies like Tesla, Impossible Foods, and Beyond Meat.

The final two research questions were answered together in the analysis parts of Chapter 4 and the entirety of Chapter 5. For reference, these research questions were:

3. *What developments have proven key to increasing innovation and investment in electric cars and plant-based meat alternatives?*
4. *What are the challenges faced by sustainable deep tech innovators attempting to commercialise their technology?*

Regarding question 3, changes in these innovation systems were mainly characterized by a reimagination of markets by visionaries: rather than supplying to low-end and low-margin niche markets, breakthrough companies focused on high margin sections of the mainstream market, competing directly with incumbents. Key developments enabling this reimagination included a focus

on B2C products, extensive offshoring within incumbent industries, and then-recent developments in ingredients or components. They were further aided by incumbents' hesitance regarding creative destruction, the overall push towards sustainability by governments and consumers.

Finally, to answer question 4, these challenges revolved around repositioning their technology to fit the expectations of the VC in their gatekeeper role. This meant breaking from the existing niche markets to a larger ocean competing directly with the unsustainable regime and raising product quality and price (leading to a higher margin) as compared to the established niche. Finally, socio-cultural aspects were and still strongly influence the transition. Many technologies that need to transition are heavily embedded in modern culture.

Returning to the main research question, showing the potential to challenge the regime outside a protective niche seems to have been the key driver for investor interest. Once the technology has been proven to be possible and superior, the question focuses on scaling to efficiency. To repeat Arrow (1995) as mentioned in Ch 1.4: "venture capital has done much more, I think, to improve efficiency than anything". This is a game they know through and through.

7 Discussion

7.1 Considerations: VCs, Start-ups, & High-End Niche Strategies

This research explored the development of the TIS surrounding BEVs and PBMA. To limit the scope of the research, a narrow scope was used; the research focused on success stories of the recent past, selected on specific criteria. It needs to be acknowledged that this research observing a VC-backed high-end product to be the breakthrough technology is a direct result of the research and case study design: the case studies were retroactively selected *because* they featured successful VC backing, to study the events leading up to these investments and their subsequent impacts on the industry.

VC investment generally seeks high margins and "10x" products, naturally predisposing them to invest in high-end niche strategies. This in turn leads to many start-ups pursuing (or trying to pursue) high-end niche strategies in order to suit their investors demands, even where other approaches might be more effective. As the start-up depends on VC backing, it has to follow the playbook and whims of a possibly misinformed investor or die; incumbents are not bound by the same rules. They can pursue multiple strategies, benefit from existing supply chains, and internal synergies. This might lead them to other niche strategies, such as hybridization—a niche strategy which led the automotive industry do develop the Prius, and still actively follows to this day. When this same strategy was attempted by the VC-backed start-up Fisker, it failed miserably, unable to overcome the competitions unsurmountable advantage.

There are numerous sustainable innovations where VC failed: the Cleantech bust and in particular the thin-cell photovoltaics industry was an expensive way to prove this. China's mass production of crystalline silicon photovoltaics trampled the US's start-ups as subsidies dried up. As such, the contributions of this research should be sought in the breakdown of these TISes, and generalizability should be kept to start-ups operating in TISes similar to those studied here.

7.2 Relevance

7.2.1 Managerial Contributions

Building from the previous chapter, the conclusions of this research are that rather than incremental technological innovation, it can be key to re-examine the business model and especially target audience of sustainable technologies. While it is undeniable that protective niches are indispensable for discovery and development of new technologies, the case studies have shown that

breaking from the niche into the mainstream with a premium product, when the opportunity presents itself and funding to do so is available, can be extremely beneficial for an emerging technology.

As the report has shown, this can be a way to subsidize further development of the technology, drive interest, and bring the wheel of innovation in motion. Considerations here include the customers (consumers), competition (can you break into the market?) product quality (what are its unique advantages?), and product price (margin!).

Key is for the product to become inspiring and aspirational: Initial production capacity does not need to be high, and the product does not need to be affordable. “Back then we had a little Th!nk driving around. It was almost a golf cart; you kind of felt sad for the person inside. […] Tesla, they made a club out of it. Driving a Tesla was an extension of your ego.” (Interview 9)

7.2.2 Societal Contributions

The research has attempted to create a first link between innovation system science and venture capital. It posits that if VCs are active gatekeepers, they could play many of the same roles that governments traditionally play in creating and nurturing niches.

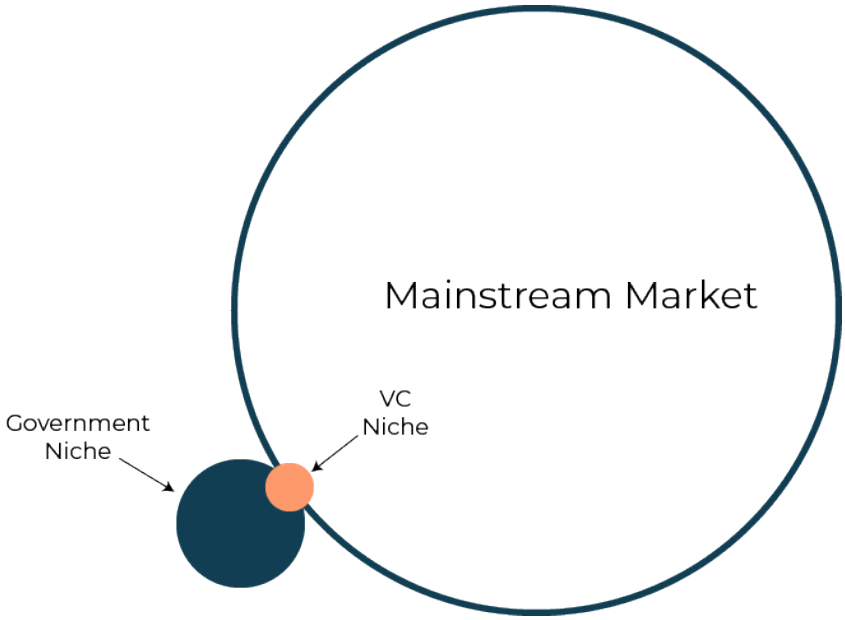


Figure 22: A schematic example of VC’s “steering” a niche

However, their position as a private party allows them to “pick winners” where a government would normally not, enabling them to reap rewards, creating a strong incentive to succeed. Figure 6 above attempts to schematically show this, where the VC-enabled niche expands from the government nurtured niche towards the mainstream market.

While this is not a new notion, previous work has generally shown this to be true through quantitative econometric analysis rather than qualitative analysis of the innovation system (Murray 2021; Brander et al. 2015). Governments have responded by setting up their own VC funds, to provide bridging financing to start-ups and recoup some of their costs, but private VCs remain the best route to commercialization (Murray 2021; Luukkonen et al. 2013; Hargadon and Kenney 2012).

7.2.3 Academic Contributions

Generalizability

Overlap in the forces driving both case studies suggest that some results are generalizable. Specifically, products that can potentially be marketed to consumers and are currently active in protective niches could benefit from similar strategies. Examples that seem to have done so successfully include plant-based milks (Oatly) and the greater organic food movement (Whole Foods). Outside sustainable innovations, it could also be compared to the evolution of sportswear to leisurewear, or the evolution of consumer espresso coffee machines.

Perspective

the research adds to the TIS-framework. It does this primarily by exploring its use when analysing a different perspective, namely that of the investor. Some parts were found to be closely linked to traditional investor priorities (market & customers, product quality, and competition), whereas other factors seemed unimportant when considering investor interest. A key drawback to the usage of the framework in this way (that could also affect its normal usage) is the lack of explicit distinction between influencing conditions or building blocks that can be directly affected by the chosen perspective, and those that cannot.

Methods

Second to the new perspective, this research has refined individual tools within the framework, such as breaking out the repositioned technology from the extant niche in the dashboard to help visualize a sequence of niche strategies.

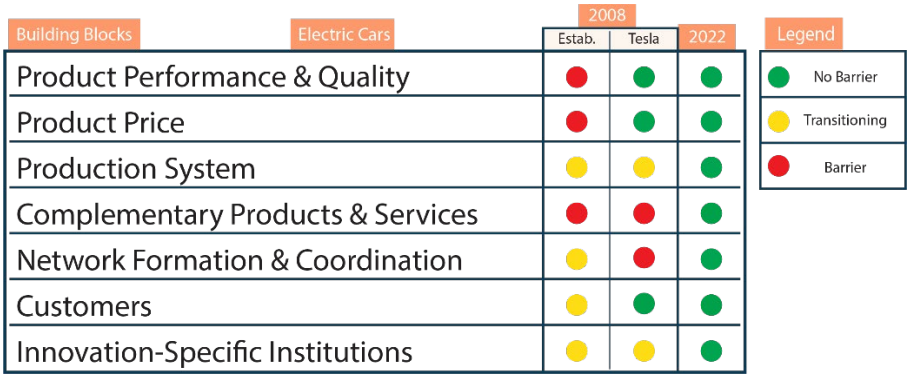


Figure 23: Example of the TIS dashboard timeline. For context, see Figure 9.

Finally, there was also the idea to represent key events in a graphic timeline to communicate the development of the TIS more clearly, and split facts from analysis.

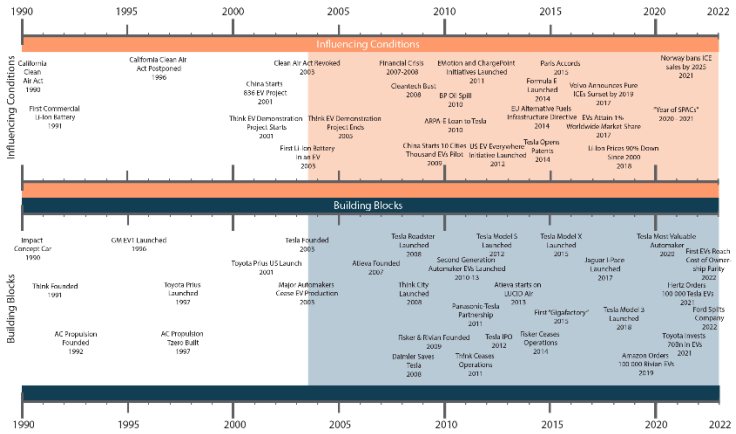


Figure 24: Example of the TIS event timeline. For a full-size picture see Appendix II-B.

7.3 Limitations

7.3.1 Limitations in Case Selection

The cases were selected on several criteria. First and foremost were their status as recently commercialized climate-related technologies. From the technologies fitting this description, electric cars and plant-based meats were chosen because they were very heterogenic: BEVs are a very capital-intensive product with a global supply chain, which results in a one-time purchase by a given customer. On the other hand, PBMA is a much simpler product that can be coproduced or even made by hand and relies on repeated purchasing of the product. Despite these selection criteria, they still overlap on other aspects. Both cases leaned on technologies that had been available for decades, pioneering companies were consumer-facing, and both technologies are what would be considered hardware, whereas a large amount of (Climate Tech) VC investment goes towards software.

