Development of Innovation System and Role of Entrepreneurs in Context of Heavy Duty Hydrogen Trucks

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Abstract

Today, as the world is experiences the severe effects of climate change, there exists a high demand for sustainable solutions. To achieve the sustainability goals set by the Paris Agreements, a complete decarbonization of the transportation sector is required. This is only possible by achieving carbon neutrality and the zero use of fossil fuels. In the sustainable fuel sector, Green Hydrogen is rising as a potential alternative for fossil fuels. The use of Green Hydrogen has a high potential to drive changes in the logistics sector. Heavy-duty trucks are required to carry shipments over long distances, and we see that electric trucks have disadvantages because of their low charging speed and short travel ranges. In contrast, hydrogen fuel cell trucks have the potential to meet consumers' demands. In the following research, we focus on the innovation system development that takes place due to the arrival of heavy-duty hydrogen trucks in the logistics market. The development of this innovation system study is divided into three parts, the first part is an analysis of the disruptive nature of hydrogen trucks, in the second part we discuss the role of entrepreneurs introducing hydrogen trucks to the market, and the third part discusses the development of hydrogen trucks with relation to the current socio-technical system. Through this analysis the research has contributed framework for innovation system development.

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Contents

Glossary

1. Hydrogen trucks = Heavy duty Hydrogen fuel cell trucks
2. Fossil fuel trucks = Heavy duty Diesel and Gasoline trucks
3. IC engine = internal Combustion Engine
4. FCEV = Fuel Cell Electric Vehicles
5. BEV = Battery Electric Vehicle
6. STS = Social-technical System
7. ST landscape = Socio technical Landscape
8. TCO = Total Cost of Ownership
9. GCM = Gross Combine Mass
10. MLP = Multi-level Perspective
11. Incumbents = Established companies
12. km = Kilometer
13. kWh = Kilo watt hour
14. km/l = kilometer per litre
15. kg = kilogram
16. ct/km = cents per kilometer

List of Tables

List of Figures

Chapter 1

Introduction

Today, in order to achieve the climate goals of the Paris Agreements, transitions in the energy industry require a boost, and Hydrogen fuel as an alternative can make an important contribution in this direction. Over the past few years, there has been an increasing interest in clean energy research all over the world to combat climate change and move towards a more sustainable future. One proposed alternative clean energy source is *Green Hydrogen*. Green Hydrogen is produced through the electrolysis of water, the power required for which is derived from natural sources such as wind and solar energy (Cho, 2021).

In the automotive industry, there is a high volume of research being carried out to reduce carbon emissions. New technologies have led to substantial improvement in environmental efficiency. Environmental efficiency is primarily concerned with increasing production and economic growth while using the least amount of resources and producing the least amount of pollution and waste (Song, Wang, and Liu, 2013). A Environmental efficiency improvement by factor 2 is a general average, but the larger spring in environmental efficiency is possible by 'factor 10' (Geels, 2005). This shift can be accomplished by system innovation in transport systems based on Hydrogen and fuel cells (Smith, Voß, and Grin, 2010; Geels, 2010), which is currently in focus in the automobile industry.

Hydrogen has long been thought to be a necessary component for total *decarbonization* of the trucking industry (H.D.T.Staff, 2020). Hydrogen is abundantly available in the universe but is not present in pure form (Mulder, Perey, and Moraga, 2019). Extracting this abundant fuel and transforming it into useful energy provides a zero emission alternative for fossil fuels. The production of Hydrogen is either by Steam Methane reforming or electrolysis (Mulder, Perey, and Moraga, 2019). Based on the carbon emission during the process of production, Hydrogen is divided into three types. Grey (carbon emission is not captured), Blue (carbon emission captured and stored), and Green Hydrogen (no carbon emission) which is produced by electrolysis. The electricity utilized here is sourced from renewable energy sources such as wind energy and solar energy (Vigna, 2020). Green Hydrogen is the only one of these three kinds that have no carbon footprint.