Both studied topics are still highly in flux. While it seems as though the inflection point for BEV companies has been reached, it is less certain for PBMA, and a lot can still change that would make the results of this research invalid.

7.3.2 Data Limitations

Part of the proposed research approach included a quantitative time-series analysis of VC investments in the case study areas. As this dataset is proprietary and not freely available, the researcher attempted to obtain the data from a third party. Several data providers were approached with requests for academic access, but all requests were ultimately rebuffed. This limited the scope of the research to be purely qualitative. No high-level assessment of the studied sectors could be performed, leaving this to future research.

7.3.3 Interview limitations

The interviews were highly opportunistic. While a significant amount of effort was spent approaching a highly diverse and complete interviewee pool, positive responses were rare, especially among those that had a longer history with the studied topics.

In the case study on PBMA, many interviewees were only involved after 2015, inspired by the events studied in this research.

For the case study on EVs, the interviewee pool was very diverse, but the sample size was extremely small (4). Two additional mobility VC investors were interviewed to expand the sample size, but this was of limited value.

On top of limitations with regards to the sample size, the quality of interviews also varied. Interviewees were generally highly exclusive people with busy schedules, so interview length varied from just 20 minutes to 90 minutes, with shorter interviews often remaining more surface level and the questions in these interviews being more closed off.

Finally, the highly specialized and sometimes well-known nature of the interviewees means that the exact contents of interviews cannot be included as a record for further research, as it would be impossible to anonymize these records.

7.4 Future Research

This research was highly exploratory. Further research can take several different trajectories to uncover the drivers of sustainable transitions. This can be roughly divided into two distinct themes: further development of our understanding of (sustainable) transition pathways, relying on the TIS and intercomparison of different perspectives on one side, and further exploration of the role of Venture Capital and other gatekeepers within the (sustainable) innovation system on the other side.

7.4.1 Developing Understanding of Transition Paths

One of the additions this research made to the TIS was the idea of different perspectives on a shared innovation system. This opens the door to understanding transition dynamics on a much more granular level: analysing the perspectives players pursuing different transition strategies can help understand how the state of various influencing conditions and building blocks could be considered barriers to some niche strategies but not to others, and vice versa. This research has explored the triumph of high-end niche strategies over low-end and hybridization strategies pursued by extant niche players and incumbents. Fault lines to split perspectives on include the initially targeted customer base (consumers versus businesses), the experiences of large businesses markets versus start-ups both trying to enter the same market, competing standards or technologies, and even business models. Some of this already exists, for example when different National Systems of Innovation are compared for the same technology sectors. This could even be done for the technologies studied in this research, contrasting it to the Chinese perspective.

7.4.2 The Role of Venture Capital and other Gatekeepers in Innovation

A major focus of this reason has been to explicitly explore the role of VC investment from an innovation studies point of view. It has found that VC required rather specific innovations, and for the TIS to progress to a somewhat specific stage before they were willing to commit to these technologies. Beard et al. (2012) has argued that the role of VC is to be the gatekeeper of innovation. This perspective changes the Valley of Death from a “bug” into a feature: it is a natural result of the transition from unfocused stimulation by government that should not “pick winners” (Strategic Niche Management) to a focused one when VCs or other private parties back and support certain technologies. It could be exceptionally interesting and useful to explore the different ways that winners are picked by various actors, the dynamics that play a role in this, and how these dynamics differ between different actors.

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Appendix I: Interviews

Appendix I-A: Interview Overview

Table 3: Overview of Interview Subjects

#	Interviewee Description	Interview Date	Locale
1	Founder of Plant-Based Protein Start-up	19-11-2021	US
2	Food Journalist	06-11-2021	US
3	Micro mobility Investors	07-12-2021	Netherlands
4	Impact Investment Advisor	08-12-2021	Netherlands
5	Founder Cultured Meat Start-up	15-12-2021	Netherlands
6	Early Employee E-Mobility Start-Up	15-12-2021	Europe
7	AgriFood VC Investor #1	17-12-2021	Netherlands
8	Impact VC Investor	20-12-2021	Netherlands
9	Ex-EV Company Board Member	23-12-2021	US
10	EV Company Investor	06-01-2022	US
11	Alternative Proteins Advisor	11-01-2022	US
12	Plant-Based Angel Investor	13-01-2022	Netherlands
13	Food Corporate VC Investor	14-01-2022	Netherlands
14	AgriFood VC Investor #2	14-01-2022	US
15	Consumer Foods Strategist	18-01-2022	Netherlands
16	New Foods Lobbyist	20-01-2022	Netherlands
17	AgriFood VC investor #3	20-01-2022 & 26-01-2022	US
18	Ex-EV Company Executive	08-03-2022	US
19	Scale-Up Consultant	16-03-2022	US

Interviewee descriptions are intentionally kept vague to preserve interviewee anonymity.

Appendix I-B: Request for Participation

Interviewees were generally approached over LinkedIn with a brief message similar to the one below, which could have been sent to, for example, Elon Musk, the current CEO of Tesla. Elon Musk was **not** approached or interviewed for this research.

Dear Mr. Musk,

I'm a Master's Student at the Universities of Delft and Leiden in the Netherlands doing research on the innovation system surrounding EVs, with a specific focus on the role of Venture Capital. I've spoken to a number of investors and board members of other EV companies, and everything always leads back to Tesla paving the way.

I was wondering whether I could interview you for 30 to 60 minutes about the role VC played in Tesla's early development, your experiences raising this before the ARPA-E loan came through, and how you think the landscape has developed since. I've attached a one-pager with more information on the research.

Kind regards,

Edward van der Hout

The aforementioned one-pager can be found on the next page.

Striking Gold in the Valley of Death

Exploring the key drivers to unlocking financing to scale up sustainable innovations

Introduction

In order to decarbonize the whole economy, many different technologies have to be brought to market. A widely observed challenge here is the Valley of Death.[*] This study seeks to understand to what extent the valley of death exists for decarbonization technologies, and specific innovations have overcome it. In order to do so, two case studies have been selected which have seen a dramatic increase in VC funding over the past 15 years, projecting them from the niche into the mainstream. This project hopes to learn what contributed this development, and to what extent these factors can be generalized.

Research Questions

How have developments in the innovation system affected the prevalence of the valley of death for different climate technology innovations?

1. How have the innovation systems encompassing electric vehicles and plant-based proteins developed over the past 20 years?

2. How has prevalence of the valley of death phenomenon changed with regards to electric vehicles and alternative proteins start-ups over the past 20 years?

Interviews

The research aims to interview several investors and other participants in the sustainable innovation space. The aim of these interviews is to reconstruct a timeline of major developments regarding investment in these sectors. When interviewing investors, I'd like to discuss:

- Their views on the "Valley of Death" for decarbonization technologies
- Financing of start-ups in the electric vehicle and plant-based protein spaces
- How the factors above have developed in the past 20 years

Goal

The project aims to explore the drivers behind the development of the funding landscape in the electric vehicle and plant-based protein spaces. These are thought to be useful to help develop other sustainable sectors. Furthermore, the research will contribute to our broader understanding of innovation barriers. This could be of great value to both innovators and investors to help them focus their efforts.

Who is doing this?

The research is performed by Edward van der Hout, a student of the Industrial Ecology Joint Master's Programme of the TU Delft and Leiden University. This project is executed in cooperation with Carbon Equity, a start-up focused on making sustainable investments in private markets more accessible. Results will be published academically, as well as in the form of a white paper by Carbon Equity.

Privacy

Several measures will be taken to ensure confidentiality. Recordings will be destroyed after transcription. Furthermore, participants will not be named, unless they explicitly indicate otherwise. As is common in academic publications, there would be references to ex. a 'Netherlands-based Venture Capital Investor'.

[*] The Valley of Death has several definitions. This study focuses on the problem faced by companies in the scale-up phase: they have a working product but capital providers available to them deem the risk too high/the payoff too low to provide them with the capital they need to commercialize their product.

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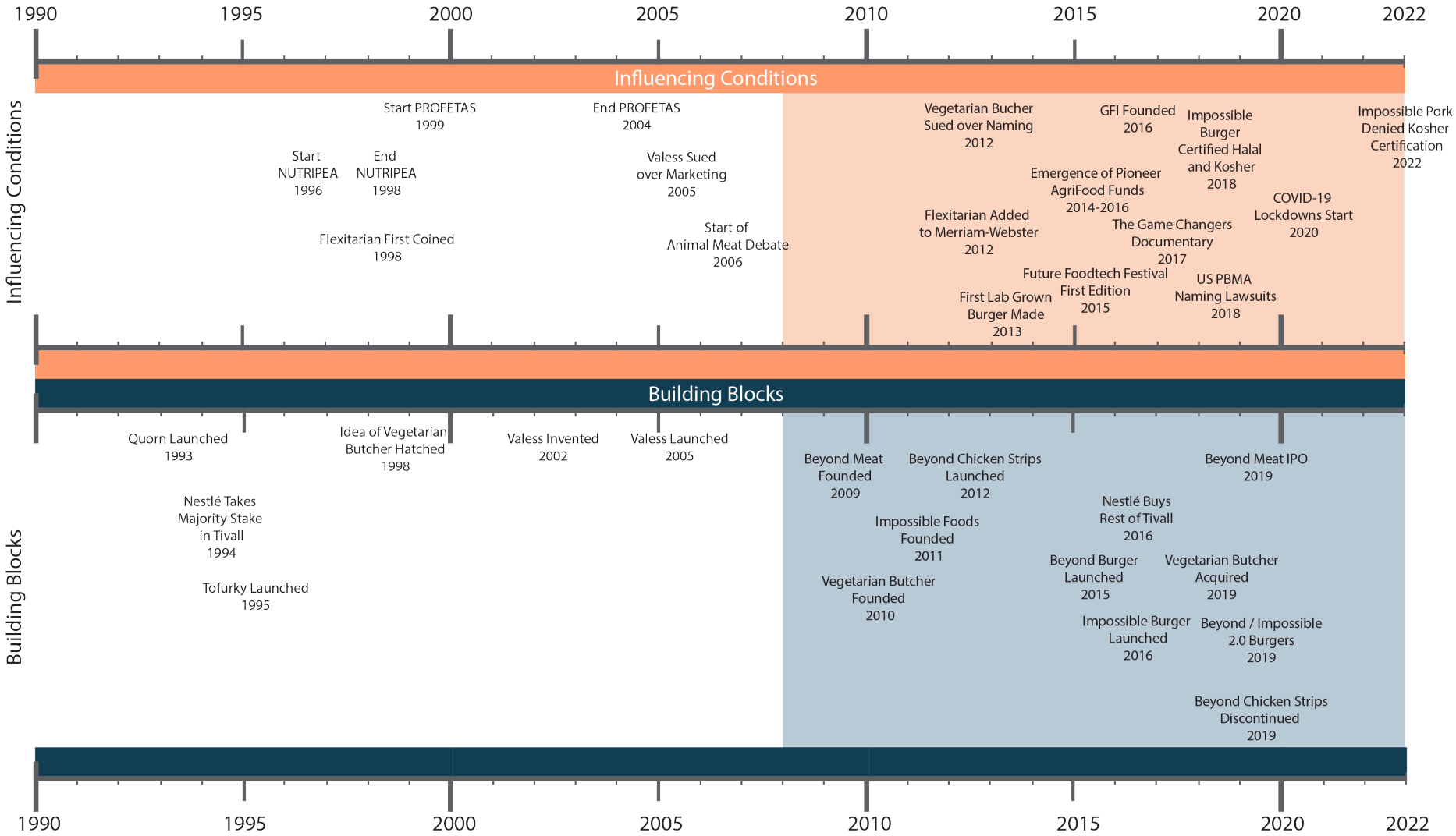
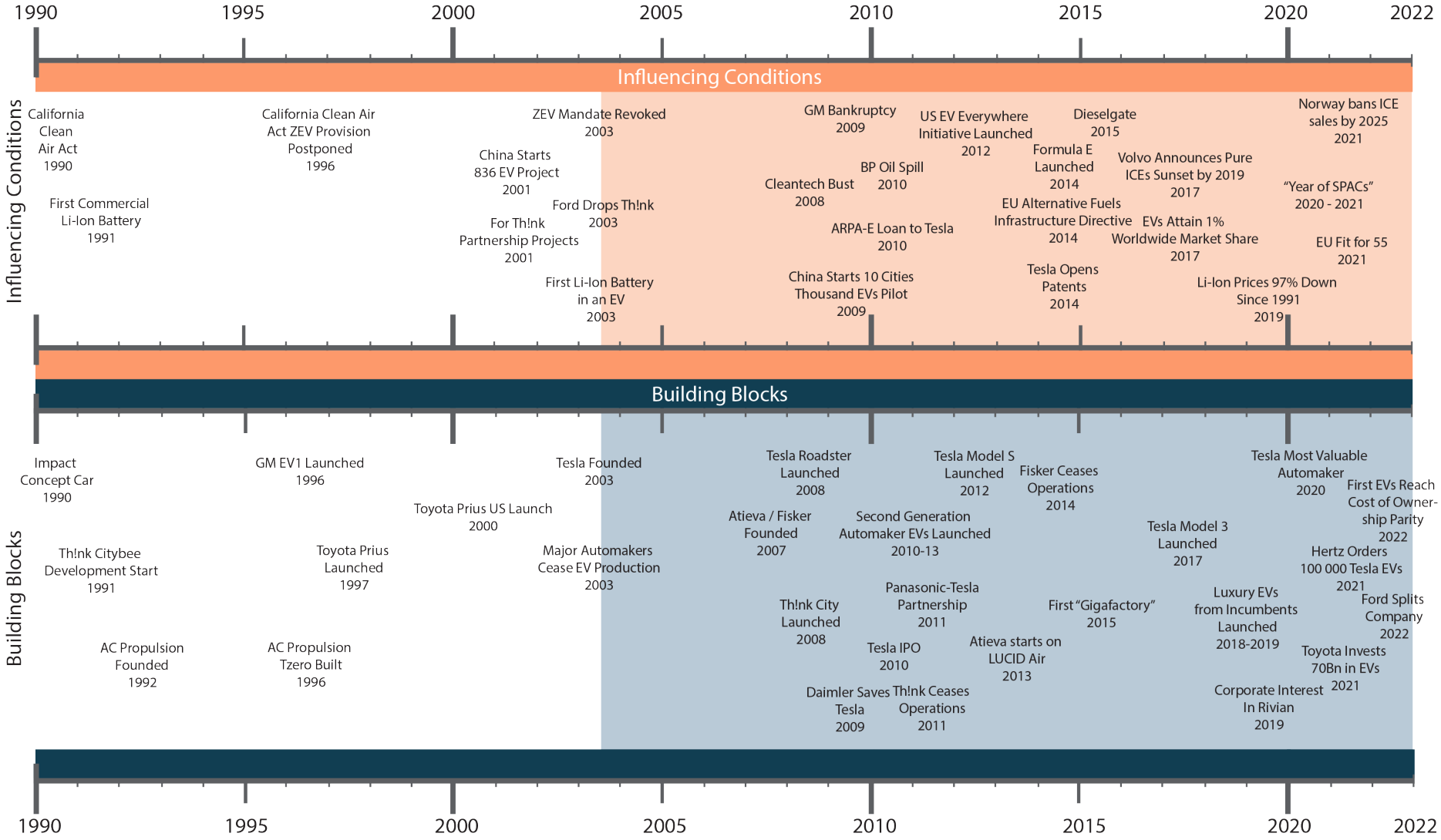
Master Industrial Ecology | TU Delft & Leiden University | October 20th, 2021

Appendix II: Full Page Images of Timelines

Appendix II-A: Timeline of the Plant-Based Meat Alternatives Technological Innovation System



Appendix II-B: Timeline of the Electric Cars Technological Innovation System



Appendix III: Case Data Repository

Appendix III-A: Plant-Based Meat Alternatives

Table 4: Influencing Conditions of the PBMA TIS

Event	Year	Quote	Source
NUTRIPEA Programme	1996-1998	*"The main objectives of the project are: - to use new technologies to develop improved pea protein products which are devoid of antiphysiological[sic] and antinutritional factors; - to design and develop a technical process to prepare improved pea protein products under pilot plant and factory conditions; - to evaluate the functional and sensory properties of improved pea protein products added to a variety of foods for human consumption; - to screen in vitro and in animal models the nutritional properties and antigenicity of the protein products; - to develop an infant formula based on the improved pea protein products and to evaluate the formula for antigenicity and protein quality in animals and iron absorption in infants."*	(European Commission 1996)
Flexitarian Coined	1998*	*"Flexitarian (from 1998, referring to a person who keeps a primarily but not strictly vegetarian diet) and pescatarian (from 1991, referring to a person who keeps a diet that includes fish but not meat), are the latest in an eclectic line of -arian diet words to enter the OED."*	(Martin 2014)
PROFETAS Programme	1999-2005	*"The most notable consequence of the NPF program was the establishment of the subsequent research program Profetas (Protein Foods, Environment, Technology and Society) (Aiking et al., 2006). In 1999, various ministries and academic bodies funded Profetas with 3 million Dutch Guilders (around €1.4 million} [F6] (Aiking et al., 2006). The program delivered knowledge on technological feasibility, sustainability, consumption opportunities and barriers regarding meat substitutes based on a single crop,*	(Dagevos et al. 2018, 188)

* Arguably the year it was added to the OED (2014) is more relevant. Either way the term has been a major indicator of a changing innovation system.

		pea [F2] (Aiking et al., 2006). In terms of technological feasibility, the results were equivocal. They illustrated that research in texturization processes was needed and it could not yet be assessed whether new products would better satisfy consumer preferences."	
Valess Sued for Meat Comparison	2005	*"The introduction of Valess and rising popularity of meat substitutes also triggered, for the first time, dissent. A dispute started between Friesland Campina and the animal welfare NGO Wakker Dier over the origin of the eggs used (De Volkskrant, 2005b). Additionally, the Dutch meat information office filed a complain against Valess because the promotional campaign directly compared the meat substitute with meat (ANP, 2005). The Dutch Nutrition Center issued a statement which clarified that dairy based[sic] substitutes do not have the same nutritional value as meat. The court ruled against Valess, which had to modify information on their website. This shows that the dominant cognitive institutions were well aligned with meat consumption and not shifting towards plant-based substitutes."*	(Tziva et al. 2020, 222)
Start of the Animal Meat Debate	2006	*"From 2006 onwards, the adverse impact of livestock production on sustainability and animal welfare became an important issue in public discourse for the first time. The publication of "Livestock's Long Shadow" (Steinfeld et al., 2006) from the FAO was a turning point regarding wider awareness of the link between livestock, climate change and environmental degradation. In the Netherlands, the publication was used as a reference from political parties and societal organizations in emerging discourses regarding the sustainability of meat production."*	(Tziva et al. 2020, 223)
Vegetarian Butcher Naming Dispute	2012	*"Gehakt wordt Gehackt! De pluimveesector is het er niet mee eens dat De Vegetarische Slager "meelift op de goede naam van kip" en dient bij de Nederlandse Voedsel- en Warenautoriteit een klacht in over onze productnamen. Er worden zelfs Kamervragen gesteld over de kwestie, die gekscherend #schnitzelgate wordt genoemd. Onze productnamen worden aangescherpt waarmee we duidelijk maken dat we de smaack en structuur van dierlijk vlees 'gehackt' hebben. Het nostalgische taalgebruik met 'ck' wordt nieuw leven ingeblazen, zoals wij ook het slagersambacht nieuw leven inblazen."*	(de Vegetarische Slager 2020)

First Lab Grown Burger	2013	*The ability to successfully culture meat has been demonstrated on several occasions – first as part of an art project by Oron Catts and Ionat Zurr in 2003 that used frog cells, then again in 2013 when Dutch Professor Mark Post cooked and taste-tested a cell-based hamburger live on British television (at a cost of some $50,000) (Stephens & Ruivenkamp, 2016). Since that time, several new companies have created proof of concept demonstrations for a variety of cell-based meat and seafood products, while a growing list of start-ups – mostly headquartered in Silicon Valley, but also in Israel, Japan, Singapore, and elsewhere – have been formed (Cameron & O'Neill, 2019a).*	(Broad 2020, 925)
Launch of Future Food-Tech	2015	*"It was 2016 and it was the very first installment of Future Food Tech. By 2019 the event welcomed thousands of attendees, but in 2016 it had yet to become the staple it is today in promoting the plant-and cell-based industry of future foods; there were just two hundred of us."*	(Zimberoff 2021, 67)
Emergence of Early Accelerators and Investors	2014-2016[3]	*"Well, when I started (2014), I was one of the few in the world. Uh, people didn't even really know what vegetarian was, let alone vegan plant based."*	Interview (12)
Emergence of Early Accelerators and Investors	2014-2016[*]	*"Two years prior, in 2014, and with only the barest of ideas—to make milk proteins using microbial fermentation—Pandya and Gandhi applied to a synthetic biology accelerator in Cork, Ireland. […] Eventually, that accelerator—since named IndieBio—has become the preeminent SF Bay Area network for fostering advances in synthetic biology."*	(Zimberoff 2021, 69)
Good Food Institute Founded	2016	*"GFI was founded in 2016 by Executive Director Bruce Friedrich. GFI has since grown to include more than 100 team members in six regions: the United States, Europe, Brazil, Asia-Pacific, India, and Israel. GFI attracted more than 500 alternative protein industry stakeholders to its inaugural Good Food Conference in 2018 and hosted more than 900 attendees at our second conference in 2019."*	(Cereals and Grains Association 2020)
Impossible Burger Certified Halal	2018	*"Securing halal certification is a significant milestone for us. Our goal is to make delicious, plant-based meat available to everyone around the world -- regardless of religion or culture heritage. Earlier this year, we received our*	(Impossible Foods 2018)