The road transportation sector has a large impact on the environment. Globally, road freight transportation consumed almost one-fifth of the total oil demand (IEA, 2017) in 2017, as a result, road freight accounts for more than 35% of transportation-related CO_2 emissions. In Europe, according to data provided by European Automobile Manufactures Association (ACEA), road transport sector is responsible for 21.1 % of total EU green house gas emissions. Of this, 5.6% emission is due to heavy-duty trucks (class 7 and class 8) and buses (ACEA, 2020a). Road freight transportation is a cornerstone of the European trade, around 73.1% of freight is carried by trucks (ACEA, 2021). The year 2020 data of EU truck registration shows diesel trucks are dominating market with a market share of 96.5%, and remaining is divided between petrol (0.1%), electrically-chargeable vehicles (0.4%), hybrid electric vehicles (0.1%), and alternatively-powered vehicles (2.9%) (ACEA, 2020b). These figures demonstrate the necessity of the shift to Hydrogen trucks and their widespread adoption.

To analyse diffusion of Hydrogen trucks, this study circles around evolution of innovation systems.

> The aim of the research is to investigate, *the development of the innovation systems that take place due to emergence of disruptive innovations.*

Hekkert and colleagues claim that the innovation system approach comprises particular technical characteristics, individual firm dynamics, and adoption mechanisms (Hekkert et al., 2007). Extending the principles discussed by Hekkert et al., we propose a new framework for this study. The research goal can be accomplished in three sections: the first section analyzes disruptive innovation, the second section emphasizes the importance of entrepreneurs in the development of the innovation system and, since the innovation system involves transition of a socio-technical system (STS), the third section focuses on the development of a STS.

This study report will address the three research questions listed below:

1. *How disruptive would advancement in the Hydrogen fuel cell truck development be for the fossil fuel truck industry? How viable are the Hydrogen trucks concerning the current market?*

2. *What is the role of entrepreneurs in the transition to the socio-technical system of Hydrogen trucks?*

3. *How is the transition of the present socio-technical system to socio-technical system for road transportation by Hydrogen fuel cell trucks expected to take place?*

By studying the aforementioned study themes, we expect to better understand the process of how Hydrogen fuel cell trucks can enter the market and build a new sustainable STS.

Prior research in the field looked at disruptive innovation, entrepreneurship, and technology development through the STS individually. Some researchers had integrated different domains in their study like relations between disruptive innovation and entrepreneurship (Kamolsook, Badir, and Frank, 2019; Walsh, Kirchhoff, and Newbert, 2002; Si et al., 2020), entrepreneurs and STS (Smith, Voß, and Grin, 2010; Gibbs and O'Neill, 2014). The literature on STS mostly uses a Multi-Level Perspective model (MLP). However, that does not give a clear understanding of how technology enters into niche zones or discuss the role of entrepreneurs in system building. Moreover, available literature does not have a model that considers technology emergence and development, the role of entrepreneurship and the transition of STS. The present research aims to fill this gap, by holistically addressing innovation systems to understand roles of product (disruptive technology), processes (transition of STS), and people (role of entrepreneurs or actors) in system development.

The three research questions need to be analyzed keeping in mind their correlations. The first question addresses emergent technology and its innovation type. The second question analyzes business activities based on innovation type. The third question deals with the technological and societal factors changes based on business activities.

The research was carried out in two steps, structured chronologically as the development of the innovation system. First, the development of propositions and conceptual framework through a study and analysis of previous literature, which is facilitated by combining disruptive innovation theory and MLP theory to analyze the development of an innovation system. Second, the formed propositions are discussed using a case study approach, which could validate the conceptual framework. Finally, we conclude the research with discussions, conclusion, suggestions for the case, limitations, and future directions.

Chapter 2

Literature Review

Innovation system is a transformation of existing supply chain networks, driving radical change in infrastructure, forming new laws, resulting in changes in utilization methods and consumption behaviors, and other socio-technical systems that offer basic services like energy and mobility (Smith, Voß, and Grin, 2010). The research of Frank Geels cited four phases of innovation through which technological developments occur. In phase one, novel technologies emerge from outsiders such as independent inventors or research institutions. The second phase arrives when the inventions are introduced in a niche market. The third phase is the breakthrough of new technology, large-scale diffusion and competition with the established regime. The fourth phase is gradual displacement of the established regime with a wider impact on society (Geels, 2005).The focus of the literature review is on three aspects of innovation evolution process: technological innovation (i.e. disruptive innovation), entrepreneur's role, and the socio-technical system.