[*] See also: (Johnson et al. 2021)

		kosher certification(opens in a new tab) from the Union of Orthodox Jewish Congregations of America, and last month, we received the highly regarded Safe Quality Food (SQF) certification as administered by the Safe Quality Food Institute (SQFI). Now, the Impossible Burger can be served in halal establishments and enjoyed by those who adhere to a halal diet. To say we're thrilled is an understatement."	
The Game Changers Documentary	2017	*"Coupled with the introduction of the political party "Party for the Animals" and the release of the documentary, Meat the Truth in 2007 narrated by the leader of the party (NGPF, 2019)., meat production and consumption became an increasingly contentious issue."*[*]	(Interviewees (7, 12, 14, 17), Tziva et al., 2020, p. 223)
US Lawsuits on PBMA Naming	2018	*"Call that veggie burger what you like, but if you're in Missouri, don't call it meat. A bill that was passed in May and went into effect on Tuesday prohibits companies from "misrepresenting a product as meat that is not derived from harvested production livestock or poultry." But proponents of plant-based products aren't letting this go without a fight. Four organizations sued the state of Missouri on Monday, seeking an injunction preventing the law from being enforced. That set off a legal battle in which both sides say they are looking out for baffled consumers who want to know what exactly has gone into their burger, hot dog or chicken."*	(Tsang 2018)
COVID-19 Start	2020	*"The scanner data we use cover the period of the Coronavirus Disease 2019 (COVID-19) pandemic, when the PBMA market expanded dramatically. A summarized observation from Information Resources, Inc. (IRI2020) retail data shows PBMA sales accelerated more than 200% during the pandemic compared with the same period in 2019 (Gaan, 2020). With a much more automated production system, PBMA fulfills[sic] consumer needs in meat-like protein with less susceptibility to labor fluctuations while providing safer work conditions for manufacturing employees in times of the pandemic (Sha & Xiong, 2020)."*	(Zhao et al. 2022)

[*] This quote form Tziva et al. is about a Dutch documentary. Much of the sentiment was repeated by interviewees regarding *The Game Changers* and other documentaries, but on a global scale.

Impossible Pork Not Deemed Kosher	2022	*‘"We didn't give an 'OU' to it, not because it wasn't kosher per se," Rabbi Menachem Genack, CEO of the OU's kosher division, told the JTA. "It may indeed be completely in terms of its ingredients. If it's completely plant-derived, it's kosher. Just in terms of sensitivities to the consumer...it didn't get it."* *Genack recalled when the OU had chosen to certify imitation "bacon." Consumers were so unhappy with the idea of consuming "bacon" that tons of disgruntled kosher-observant folks called in to the OU to complain. "We still get deluged with calls from consumers who either don't get it, or they're uncomfortable with it," Genack told JTA.’*	(Rothman 2022)

Table 5: Building Blocks of the PBMA TIS

Event	Year	Quote	Source
Quorn Launch	1993	*“In the 1990s, Marlow Foods, located in Marlow, England, was created as a joint venture by ICI and RHM to commercially develop the new food. […] Before 1993, sales were less than $3 million per year. After extensive television advertising of the national launch in the UK, awareness of the brand rocketed to 80% of all households. Sales climbed rapidly, and between 1994 and 2000, the company’s compound annual growth rate was 37%.”*	(Wilson 2001)
Nestle Invests in Tivall	1994[*]	*“Osem already holds 51% of Tivall, after paying US$9m in 1994 for 50% and an additional US$1.5m for another 1%, as well as investing US$4m in the operation of the plant.”*	(“Nestlé’s Osem” 2004)
Quorn / Tivall relevance	1994	*“During the early 1990’s, the meat substitutes industry was already comprised of users, a few firms and commercial but low-performing products. European vegetarians and vegans, driven by ethical, cultural or religious factors already consumed early meat substitutes. In the Netherlands, two international firms Quorn and Tivall dominated the market. A few Dutch firms, including Schouten Europe and Vivera, were established.”*	(Tziva et al. 2020, 221)

[*] Exact moment unclear. Other sources report first investment as a late as 1998. No corporate disclosures could be found, so the earliest source was considered leading.

Tofurky Launched	1995	*"He expands operations to a vacant elementary school in 1983 -- and decades ahead of the tiny house trend, he builds a 300-square-foot treehouse to call home. Fast forward to 1995, Tofurky debuts the very first Holiday Roast. It strikes a cultural chord with a nation hungry for a tastier meat-free Thanksgiving."*	(Tofurky)
Vegetarian Butcher Pitched	1998	*"Hij legt contact met producenten van plantaardige eiwitten en wetenschappers om vegetarisch vleesch te ontwikkelen dat niet van dierlijk vlees te onderscheiden is. Geen vleesvervangers als tofu of bietenburgers zoals we die al kennen, maar 'vleesopvolgers'. Samen met innovatieve chef-koks wordt er gewerkt aan processen om de smaack van rund, varken en kip te vangen in vegetarische producten, die minstens dezelfde kwaliteit hebben als de dierlijke variant. Met succes!"*	(de Vegetarische Slager 2020)
Valess Invented & Launched	2002 / 2005	*"Valess was established by the Dutch incumbent dairy cooperative Friesland Campina. Friesland Campina acquired a process for the texturization of dairy protein that had been developed by an individual a few years earlier. In 2005, the brand Valess was introduced to the Dutch market. Friesland"*	(Tziva et al. 2020)
Beyond Meat Founded	2009	*"In 2009, we opened our first operation in a small commercial kitchen in Maryland and we began selling an early plant-based product to Whole Foods Markets Prepared Foods in the Mid-Atlantic region. […] During this period, Ethan began working extensively with two researchers at the University of Missouri's Bioengineering and Food Science Department at the College of Agriculture and Natural Resources, along with faculty and students at the University of Maryland's Nutrition & Food Science Department. Ethan ultimately licensed a process developed by the researchers that combined proteins from plants into a basic structure resembling animal muscle, or meat, and used this as an initial foundation for Beyond Meat products. With this basic protein platform and an understanding that the balance of parts of meat, namely lipids, trace minerals, and water, were also present in abundance outside the animal, it became clear that with appropriate resources, building meat from plants was indeed possible."*	(Beyond Meat 2019)
Vegetarian Butcher Founded	2010	*"Dierendag 2010 is de officiële start van De Vegetarische Slager. In hartje Den Haag opent Jaap een nostalgische slagerij, waar ambacht en lecker eten*	(de Vegetarische Slager 2020)

		voorop staan. Een slagerij van toen met het vleesch van nu, waar alleen hardnekkige vooroordelen worden geslacht."	
Vegetarian Butcher Founded	2010	*"Focusing on product attributes such as taste, texture, bite, and nutritional value, The Vegetarian Butcher was able to deliver a product that outperformed many competitors and earned the firm growing interest from the media and public."*	(Saari et al. 2021, 163)
Impossible Foods Founded	2011	*"Impossible Foods was founded in 2011 by Patrick O. Brown, M.D., Ph.D. to end the use of animals to make food. Instead, we aim to make meat, dairy, and fish from plants."*	(Impossible Foods)
Impossible Foods Founded	2011	*"I was like, I can't believe that in San Francisco with all this Venture backing, we can't do anything about climate change and that no one cares. And we learned that consumers won't pay more for power, consumers won't pay more for fuel for their cars. And I'm like, I can't believe this, are we really just going to let climate change go unabetted, and with all the money we've spent and technology, can't make a difference there? […] People will pay more for food, they'll pay more for what they put in their bodies. They'll certainly pay more for what they put in their kids' bodies. And if we address this, it also has this massive impact on the environment, which was pretty much the main reason I left Flagship to move out to California and start Khosla Ventures. And from that came Impossible Foods, started with Pat in my office. All of these food companies, this was nine years ago, and my friends were like, 'You're crazy.'"*	(Samir Kaul 2020)
Impossible Foods & Beyond Meat Founded	2009 / 2011	*"The US West Coast was already home to household plant-based brands (e.g., Tofurkey in Oregon, Miyoko's Kitchen in northern California), yet the founding of Beyond Meat (Los Angeles), JUST, and Impossible Foods (Bay Area) between 2009 and 2011 saw a distinct departure in technological approach, branding, and business model. JUST and Impossible Foods are still headquartered in the Bay Area, and all three companies received early investment from venture capitalists (VCs) and high net-worth individuals connected to Silicon Valley. These companies are frequently held up as the original movers among their industry peers in the latest generation of plant-based biomimicry on account of their pioneering multimillion dollar investment rounds, record-breaking market debuts, and transformation of plant-based substitutes into products now increasingly purchased by nonvegans."*	(Sexton 2020, 457)

Beyond Meat Chicken Strips Launched	2012	*"Beyond Meat founder and CEO Ethan Brown was so impressed with the pair's work that he decided to license the formula from them. The company launched Beyond Chicken Strips in 2012, and by 2013 the product could be found in Whole Foods stores across the nation."*	(Andrews 2019)
Beyond Burger Launched	2015	*"While he is quick to admit that he's far from his ultimate goal, his early stage attempts are already on grocery-store shelves. Released in February and available at Whole Foods, Beyond Meat's Beast Burger does beef one better and packs even more protein than the juiciest bistro burger."*	(Haber 2015)
Nestle Buys Rest of Tivall	2016	*"Other early companies active in the Dutch market of vegetable meat substitutes are Garden Gourmet (originally an Israeli company called Tivall which entered the Dutch market in 1986, and was renamed after being taken over by the food giant Nestlé in 2015)."*	(Dagevos et al. 2018, 186)
Impossible Burger Launched	2016	*"Impossible Foods Inc., announced today that it will introduce the Impossible Burger on Wednesday, July 27, at Momofuku Nishi in Manhattan. This is the first time the Impossible Foods "animal-free" burger will be regularly featured on a restaurant menu, and marks the commercial introduction of a new generation of delicious plant-based foods that promises to revolutionize the world's food system.* *Opened in January 2016 in New York City's Chelsea neighborhood, Momofuku Nishi is part of the Momofuku Group of restaurants founded by world renowned chef David Chang."*	(Impossible Foods 2016)
Tyson Foods Invests in Beyond Meat	2016	*"Tyson Foods invested in Beyond Meat in 2016, and it received funds of more than US$200 million over the next 2 years."*	(Choudhury et al. 2020, 1056)
Vegetarian Butcher Acquired	2018	*"Next, The Vegetarian Butcher moved into the global meat alternative sector, which was estimated at $4 billion in 2017. The firm had an annual turnover of $17.53 million, however, its success invited larger players to take interest in acquiring control of the company. And in fact, The Vegetarian Butcher was acquired by Unilever for an undisclosed amount in December 2018."*	(Saari et al. 2021, 163)
Beyond Meat IPO	2019	*"Beyond Meat Inc. stock skyrocketed Thursday in the best-performing public offering by a major U.S. company in almost two decades.*	(Murphy 2019)