During system innovation, disruption occurs on a larger scale (Smith, Voß, and Grin, 2010). The word *"disruption"* refers to a process in which smaller firms with fewer resources can compete effectively against incumbents (C. Christensen, Raynor, and McDonald, 2015). The most prevalent misconception is that disruption is an event, whereas in fact, it is a process (C.M. Christensen, Anthony, and Roth, 2004) that takes years to replace old technology with new technology (G. Clark, 2003). Furthermore, Christensen et al. cited that, "The term disruptive innovation is misleading when it is used to refer to a product or service at one fixed point, rather than to the evolution of that product or service over time" (C. Christensen, Raynor, and McDonald, 2015). The disruption is not a technological characteristic either, but it is more to do with the company's strategy to deploy or respond to the novel technology (C.M. Christensen, 2006). Walsh et al. define disruptive innovation based on business strategy, stating, "the disruptive technologies are those that do not support current firm-based manufacturing practices," (Walsh, Kirchhoff, and Newbert, 2002). One reason for this could be a knowledge barrier, the workforce could not cope with the new technology (C.M. Christensen, 2006, Si et al., 2020). In such a scenario, incumbents reject the new technologies in order to avoid major changes in their business, whereas disruptors are more concerned with perfecting their business strategy than with perfecting their goods (C. Christensen, Raynor, and McDonald, 2015). Disruptive innovation occurs when there is a technology discontinuity, and a majority of the time, they appear outside of the current technological basis (Utterback, 2004). If the market lies outside of incumbents serving vicinity, they fail to recognize the disruptive nature of the new product (G. Clark, 2003). The outsiders, like independent inventors, research institutes, and startup firms, are essential in the development of radical new ideas and niches (Geels, 2010). New actors are more flexible than incumbents in adopting new technology and exploiting them in the market. Emergent technologies may be a sustaining or disruptive innovation. Innovations that come into the market with a goal of performance improvement are referred to as sustaining innovations (C.M. Christensen, 2013), whereas disruptive innovations focus on defining new performance trajectories by introducing technologies inferior to established technology (C. Christensen and Raynor, 2013). For further growth of the innovations, distinct activities have to be performed for both circumstances, hence it is important to discern between the type of innovations (Hüsig, Hipp, and Dowling, 2005). The transition of one STS to another chooses the path according to the circumstance.

Disruptive innovations either emerge at a low-end market or create a new market (C. Christensen, Raynor, and McDonald, 2015). Low end markets develop when present products or services are comparatively better and expensive in relation to the value existing consumers can utilize, therefore buyers are prepared to pay a lower price for a lesser (but adequate) offering (C.M. Christensen, Anthony, and Roth, 2004). Based on the market type Christensen and Raynor proposed two types of disruptive innovations, low-end disruption; those that are cost-competitive innovations, and new-market disruption; those that create a new market to serve non-consumers (C. Christensen and Raynor, 2013). This distinction is essential for the entrepreneurs aiming to start new firms (C. Christensen and Raynor, 2013) because it suggests a potential market to introduce new products. According to Christensen's original definition, disruptive technologies are less expensive, simpler, smaller, and more convenient to use (C.M. Christensen, 2013). However, this is not always the case, the disruptive technologies are also more expensive than the current technologies, but often offer extra performance benefits (Reinhardt and Gurtner, 2015). Most of the time, the expensive products fail to attract many customers, but further development makes disruptive innovations affordable for large customer groups (C.M. Christensen, Anthony, and Roth, 2004, C. Christensen and Raynor, 2013).

The rationale and remedies for incumbents' failure were also emphasized in the previous disruptive innovation literature. Most established firms create and market sustaining or incremental technologies, which are the outcomes of their mainstream consumers' need for next-generation performance (Bower and C.M. Christensen, 1995). Due to sustaining innovations occurring frequently, incumbents try to use the same business strategy for disruptive innovations and try to sell to their established customers (C. Christensen and Raynor, 2013). The pioneer of disruptive innovation considered three main factors to explain incumbents' failure. Firstly, analyzing sustaining and disruptive natures of novel technology, secondly, the development of technology beyond the market demand and finally, their interpretation of financially unattractive decisions (C.M. Christensen, 2013). Incumbents find the disruptive innovations unattractive due to low revenue generation through sale of products that could not satisfy their growth requirements (Bower and C.M. Christensen, 1995; C.M. Christensen, McDonald, et al., 2018).

Disruptive innovations are defined by some set characteristics that can be observed in most of the disruptive products. Disruptive innovations are viewed as an inferior by the majority of incumbents' customers, at first (C. Christensen, Raynor, and McDonald, 2015, Hüsig, Hipp, and Dowling, 2005). Therefore they start growing in a niche market (Thomond and Lettice, 2002), where incumbents do not provide much attention. When the performance of disruptive innovations meet mainstream customers' demand, entrant businesses assault the established market, leaving incumbents with little choice but to play a defensive role (Bower and C.M. Christensen, 1995). As established market customers start to adopt innovation in large numbers, the disruption of market occurs (C. Christensen, Raynor, and McDonald, 2015). Incumbents who analyze the disruptive nature of the new technologies become successful in gaining market share and those that ignore these technologies fail to sustain their position (Nair and Ahlstrom, 2003,Si et al., 2020). It is not easy for established companies to focus on both types of innovations in a single organization (Paap and Katz, 2004). This is a conundrum for the incumbents: it is difficult to manage sustaining and disruptive innovations in a single firm because disruptive innovations require new business activities that conflict with existing business strategies which are based on sustaining innovations (Markides, 2006). This can be illustrated by a example of P&G (Procter Gamble). P&G was able to introduce some interesting and remarkable goods, it did so at expense of its established brands, losing significant market share to aggressive competitors (Paap and Katz, 2004). This threat of losing market share insists incumbents to take a step off from introducing new technology. Thus, innovation becomes disruptive to incumbents (Markides, 2006).

Disruption is dependent not just on breakthrough technology but also on creative business models (C. Christensen, Raynor, and McDonald, 2015). Entrepreneurs are actors who assist in introducing new products into the market. Therefore the role of entrepreneurs is highly important in development of disruptive innovations and establishing the STS. Second section of this literature review addresses the role of entrepreneurs in radical or disruptive innovation growth. Entrepreneurs are primarily active in bringing novel inventions (radical innovations) to the market, whereas incumbents use mass manufacturing and intense marketing to bring sustainable innovations to the mainstream market (Bodde, 2004). The entrepreneurs often utilize business strategies different from the traditional business model (incumbents' business model) (C. Christensen, Raynor, and McDonald, 2015). One of the most essential responsibilities for an entrepreneur is to identify and evaluate opportunities (Byers et al., 2011). For incumbents, it is challenging to anticipate the disruptive nature of emerging technologies because of limited or no data available to forecast the future, which leads to misinterpretation and oversimplification (Jr and Goh, 2009). The firms need an entrepreneurial mindset which perceives business and its opportunities differently, allowing them to take benefit of uncertainties (Hitt et al., 2002). The entrepreneurs identify opportunities based on market needs, socil trend and emerging technology(Byers et al., 2011). Emergent technologies create opportunities for new firms as well as established incumbents (Woolley, 2014). Entrepreneurs should not just recognize good opportunities, as claimed by John Mullins, they also have to define the market i.e. mainstream or niche (Mullins, 2017). Some discontinuities open up completely new market sectors, attracting a slew of new entrants. Here, established businesses are unlikely to participate successfully, and new businesses have a higher survival rate (Utterback, 2004). Usually entrepreneurs and outsiders foster and develop radical innovations in the niches without being noticed by incumbent regime actors (Gibbs and O'Neill, 2014). Acceptance in niche markets encourages additional investments in a product, service, or business approach for further performance development (Thomond and Lettice, 2002). In the industries like automotive sector, competitive landscape not only transforming in terms of technology but also in terms of business strategy and markets (Teece, 2018). Business model innovation allow entrants to offer their product effectively and at reduced prices (C.M. Christensen, Anthony, and Roth, 2004). Entrant firms could gain a competitive advantage in manufacturing costs and experience as a result of their early entry in to the industry (Hüsig, Hipp, and Dowling, 2005). But, if the innovation is sustaining to the business strategy of established firms, then it is hard to achieve success for entrant firms (C. Christensen and Raynor, 2013). Markides claimed that the successful firm not only time their entry into the market, but also deliver appropriate sequence of actions to develop from the niche market into mainstream market (Markides, 2006). In addition, taking reference of Jennings et al., 2013, Gibbs and O'Neill, 2014 stated, "Entrepreneurs may act as system builders by carrying ideas from one field (or niche) to another (regime)." The entrepreneurial actions may includes opportunities recognition, allocation of resources (Byers et al., 2011), finding niche markets, and improvement in the product to carry technology from niche to regime. This leads to STS transition.