		Shares of the plant-based meat maker — which priced its IPO at $25 a share Wednesday evening — started trading at $46 a share shortly after noon on the Nasdaq, and surged to $65.75 by the end of the session, for a gain of 163%. Prices hit almost $73 a share at their intraday peak. Shares were up another 4% after hours."	
Beyond Meat Chicken Strips Discontinued	2019	*"Beyond Meat's decision to discontinue the chicken strips, a product with a modest yet passionate following, came after a growing number of reviews saying the product's likeness to real chicken was tolerable, at best. […] The problem was exacerbated by the release of the Beyond Burger, which many agreed pulled off the "meatless meat" trick more convincingly."*	(Andrews 2019)
Beyond Meat IPO	2019	*"Beyond Meat filed an initial public offering (IPO) in 2019, which valued the company at US$1.5 billion. Another high-profile company, Impossible Foods, secured funding of US$1.2 billion after closing series F funding of US$500 million in March 2020. The enormous potential of plant-based meat alternatives has brought various incubators (ProVeg, Spring Board, Food Frontier, and Purple Carrot) to support start-ups."*	(Choudhury et al. 2020, 1056)
Beyond / Impossible 2.0 Burgers	2019	*If true disruption is to follow from achieving parity with conventional products across taste, price, and convenience, significant work remains. At this stage, even the best plant-based meats still struggle to convince all eaters of their worthiness, and although they've picked up more widespread distribution – with Beyond Meat and Impossible Foods products, in particular, now available across retail, fast food, food service, and restaurant contexts – cost equivalence has not yet been achieved. But advocates point to the significant progress that has already been made, and draw from technology industry metaphors that highlight the possibility of continuous improvement – building the Impossible Burger version 2.0, for instance – to signal their optimism."*	(Broad 2020, 928)
Beyond / Impossible 2.0 Burgers	2019	*"These adaptations have been fundamental to bringing the world of food into the institutional language and models of Silicon Valley–style innovation and have been a distinct feature in the subsequent marketing of the region's AP companies: for example, when Beyond Meat launched a second iteration of their plant-based burger in 2019, it was promoted as the Beyond Burger 2.0, a clear nod to the terminology commonly used by Apple and other IT companies to launch new generation versions of their products. This framing took the*	(Sexton 2020, 463)

		potentially unsexy process of recipe development common to new food companies and repackaged it in the more exciting language of software development. Media coverage presented this approach as signaling a "new era" of meat production where "new versions of the product are constantly being tweaked, updated, and released. In short, we are entering an era where food is becoming more like software" (Albrecht 2019). This analogy formed the basis of an influential industry report by RethinkX published in 2019 in which it coined the term Food-as-Software to describe the new era of post animal food products."	

Appendix III-B: Electric Cars

Table 6: Influencing Conditions of the BEV TIS

Event	Year	Quote	Source
California Clean Air Act	1990	*"Interestingly, pre-1990 drafts of LEV did not include ZEV provisions. Although Don Drachand, CARB's Motor Vehicle Emissions Control Division Chief, was convinced that ZEVs were needed to meet air quality standards with future population growth, he saw their commercial potential as limited by high costs and low battery range. This turned around when General Motors unveiled an EV concept car in Los Angeles in January 1990, which "mistakenly led the regulator to believe that electric vehicles … could be mandated""*	(Collantes and Sperling 2008, 1304)
First Li-Ion Batteries Commercialized	1991	*"Lithium-ion batteries captured the market for energy storage and movable electric products after being first commercially produced by Sony Company in 1991. They simultaneously have a large power storage capacity, small size and are lightweight [48]. Compared with other batteries shown in Figure 4, the lithium-ion battery has significant advantages in terms of specific energy and energy density. Additionally, since lithium-ion batteries have high energy efficiency, an unnoticeable memory effect, long cycle life, and high-power density, they are presently the most competitive choice of energy storage device for EVs"*	(Sun et al. 2019, 5)
California Clean Air Act ZEV Provision Postponed	1996	*"From the early 1990s, car firms voiced their dissatisfaction with California's ZEV regulation and put pressure on US federal and European legislators to limit emission regulations. Although there were electric vehicle associations in Europe, US and Asia (mostly created by BEV enthusiasts), public support for BEVs was not strong enough to counterbalance the industry lobby. As a result, the Mandate was relaxed in 1996 (the requirements for 1998–2002 period were abolished), and again in 1998 (ZEV credits could be earned through partial electric vehicles). With the Mandate watered down, by early 2000s the political support for BEVs in the US had faded away. As a result, between 1995 and 2000 only a few thousands BEVs were sold worldwide, and poor sales records clearly reflected the market failure of BEVs in California and elsewhere, closing another EV hype-disappointment cycle."*	(Dijk et al. 2013, 137)

China Starts 863 BEV Project	2001	*As a result, in 2001, new energy vehicles were incorporated into the 863 Project for the 10th Five-Year-Plan (FYP), China's primary national planning document. China also developed its first new energy vehicle technology roadmap, the "Three- by-Three Research and Development Strategy." It included three new energy vehicle technologies as pillars—fuel cell, hybrid, and electric—and three component technologies: powertrain control systems, driving motors, and batteries. These guided China's new energy vehicle development for the next 15 years.* *The 863 Project invested ¥880 million ($135 million1), during 2001–2005 and engaged a select group of industry and university partners to develop prototype models under the three main technology paths."*	(Jin et al. 2021, 2)
Th!nk Greatly Expands	2001	*"The creation of the PIVCO network has obviously been an important impetus for the BEV niche in Norway, but this has not yet been reflected in sales. As of 1999, only 300 EVs, about 70 of them City Bees, were in use throughout the country.65 The numbers started growing in 2001 (see below). In the United States, the Bay Area demonstration contributed to the creation of a niche for station cars and shared cars. The National Station Car Association used the results of the Bay Area demonstration, together with those of other local demonstrations elsewhere in the country, to write a proposal advocating a large national demonstration that would involve 3,000 to 5,000 cars in several cities. Also, as of 1999, BART was planning to expand the station car concept to a car-sharing system. Furthermore, Hertz was to include the BEV in its rental car line-up. Marketing in the rest of Europe and in the US started in 2001, in time to meet the deadlines set in the ZEV mandate. The initial sales target was set at 5,000 vehicles a year.71 If the company meets this target, the TH!NK will become the best-selling battery-EV worldwide."*	(Hoogma et al. 2002, 85)
Th!nk Dropped by Ford	2003	*"Instead, it became a niche within the traditional automotive industry, heavily rooted in American car culture. The outcome was a series of backlashes, which came as the result of what Andersen (2013) has described as "guerrilla attacks" from within Ford, who argued that the simple, plastic cars would not succeed on the US market. Ford discontinued Th!nk in 2003."*	(Skjølsvold and Ryghaug 2020, 237–238)
ZEV Mandate Revoked	2003	*"Program reviews in 1998 and 2000 led to further reforms, allowing*	(Stokes and Breetz 2018, 83)

		automakers to meet 40% of their obligations with partial ZEV (PZEV) and advanced technology ZEV (AT-ZEV) vehicles, such as hybrids. Automakers challenged the cap in court, and in 2003 CARB created an "alternative compliance path" allowing manufacturers to meet their entire mandate with PZEVs and AT-ZEVs."	
First Li-Ion Battery in an EV	2003	*"San Dimas, CA – September 15, 2003 - After 63,000 miles, the original tzero prototype wears the scars of daily use and, except for new air scoops and a decal reading super LIght versION, it still looks the same. But now, on the streets again after a six-month battery transplant, it moves with a new spring in its step. A new lithium-ion battery has replaced the lead-acid battery and saved 500 pounds. The whole car weighs in at 1970 pounds. And despite weighing less, the LiIon tzero carries three times more energy than before. "The results are staggering" according to AC Propulsion President Tom Gage. "The LiIon tzero will drive 250 miles in left lane traffic, in LA that means 75-80 mph. Alan Cocconi (AC Propulsion founder and chief engineer) drove it to San Diego and back without charging. On any type of standardized drive cycle it will go over 300 miles"."*	(Chow 2003, 1)
Cleantech Bust	2008	*"As already mentioned, in 2008, the clean-tech bubble went bust. The Renewable Energy Industrial Index (RENIXX), which tracks the largest companies by market capitalization in the renewable energy sector, crashed in a cumulative loss of 64%. Many prominent clean-tech startups, such as Evergreen Solar, A123, or Solyndra—which required massive up-front investments to develop new hardware and scale up manufacturing—filed for bankruptcy."*	(Giorgis et al. 2021, 5)
Cleantech Bust	2008	*"This paper shows that while patents filed by VC-backed firms are of significantly higher quality than the average patent, VC-backed innovation is substantially more procyclical. We trace this to changes in innovation by early-stage VC-backed startups."*	(Howell et al. 2020, 28)
Financial Crisis and GM Bankruptcy	2009	*"Some of Tesla's most important transactions were with Toyota, which in 2010 invested $50 million for shares in Tesla's IPO and sold Tesla its New United Motor Manufacturing, Inc. (NUMMI) plant in Fremont, California, for $42 million. Tesla benefited from the purchase by having a space ready to retool, and Toyota benefited by not having to write the space off at a total loss.*	(Stringham et al. 2015, 87)

		Recycling the factory freed up by General Motors and Toyota thus gave Tesla space to produce the Model S and subsequent higher-volume vehicles."	
Financial Crisis and GM Bankruptcy	2009	*"Under the Toyota-GM Partnership, if one of the parties in the Fremont factory went bankrupt, the whole plant would go to the other party. When GM went bankrupt, Toyota suddenly found themselves with a white elephant. Selling it to Tesla was the easiest way for them to get rid of it."*	Interview (19)
10 Cities Thousand EVs Programme	2009	*"In January 2009, a demonstration project "Ten Cities Thousand Vehicles Project" (the Project) was initiated by the Ministry of Science and Technology (MOST), Ministry of Finance and National Development and Reform Commission (NDRS) to stimulate BEV adoption. The project target was 1000 EVs in each of 10 pilot cities every year, and EV market share to reach 10% by 2012."*	(She et al. 2017, 29)
10 Cities Thousand EVs Programme	2009	*"In particular, the nationwide EV demonstration program known as "Thousands of Vehicles, Tens of Cities (TVTC)" is seen as China's first step in going from BEVs laboratory stage to market deployment. This program was implemented with city-based pilots focusing on the use of EVs in public transport (Zheng et al., 2012). Although the TVTC program has not reached the targets planned at the beginning, no one can deny its significance in gaining experience in exploring new solutions for deploying EVs in China."*	(Li et al. 2016, 272)
ARPA-E Loan to Tesla	2010	*"In 2009, it was easy to think that the government would continue to support cleantech: "green jobs" were a political priority, federal funds were already earmarked, and Congress even seemed likely to pass cap-and-trade legislation. But where others saw generous subsidies that could flow indefinitely, Tesla CEO Elon Musk rightly saw a one-time-only opportunity. In January 2010—about a year and a half before Solyndra imploded under the Obama administration and politicized the subsidy question—Tesla secured a $465 million loan from the U.S. Department of Energy. A half-billion-dollar subsidy was unthinkable in the mid-2000s. It's unthinkable today. There was only one moment where that was possible, and Tesla played it perfectly."*	(Thiel and Masters 2014, 167)
Deepwater Horizon	2010	*"The zero-emission vehicle mandate imposed by the California Air Resource Board is considered as a turning point in the new EV era and manifested the idea of pollution reduction by transport electrification. Recently, Dieselgate and studies about the growing gap between official and real-world emissions*	(Pelegov and Pontes 2018, 1)

		have confirmed the importance of further EV adoption support. The Deepwater Horizon oil spill clearly demonstrated the real cost of oil production and well-to-wheel transportation risks. The social and economic costs of greenhouse emissions are too numerous to account for all correctly."	
US BEV Everywhere Programme Launched	2012	*"Improvements in battery technology have the capacity to resolve all of these issues. Accordingly, the Department of Energy (DOE), the United States Advanced Battery Consortium (USABC), and others are directing significant resources towards the development of batteries for BEVs. For example, the DOE has initiated its EV Everywhere Grand Challenge to accelerate BEV advancement, with a heavy focus on advanced battery technology. […] Consequently, in 2012, the DOE and USABC jointly set out to create a new set of battery technology targets for EVs. It was desired that the targets be designed to deliver a BEV capable of broad market success if achieved."*	(Neubauer et al. 2014, 615)
EU Alternative Fuels Directive	2014	*"Charging infrastructure regulation is needed at both national policy and local planning level. This has been partly achieved in the Nordic countries due to, e.g., changing the requirements for concessions in Sweden and political support for charging along roads in Norway. At the EU level, the Alternative fuels directive 2014/94/EU supports development."*	(Nilsson and Nykvist 2016, 1367)
Formula E Launched	2014	*""Since its first race in Beijing in 2014 and with every E-Prix thereafter, Formula E has proven that the concept of cutting-edge electric racing works. I wholeheartedly welcome Formula E as the latest FIA world championship." The announcement follows Formula E's most successful season to date - with nine different race winners and growing audience figures - and shortly after the opening two rounds of season six and the much-anticipated arrival of Mercedes-Benz and Porsche at the SAUDIA Diriyah E-Prix."*	(FIA Formula E 2019)
Dieselgate Scandal	2015	*"At the level of the international landscape, Serra (2012) posits three key factors driving political motivation for governments at all levels and in turn seeking to shape industrial, societal and consumer attitudes. […] The second is the environment and the debate over the impact of man-made CO2 emissions on accelerating climate change, and the role of automotive transport in this process; as well as concerns over air pollution and its effects on health*	(Berkeley et al. 2018, 324)

		resulting from urban traffic congestion, particularly in the wake of the Volkswagen 'Dieselgate' scandal (Bailey, 2016)."	
Volvo first Incumbent to always include Electric Drivetrain	2017	*"Volvo Cars has been in the news recently in relation to their announcement this Wednesday on their decision to leave the internal combustion engine only based automotive industry.* *The Chinese-European company announced that from 2019 all their vehicles will be either pure electric or hybrid electric. In this way it has been argued the company is making a bold move towards electrification of vehicles."*	(Gonzalez and Grande 2017)
BEVs reach 1% of Market Share and continue growth*	2017	*"In the world of clean energy, few areas are as dynamic as the electric car market. In the whole of 2012, about 130 000 electric cars were sold worldwide. Today, that many are sold in the space of a single week.* *Growth has been particularly impressive over the last three years, even as the global pandemic shrank the market for conventional cars and as manufacturers started grappling with supply chain bottlenecks. In 2019, 2.2 million electric cars 1 were sold, representing just 2.5% of global car sales. In 2020, the overall car market contracted but electric car sales bucked the trend, rising to 3 million and representing 4.1% of total car sales. In 2021, electric car sales more than doubled to 6.6 million, representing close to 9% of the global car market and more than tripling their market share from two years earlier. All the net growth in global car sales in 2021 came from electric cars."*	(IEA 2022)
Lithium-Ion Battery Prices Fallen by 97%	2019	"Taken together, the data reveal a consistent decrease in lithium-ion cell price over time, with a few exceptions around 1995 and 2008. Overall, prices have declined by about 97% since the commercial introduction of lithium-ion cells in 1991."	(Ziegler and Trancik 2021)
Year of SPACs	2020	*"The demand for electric vehicles (EVs) is fueling on the back of climate change concerns, favorable government policies and superior technologies. Investors are intrigued by automakers that look for solutions to lower global carbon emissions for providing a cleaner energy future. With green vehicles striking the right chord with investors, it has been raining IPOs in the EV market this*	(Singhi 2020)

* See graphic in chapter 4.2.5.6 Customers for the 1%.

		year. Seemingly, merger with special purpose acquisition companies (SPACs) turned out to be the most popular course of action for an EV IPO in 2020."	
Norway Bans Consumer ICE Sales by 2025	2021	*"Norway is ahead of the game in EV sales, with gasoline's share of the new car market vanishing more and more every month, faster than almost anyone outside of Electrek's Slack channel could have predicted. This has led Norway to have the earliest target for the phaseout of new gas vehicle sales in the world – 2025."*	(Dow 2021)
EU Bans ICE Vehicles by 2035	2021	*"One of the main goals of the Fit for 55 package is to support the transition to cleaner mobility. The way that the EU aims to do so is by effectively limiting net emissions from new vehicles. The new European targets propose that by 2030, emissions from new cars must be reduced by 55 percent compared to 1990 levels. However, it doesn't end there.* *In a historic first, the European Commission has proposed a complete phase-out of ICE vehicles by 2035—only five years later."*	(Noyens and de Rosa 2021)

Table 7: Building Blocks of the BEV TIS

Event	Year	Quote	Source
GM Impact Car Unveiled	1990	*"On January 3, 1990, at the Los Angeles Auto Show, General Motors unveiled the impact – a prototype two-seater that was designed from the bottom up as an electric vehicle. The Impact showed important progress in performance relative to previous electric cars. […] CARB relied heavily on what they knew of the General Motors Impact. Supporting documentation stated: ''General Motors has indicated it plans to introduce its Impact electric vehicle by 1996, and this vehicle is competitive in performance to gasoline-powered vehicles, although battery life is less than desired""*	(Collantes and Sperling 2008, 1306)
Development of Th!nk Citybee starts	1991	*"Hoogma et al (2002) studied the European demonstration experiments with electric vehicles in Germany (Rugen Island, 1992–1996), Switzerland (in the town of Mendriso, after 1995), and Norway (via the development of an EV called Th!nk, after 1991), among others."*	(Dijk et al. 2013, 136), summarizing (Hoogma et al. 2002)
AC Propulsion Founded	1992	*"Alan Cocconi, an automotive engineer prominent in the development of the GM Impact electric concept car (while working at the California vehicle design*	(Thomas and Maine 2019, 656)

		firm, Aerovironment), founded AC Propulsion in 1992 (Eberhard, 2006a; Black, 2009).”	
GM EV1 Launched	1996	*“From 1996 to 1998, GM introduced over 1,000 first-generation EVs (EV1) in California, mostly made available through leases. In 2003, GM crushed their BEVs upon the expiration of the leases.”*	(Li et al. 2017, 90)
Tzero Prototype Constructed	1996	*“In 1996, the same year that GM launched the EV1, AC Pro- pulsion demonstrated the 1st generation tzero, a battery electric vehicle with lead acid batteries and a total range of nearly 100 miles. The revolutionary drivetrain also enabled this prototype to accelerate rapidly from 0 to 60 mph in under 6 s, which was phenomenal for an electric vehicle at the time.”*	(Thomas and Maine 2019, 656)
Toyota Prius Launched	1997	*“While the interest for battery-electric cars waned by the end of the period the first mass produced hybrid-electric car, Toyota Prius, entered the market in December 1997. Still, actual sales were very limited. […] Due to raised fuel prices, public debates on global warming and an expanding segment of environmentally concerned buyers in the mid-2000s, the American demand for the second-generation hybrid car Toyota Prius started to soar (Sperling & Gordon, 2009). Several of Toyota’s Japanese and American competitors responded by introducing hybrid cars on the market.”*	(Magnusson and Rickne 2010, 6)
Toyota Prius Launched outside Japan	2000-2004	*“After capturing the Japanese niche, the Prius II was launched California in 2000. The new version had increased acceleration (causing consumption to grow to 5.1 l/100 km) and a more attractive appearance (design). The new version was well received by American consumers, ramping up sales quickly and motivating Toyota to go one step further and launch the third generation of the hybrid technology (Prius III) worldwide in 2004. Toyota rolled out the Prius vigorously, which appealed to a broad set of consumers, such as the tech-savvy, paving the way for wider applications of hybrid-electric technology in other models. Overall, the car has been a huge success for Toyota, who earned the reputation of the greenest volume carmaker in the world. In the period 1997–2007, Toyota sold more than one million Prius worldwide. “*	(Dijk et al. 2013, 137)
Incumbents Halt BEV Development	2003	*“From 1996 to 1998, GM introduced over 1,000 first-generation EVs (EV1) in California, mostly made available through leases. In 2003, GM crushed their EVs upon the expiration of the leases.”*	(Li et al. 2017, 90)