The emergence of innovations disrupts existing established systems and builds a new system. This technology change will affect society as a whole. Changes in elements such as user habits, legislation, industrial networks, infrastructure, and symbolic meaning are all part of the technology transition process (Geels, 2002) and is labelled as socio-technical system. Frank Geels defined STS as, "At the level of societal functions, a range of elements are linked together to achieve functionality, for example, technology, regulation, user practices and markets, cultural meaning, infrastructure, maintenance networks and production systems. This cluster of elements is called a socio-technical system," (Geels, 2005). In an STS, three levels of aggregation are distinguished, see figure 2.1 (adapted from Rip and Kemp, 1998; Rip and Groen, 2001). The first level is where an innovation is introduced as a novel combination that functions in a certain way, hydrogen trucks being studied here could be seen as still being on this level of introduction to the system . Then, usually after a first adaptation and some early adoption, it moves up to the level of regimes, which work parallel in the market. Studied here, the hybrid and battery electric vehicles are playing a role next to each other, and next to the combustion engine vehicle (diesel, petrol, LPG), which is on the third level as a dominant technology and stable part of the ST landscape in all its forms. Many actors in many places use this technology, hence many visible hands are involved in the process (Rip and Groen, 2001).

Niches is the first level of MLP, and are also crucial for the understanding of diffusion process (Geels 2005), where disruptive or radical innovations initially emerge. As earlier mentioned, niches form protective space for innovation developments (Rip and Kemp, 1998). The outsiders and entrepreneurs introduce and develop disruptive or radical innovation in a niche market, where their business is not involved in competition with es-

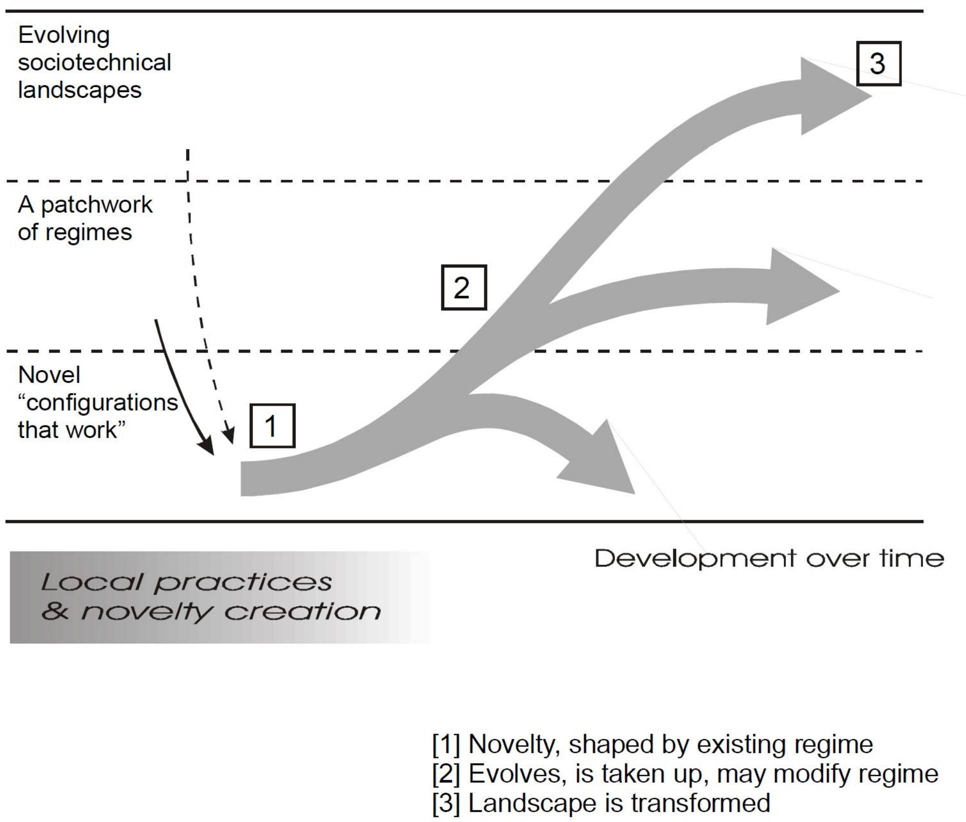

Figure 2.1: Dynamics of Socio-technical system

tablished firms (Geels, 2010). Schot and Geels (2007) differentiate between market niche and technological niche. Market niche is lie outside the existing market (fringe market), that is not served by mainstream firms, whereas technological niches provide necessary protection during the development of innovations(Schot and Geels, 2007). Thus, niche is a *Trivium* [1] in the innovation system that is based on disruptive innovations where three domains intersect.

Regimes serve as a link between innovations and the wider socio-technical context in which they are conceived, developed, and implemented (Rip and Kemp, 1998). When niche technologies enter into the regime, they co-exist with previous technology for a long time until that previous tech-

[1] The word Trivium came from Latin, etymologically it refers to the point where three roads meet https://www.merriam-webster.com/dictionary/trivium.

nology is completely supplanted (Geels, 2005). The outsider groups have a major impact on the regime, they may not be present from the beginning of the innovation but enter gradually into a socio-technical system to respond to negative effects (Geels, 2007). Van De Poel, 2000, mentioned by Geels, 2007 , discusses three outsider groups that have an impact on the regime level- (1) Societal groups who put pressure on policymakers by protesting, (2) Scientists and engineers that previously were not a part of innovation, (3) new firms and entrepreneurs who enter from outside. However, early actors are focused on the technical aspect of the innovations, while the actors who join late are involved in improving quality, reducing price, and make changes in the performance of the product that could result in the product being affordable for larger customer segments (Markides, 2006). The socio-technical landscape is the third phase of technology transition in MPL. It is a macrostructure where niches and regimes are located (Smith, Voß, and Grin, 2010). The changes in the landscape can be slow, gradual or rapid (Geels, 2005). Slow changes could be caused by climate change, political ideologies, demographic change and culture, whereas rapid changes can arise from war, oil prices, economic depression (Geels, 2005), and a pandemic (for example, COVID-19). However these rapid changes have short-term effects and the system can recover through quick responses from regime actors. The technological regime is more stable, it confronts the entry of niche market innovation (Geels, 2004). When landscape changes create contrasts between societal group and regime, they form a 'window of opportunity' for innovation to emerge from the niche (Geels, 2004; Geels, 2010). Therefore, to generate new STS, the interactions between these three layers need significant modifications.

Increasing concerns about climate change are pressuring the automobile industry to create zero-carbon cars such as BEVs and FCEVs. However, the necessary supporting infrastructure for the deployment of BEVs and FCEVs has yet to be developed. As a result, an innovative business strategy is required to enable the dissemination of zero-carbon cars in order to accomplish complete decarbonization in the transportation sector.

Chapter 3

Propositions and Conceptual Framework

3.1 Forming Propositions

The arguments are based on a review of the literature. They discuss the route of innovation, the role of entrepreneurs, and the impact of the STS elements on the technology shift.

Table 3.1: Table of Propositions

Innovation System		**Propositions**	**Relevant Papers**
Technological Domain	Disruptive innovations	*P1: The development of the innovation system is path dependent on the nature of the innovation.* *P2: The disruptive technology emerges from outside of the technological domain.*	Bower, Christensen (1995), Thomond, Lettice (2002), Walsh, Kirchhoff et al. (2002), Clark, G. (2003), Christensen et al. (2004), Utterback, (2004), Paap and Katz (2004), Dyerson, Pilkington (2005), Hüsig, Hipp et al. (2005), Christensen (2006), Lucas Jr, Goh (2009), Klenner, Hüsig et al. (2013), Christensen (2013), Gibbs, O'Neill (2014), Christensen, C. M., Raynor, M. E., and McDonald R. (2015), Reinhardt, Gurtner (2015), Christensen, McDonald et al. (2018), Si, Chen (2020)