Incumbents Halt BEV Development	2003	*"With the Mandate watered down, by early 2000s the political support for EVs in the US had faded away. As a result, between 1995 and 2000 only a few thousands EVs were sold worldwide, and poor sales records clearly reflected the market failure of EVs in California and elsewhere, closing another EV hype-disappointment cycle."*	(Dijk et al. 2013, 137)
Atieva / Lucid founded	2007	*"Atieva was formed in 2007 by Weng and two co-founders, Bernard Tse and Sheaupyng Lin. The company initially worked to develop batteries and electric drivetrains, filing more than 100 patents, and delivering battery packs for electric buses in China. That all changed in 2014, when two Chinese firms invested around $100 million for a nearly 50 percent stake in the firm."*	(Harris 2016)
Fisker Founded	2007	*"The Dane's startup, Fisker Automotive, hasn't built a car in nearly a year. It fired most of its workforce, hired bankruptcy advisers and is seeking a buyer. Co-founder Henrik Fisker resigned in mid-March in a dispute with some of the directors. And despite raising $1.4 billion in private and public funds since its founding in 2007, the company is out of cash. For months, key investors have been footing the car maker's day-to-day expenses to keep it alive in diminished form."*	(Seetharaman and Lienert 2013)
Roadster Launched	2008	*"Tesla started with a tiny submarket that it could dominate: the market for high-end electric sports cars. Since the first Roadster rolled off the production line in 2008, Tesla's sold only about 3,000 of them, but at $109,000 apiece that's not trivial. Starting small, allowed Tesla to undertake the necessary R&D to build the slightly less expensive Model S, and now Tesla owns the luxury electric sedan market, too. They sold more than 20,000 sedans in 2013 and now Tesla is in prime position to expand to broader markets in the future."*	(Thiel and Masters 2014, 167)
Th!nk City Launched	2008	*"The TH!NK city electric vehicle made its debut at the 2008 British International Motor Show in London. […] Production started this year in Norway, and the first batch of right-hand drive cars will be delivered to UK customers in summer 2009."*	(Millikin 2008)
Daimler saves Tesla	2009	*"In 2009, the year before its IPO, Tesla worked out the alliance with Daimler, whose roots in automobile engineering extend back to the early days of the automobile powered by an internal combustion engine about 130 years ago. The deal provided Tesla with access to superior engineering expertise and a*	(Hoang and Rothaermel 2016, 1)

		cash infusion of $50 million, helping to save the company from potential bankruptcy."	
Second Generation Incumbent EVs	2010-	*"The competition towards the electrification of cars could be seen in the 2009 edition of the Frankfurt Motor Show, with almost every carmaker displaying EVs prototypes (or concept cars, as they are known in the industry). Besides the aggressive marketing campaign around the launch of four models of EVs by Renault– Nissan, other European volume producers, such as Mercedes and Fiat presented EV models with clear plans to be launched before 2015."*	(Dijk et al. 2013, 138)
Second Generation Incumbent EVs	2010-	*"The Tesla business model, however, also benefits from other revenue streams, such as the income Tesla obtains selling zero emission credits to others (at one stage amounting to 12% of revenues), and selling battery packs to Daimler for the electric version of the Smart used in the innovative Car2Go schemes and Toyota for the PHEV version of the RAV4 (Wells and Nieuwenhuis, 2015). Both Daimler and Toyota have invested in Tesla in the past."*	(Nieuwenhuis 2018, 42)
Tesla IPO	2010	*"Similarly, the electric car manufacturer Tesla went public in June 2010 at $17 per share and by December 2011 was valued at $30 per share placing the value for Tesla at roughly 20 times their annual revenues. The multiple can be attributed to either its expected growth in revenue and profits, or mania. Considering existing automotive companies are typically valued at less than a single year's revenues (Ford Motor Company is trading at 33% of revenue while Honda is at 59%), Tesla's valuation appears to be based on the unlikely prospect of it becoming the next Ford or Honda soon. Tesla's IPO raised $226 million, which does not cover the $365 million they owe creditors in DOE-backed loans. They are unprofitable and, indeed, are pinning their growth on an expensive mass-market sedan, similar to the already available Nissan Leaf and Chevrolet Volt, due in 2012."*	(Hargadon and Kenney 2012, 130)
Tesla – Panasonic Partnership	2011	*"Tesla motor has a good knowledge of battery packs and management system. It has innovatively equipped Roaster with thousands of laptop Lithium-ion cells and assembles them into a performance and cost optimized battery pack. During the delivery of Tesla Model S, it developed a closer relationship with its battery cell supplier Panasonic, on both battery technology and the scale of production."*	(Chen and Perez 2018, 10-11)

Th!nk Bankruptcy	2011	*"Ford discontinued Th!nk in 2003. While several attempts were made by new owners to revive the company, it eventually filed for bankruptcy in 2011 marking the end of the Norwegian EV industry venture."*	(Skjølsvold and Ryghaug 2020, 237–238)
Model S Launch	2012	*"Tesla Motors launched the aluminum bodied Model S sedan in 2012 (Stringham et al., 2015). High media interest and coverage contributed to the Model S's iconic status and has meant that Tesla Motors has not needed to conduct traditional advertising. The Model S was priced in the premium segment and has led to the formation of a dedicated base of Tesla buyers"*	(Thomas and Maine 2019, 658)
Atieva / Lucid Starts Development of the Air	2013	*"At the end of 2013 we were a highly capable producer of connected premium electric battery packs and powertrains, but we still had a grander vision. We felt that if we could break free of the existing automotive requirements and architectures, we would be in the position to create real innovation. It was a liberating experience. Unbound from conventions of the automotive industry, we were free to define our own experience. We started imagining a vehicle that takes full advantage of electrification without boundaries. In 2014, we closed a 9-digit funding round with the goal of developing a complete car."*	(Lucid 2016)
Fisker Bankruptcy	2014	*"As a result, less money is left for new promising innovative start-ups, and early-stage R&D in this field is often left to academic institutions. Later stage clean-tech funding grew in 2009 and 2010 while early-stage funding contracted. These trends provide support for the idea that VCs are increasingly funding companies like Fisker, a firm trying, but failing, to manufacture another version of the plug-in hybrid. Will funding for mature clean-tech companies like Fisker that are absorbing a higher proportion of the VCs' efforts dwarf the funding that cutting-edge firms can receive? Ten firms could survive on the funding that Fisker so far has obtained."*	(Marcus et al. 2013, 54)
Fisker Bankruptcy	2014	*"Anaheim, Calif.-based Fisker, which planned to build cars at a former General Motors plant in Delaware, filed for bankruptcy protection last week, ending a long, downward spiral that began after it received a $529 million loan commitment from the US Department of Energy. Fisker drew $192 million on the Obama administration's green-energy loan before DOE officials suspended funding in 2011 after the automaker failed to meet several sales milestones for its Karma luxury vehicle."*	(Chase 2013)

First Battery and BEV "Gigafactory"	2015	*"In 2014, Tesla Motors signed another strategic alliance — this one with Osaka, Japan-based Panasonic Corp., the consumer electronics company and a world leader in battery technology. As Tesla tries to position itself in the business of sustainable and decentralized energy, the relationship with Panasonic is significant. The two companies are jointly investing in a new $5 billion lithium-ion battery plant in Nevada. Tesla's ability to attract and manage leading companies in the automotive and other key industries as strategic alliance partners is an important part of its formula for success."*	(Hoang and Rothaermel 2016, 3)
Tesla Model 3 Release	2017	*"The much anticipated Tesla Model 3, priced at US$35,000 in April 2016, received nearly 400,000 orders before production began (Lambert, 2016). The launch of each model has steadily been downmarket[sic] to larger market segments. The market capitalization of Tesla Motors rose from US$226 million at IPO in June 2010 (Crunchbase, 2016) to over US$50 billion in 2017 (Lambert, 2017), announcing itself as a legitimate competitor to the Big Three automotive companies. […] What is striking is the move downmarket[sic] and the use of high-end, low volume production to generate revenues to support the development of the Model 3 for the mainstream automotive market. Elon Musk has argued that this was the only way Tesla Motors could have gained a foothold in the highly competitive automotive industry (Musk, 2006)."*	(Thomas and Maine 2019, 658–659)
Tesla Model 3 Release	2017	*"The growth in NCA batteries in the United States is primarily driven by Tesla, with considerable uptake after 2017 due to the release of the more affordable Model 3."*	(Jin et al. 2021, 25)
First Luxury Segment BEVs from Incumbents	2018-2019	*"On the eve of 2020, the competition for electric car buyers has become more intense, with several well-engineered luxury vehicles from well-funded European manufacturers. Porsche, Audi, Mercedes, and Jaguar have all launched vehicles that will create real competition for Tesla. Moreover, this is happening as federal tax incentives begin to wind down for Tesla, which has reached the 200,000-sale threshold at which federal EV credits start to phase out. The wave of premium European carmakers includes Porsche with the Taycan, Audi with the e-tron, and Mercedes Benz with its EQ range. In 2018, Jaguar started to deliver its I-Pace, a full-electric model with comparable entry-level prices to Tesla's Model S sedan and Model X SUV. The Jaguar I-Pace comes with a descent of luxury, racing, and engineering expertise."*	(Candelo 2019, 183)

Corporate Interests in Rivian	2019	*"And Rivian has arrived at its current position with help from two giants of the U.S. economy. Amazon owns at least 5 percent of Rivian's stock and has placed an order for 100,000 delivery vehicles with the company, which is the largest single purchase of EVs ever; the megaretailer's name appears in Rivian's IPO filing more than 80 times. Ford also owns a large share of the company. (The old-school automaker and Rivian initially planned to collaborate on an electric SUV, but the deal fell through.)"*	(Meyer 2021a)
Tesla Most Valuable Automaker	2020	*"This time investors are looking at a broader range of clean tech. About half the deals by value go to low-carbon transport, encouraged by Tesla's credulity-stretching success. In 2004 Elon Musk bought a 14% stake in the electric-car maker for $6.5m. Six years later it went public and is today worth $385bn, more than any other carmaker. Mr. Musk's stake alone is worth perhaps $72bn, just shy of General Motors and Ford combined."*	("Greenbacks for Greenery", 2020)
Rental Companies Start Taking EVs	2021	*"Hertz has decided to add Tesla Model Y to its growing electric vehicle fleet after announcing a deal to buy 100,000 Model 3 vehicles last year. Last year, Hertz announced an important effort to electrify its fleet of rental cars, led by a massive purchase of 100,000 Tesla Model 3 vehicles. The news sent Tesla's stock to record highs despite some confusion around the agreement. Tesla didn't offer any deal to Hertz, and the rental company has to order the electric vehicles like any other customer. The biggest question has been the timeline. Hertz said that it was planning to take deliveries of the 100,000 Model 3s by the end of 2022. Tesla wasn't so sure that it would be possible, but Hertz has already been taking a lot of deliveries and the automaker is still guiding deliveries of new Model 3 orders by the end of the year."*	(Lambert 2022)
Incumbents Commit to EVs	2021-	*"Toyota committed 8 trillion yen ($70 billion) to electrify its lineup by 2030, half of it to develop a battery electric vehicle lineup, as it looks to tap a growing market for zero-emissions cars. But the world's biggest automaker, which is a relative latecomer to full-electric cars, said it expected annual sales of full-electric cars to reach only 3.5 million vehicles by the end of the decade, or around a third of its current vehicle sales."*	(Reuters 2021)
Incumbents Commit to EVs	2021-	*"In the biggest deal it has done in a long time, Ford Motor Co. decided to split its electric-vehicle business from its traditional auto business last week – but notably, not spin off the EV business in pursuit of the white-hot stock*	(Mullaney 2022)

		valuations that have followed EV leader Tesla and, intermittently, fast followers like Rivian and Lucid Group, whose stock prices have suffered recently. […] The message from Ford management is that the EV business, despite solid sales of the well-received Mustang Mach-E, isn't ready for prime time. Ford chose the safer course of keeping its promising emerging business tied to the profitable mother ship for longer. That lets the EV unit, to be dubbed Ford Model e, and other tech efforts, invest up to $50 billion mostly out of the cash flow from the existing Ford, to be called Ford Blue. That cash flow was $40 billion over the last two years, meaning Model e won't have to turn to bond or stock markets to fund expansion."	
Incumbents Commit to EVs	2021-	*|In May 2021, Ford unveiled the an[sic] all-electric version of its long-running, best-selling F-Series pickup, with the F-150 Lightning. Since the initial launch, Ford has been taking F-150 Lightning reservations with a $100 refundable deposit, initially revealing that the truck had received 20,000 reservations on the first day and 44,000 reservations for the F-150 Lightning within 48 hours. […] To combat this demand, Ford has already doubled its Lightning production once, in August. That new timeline consisted of 15,000 Lightning EVs in 2022, 55,000 in 2023, and 80,000 in 2024. At the time, Ford was targeting 160,000 trucks in 2025 when the second-generation F-150 Lightning debuts. Even then, based on Ford's reservations, we predicted that would not be enough of a production capacity to meet the tremendous demand for the new electric pickup. Ford appears to have felt the same way, and is once again nearly doubling its Lightning production capacity."*	(Doll 2022)
BEVs Reach Cost Parity	2022-*	*"Analysis of first-owner 5-year owner- ship costs indicates that an average new vehicle buyer will see an attractive proposition to choose electric vehicles in the 2022–2026 time frame. The consumer ownership parity point for each vehicle application is one to two years sooner than initial cost parity, due to the high fuel savings of electric vehicles."*	(Lutsey and Nicholas 2019, 11)