Entrepreneurial Domain	Opportunity Recognition	*P3: Entrepreneurs seek opportunities when they are simultaneously involved in social trends, market need and technological innovations.*	Hitt, Ireland et al. (2002), Markides (2006)
	Business Model Innovations	*P4: Entrepreneurs are system builders with a distinct business model, who incorporate innovation into niche.*	Walsh, Kirchhoff et al. (2002), , Lucas and Goh (2009), Byeers, Dorf et al. (2011), Mangram (2012), Gibbs, O'Neill (2014), Woolley (2014), Stringham, Miller et al. (2015), Hettich, Müller-Stewens (2017), Teece (2018) Lau Shipley (2020)
Socio-technical Domain	Niches	*P5: Niches are a Trivium that brings together innovations, entrepreneurs, and socio-technical systems.*	Rip, Kemp (1998), Geels (2002), Geels (2004), Geels (2005), Dyerson, Pilkington (2005), Geels (2007), Shove, Walker (2007), Schot, Geels (2007), Smith, Voß et al. (2010), Geels (2010), Geels (2011), Gibbs, O'Neill (2014)
	Technological regime	*P6: The current network facilitates the transfer of innovation from niche to regime.*	
	ST-landscape	*P7: The landscape pressure creates a window of an opportunity, not only at the regime level but also in the niche.*	
	Gray Zone (threats and opportunity for incumbents)	*P8: The Grey Zone is a dilemma that incumbents confront in the innovation system when determining whether to invest in disruptive innovation or current technology.*	(relevant papers referred in first row)

3.2 Development of Conceptual Framework

The development of this conceptual framework is based on previous works literature. The theory on disruptive innovation suggests that disruptive technology first appears in niche markets, whereas the literature on 'strategy of entrepreneurs' to introduce radical or disruptive innovations places emphasis on the importance of finding niche spaces to grow their business in the outsight of incumbents. On the other hand, theoretically, STS showed advancement of radical innovations from niches. In all three literature, niche is present as a common factor that is demonstrated in the Venn diagram (Figure 3.1).

Technological development and entrepreneurs are involved in the growth of STS. This creates a complex structure that is difficult to analyze. To facilitate ease of analysis, the structure is divided into three areas under the framework: (a) Technological domain, (b) Entrepreneurial domain, and (c) Socio-technical domain.