* Claims have existed much earlier – this is a relatively conservative meta-study.

Appendix IV: Background on TIS Elements

Everything in this appendix is transcluded from Ortt & Kamp (2022) pp. 3-4 and pp. 7-8 (chapters 3.1 and 3.3), reproduced with permission. For citations and context, as well as to cite the information in this chapter, please refer to the full paper at https://doi.org/10.1016/j.techfore.2022.121671.

Seven Building Blocks

Product performance and quality

The first TIS building block is a new high-tech product with a sufficiently good performance and quality now, or in the near future, when compared to competing products (Magnusson and Berggren, 2018). Target customers should regard the product as a viable option, or as a viable alternative compared to other options. For example, in the case of many sustainable products, environmental performance can be valued highly, but early product versions may suffer from low quality and may be unable to meet the customers' requirements (Kemp et al., 1998). Hence, large-scale diffusion can be hampered.

Product price

Product price is an important TIS building block. Often, technological innovations are initially very expensive compared to competitive alternatives, which can hamper their diffusion (Kemp et al., 1998). The price of a product involves financial and non-financial (e.g., time and effort) costs to acquire and use the product. Acquiring products involves various costs related to selling and depreciating investments in previous products, and it also involves switching costs, i.e., costs involved in switching from one product to another, and transaction costs, i.e. costs to find the right new product and a supplier (Tsoutsos and Stamboulis, 2005). For large-scale diffusion, a product is required with a reasonable price (absolutely or relatively compared to other competitive products) (Negro et al., 2012b).

Production system

Another essential TIS building block is a production system that can deliver high quality products in large quantities. Over time, growing experience with the production process and the product itself will increase the product's quality and decrease its production costs (learning by doing) (Kamp et al., 2004). These effects increase the competitiveness of the product Geels (2004). Incompleteness or absence of this building block constitutes a problem for many radically new technological innovations. Creating a large production facility is not only a major investment, but it may also take a considerable amount of time to develop and fine-tune such production systems (Kemp et al., 1998). A lack of production system can block large-scale diffusion.

Complementary products and services

A fourth TIS building block is the availability of complementary products and services supporting development, production, distribution, adoption, use, repair, maintenance, and disposal of the innovation. Diffusion of the innovation can be hampered when complementary products and services are unavailable, incompatible, or too expensive (Geels, 2004; Kemp et al., 1998). Development of complementary products and services can induce multiple innovations in firms that are linked together and therefore motivated to align their strategy Malerba (2002). A lack of complementary products and services can block large-scale diffusion.

Network formation and coordination

The network of actors in the supply chain is an important TIS building block. Multiple types of actors are vital for large-scale diffusion of an innovation. Actors can refer to suppliers of parts, actors assembling or producing the product, distributors, and actors providing complementary products and

services (Kemp et al., 1998; Edquist, 2011; Kamp and Vanheule, 2015). Malerba (2002) describes the importance of coordination between these actors. This coordination not only involves actual collaboration between actors but also involves a shared vision regarding the technological innovation and the TIS surrounding it (Negro et al., 2012b). A lack of actors or a lack of coordination between them, can completely block large-scale diffusion.

Customers

Customers represent an important TIS building block (Kemp et al., 1998; Malerba, 2002). A customer segment needs to be identified early on (Kamp et al., 2004). Potential customers with a need for the innovation should be identified, for example through a problem solved by the innovation or because they largely benefit by using the innovation. To become actual customers, the potential customers should be aware of the innovation, see its benefits compared to other products, and have the knowledge, means and willingness to acquire and use it (Ortt et al., 2013). When innovations are developed without involving (future) customers, several customer-related issues may hamper their diffusion (Kamp et al., 2004). Potential customers may want to use a product but may lack the means to acquire it. They may lack knowledge of a product and can be uncertain about a product and hence perceive risks. Additionally, "users (..) have to integrate new technologies in their practices, organizations and routines, something which involves learning and adjustments. New technologies are sometimes said to be 'tamed' to fit in concrete routines and application contexts" (Geels, 2004, p. 902). Obviously, without actual customers there is no large-scale diffusion.

Innovation-specific institutions

Innovation-specific institutions form an important TIS building block (Kemp et al., 1998). These institutions refer to formal and informal rules such as government policies, laws, standards, and regulations (North, 1990). Such rules can either support or block development and diffusion of an innovation (Ortt and Egyedi, 2014). Geels (2004) indicates that quality norms and property rights can produce trust. A lack of a long-term consistent policy can affect development and diffusion of innovations (Negro et al., 2012b; Vasseur et al., 2013). Stable and supporting innovation-specific institutions increase certainty for companies and investors and hence facilitate development and diffusion of innovations.

Seven influencing conditions

Knowledge and awareness of technology

The first influencing condition 'knowledge and awareness of technology' refers to fundamental and applied technological knowledge. Fundamental knowledge focuses on the technological principles in components of the TIS, such as the product, the production system, and complementary products. Applied technological knowledge is required to develop, produce, repair, maintain, and improve these components. Both types of knowledge are required for TIS formation. These types of knowledge can be developed through research and development or through knowledge creation and experimentation in practice (Kamp et al., 2004; Bergek et al., 2008; Edquist, 2011). Kamp (2002) refers to education and training as important mechanisms for transferring knowledge of technology across actors. A lack of relevant fundamental and applied technological knowledge by actors in the TIS can hamper TIS formation.

Knowledge and awareness of application and market

The second influencing condition 'knowledge and awareness of application and market' refers to the knowledge how, and in which applications, the innovation can be used. It also refers to knowledge of the market structure and the relevant actors involved. This knowledge can be developed through market analysis, experimentation, learning by doing, learning by using or learning by interacting with

relevant actors in the socio-technical system (Lundvall, 1992; Malerba, 2002; Kamp et al., 2004; Kamp and Bermudez-Forn, 2016). All actors in the TIS can suffer from a lack of knowledge and awareness of application and market. For example, when potential customers are not aware of the product, or do not know how and for what purpose to use a product, or when they do not know who can supply the product, then TIS formation is hampered (Kamp et al., 2004; Ortt et al., 2013). When suppliers lack knowledge of application, they cannot target a customer segment and hence TIS formation is hampered.

Natural, human, and financial resources

Another condition influencing TIS formation is the availability of resources. Firstly, natural resources are required (Kemp et al., 1998; Malerba, 2002; Geels, 2004; Bergek et al., 2008; Vasseur et al., 2013). Natural resources to create products, production systems and complementary products can be acquired by each actor separately or by associations of organizations. Secondly, human resources with appropriate knowledge and competences, need to be mobilized (Kemp et al., 1998; Geels, 2004; Bergek et al., 2008; Vasseur et al., 2013). The appropriate knowledge and competences may be acquired via education programs or courses or in practice, via learning by doing. Thirdly, financial resources are needed for development and application of the innovation, the production system and complementary products and services (Kemp et al., 1998; Malerba, 2002; Edquist, 2011; Vasseur et al., 2013). Financial resources can come from different types of actors, such as supplying companies, investors, governmental institutions, or customers. Lack of natural, human, or financial resources hampers TIS formation.

Competition

In practice, competition refers to an important influencing condition. Especially during TIS formation, innovations based on old technologies compete with those based on new technologies (Magnusson and Berggren, 2018). At the same time, different product versions based on a new technology may compete. When competing alternatives require different components, production systems, complementary products, and services, then alternative networks of companies are formed. All of this may create a chaotic and complex pattern of competition between networks of companies. In such situations, uncertainty may increase and TIS formation may be hampered (Shapiro and Varian, 1999). So, competition can have a large impact on several TIS building blocks. Competition for example determines the relative price and performance of a radically new innovation.

Macro-economic and strategic aspects

Macro-economic and strategic aspects form important influencing conditions of the TIS building blocks. An economic recession can hamper TIS formation (Bergek et al., 2008) whereas economic growth can facilitate it, for example, by providing funds for incubation activities and consultancy services (Edquist 2011). The macro-economic situation involves conditions like the market structure and the contemporary way of doing business, and these conditions are often reflected in strategic policies of countries regarding important industries. The combination of these conditions can influence the formation of TIS building blocks (Kemp et al., 1998).

Socio-cultural aspects

Socio-cultural aspects refer to the norms and values held by potential customers and other important stakeholders in the socio-technical system. These aspects may be more informal than the laws, rules, regulations and policies mentioned as institutions, but they can have a large impact on the formation of these institutions and on the behaviour of the actors in the TIS. Socio-cultural aspects can also change over time and can thereby switch from a stimulating into a blocking factor. Socio-cultural

aspects can influence the formation of TIS building blocks (Kemp et al., 1998; Geels, 2004; Bergek et al., 2008).

Accidents and events

Accidents can refer to accidents within the TIS, such as an accident in production or an accident by a product that fails. Accidents can also refer to accidents outside the TIS, such as wars or natural disasters. Both can have a large impact on several building blocks in a TIS (Kemp et al., 1998; Ortt et al., 2013). Some accidents may also stimulate TIS formation for radically new technological innovations. Terroristic attacks in Europe in the 1980s represent an example of accidents stimulating the development of a radically new telecommunication innovation. The threat of attacks made US civilians reluctant to travel to Europe while, at the same time, a postal strike hampered communication. This coincidence stimulated the emergence of fax machines for B-to-B communication (Coopersmith, 1993).