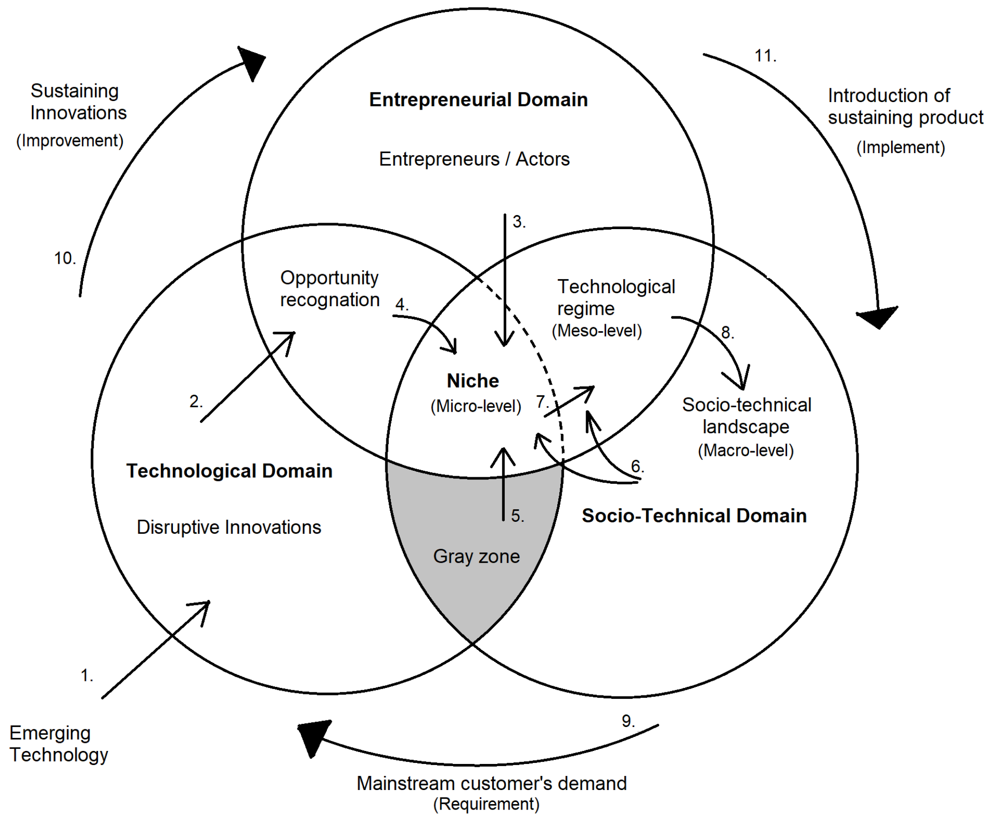

Figure 3.1: Development path of Innovation System

The framework (Figure 3.1) depicts the phases of the innovation system's evolution, from the emergence of innovation, through its dispersion into the socio-technical system. These phases include emergence of disruptive innovation, opportunity recognition, introduction of disruptive innovation into niche by entrant or incumbents, development of disruptive innovation in regime, and stabilization of disruptive innovation into landscape. The arrows in the Venn diagram indicate the path traced by the disruptive technologies during the development of the system and the interconnections between the three domains.

1. Disruptive innovation arrived from an outside technology base.

2. Entrepreneurs identify the growth opportunity in disruptive innovation.

3. Entrepreneurs locate niche markets, if a niche market is not present they set up a new market (New-Market disruption).

4. Entrepreneurs introduce disruptive innovation into a niche market (Micro level).

5. If incumbents perceive the future potential of the disruptive innovation, they introduce their product into the niche market.

6. The threat posed by the socio-technical landscape pressurizes the regime as well as niche actors to bring radical changes into STS (creation of Window of Opportunity).

7. When disruptive innovation matures enough to compete with established technology, the innovation breaks out into a technological regime (Meso level) by attracting mainstream customers (Disruption takes place).

8. The development of disruptive innovation gradually displaces existing technology and eventually stabilizes into the socio-technical landscape (Macro level).

If emerging innovations are sustaining, they do not follow the same path as disruptive innovations. Since analysis of sustaining innovation is not the scope of this research, it is assumed to trace the path shown by cycle- Requirement, Improvement, and Implement (Arrows no. 9,10, and 11), as showed in figure 3.1. The improvement in sustaining innovations is mainstream customers' demand-oriented.

9. Requirement: The mainstream customers demand performance improvement (Socio-Technical domain).

10. Improvement: The product development takes place as per customer requirements (Technological domain).

11. Implement: Managers (actors) introduce developed product to mainstream market at a specific time (Entrepreneurial domain).

The 'Technological domain' refers to the existing technology space where all technology related deeds occur, such as the emergence of new technology, sustaining or disruptive, and further development of this technology to satisfy the requirement of the customers. According to theory, disruptive inventions are said to originate from outside the present technical foundation, the outsiders such as individual inventors, research institutes, and universities assist in bringing innovations in the technological domain, whereas sustaining innovations, most of the time, emerge from inside the technological domain and changes introduced by the insiders, like research organizations in established companies. Insiders or outsiders, the innovations are always dedicated to solving societal issues. For our selected case, the technological domain refers to the current fossil fuel automotive industry. The distinction between insiders and outsiders has been established based on the firms' relationship to the automotive industry.

The second domain is labelled as 'Entrepreneurial domain.' This includes the initial actors in technological transition. The domain refers to the actors directly involved in innovation development process, such as entrepreneurs and firm managers. They identify growth opportunities in disruptive innovation and apply appropriate actions to bring these innovations to the market. Their actions include finding the market, sales strategy, and facilitating continuous improvement in technology. The entrepreneurial domain describes the role of entrepreneurs in system development. The entrepreneurial domain intersects with the other two domains at the opportunity recognition phase, and the niche and technological regime, respectively, as in the Venn diagram (Figure 3.1).

The 'Socio-Technical domain' is the third sphere in the Venn diagram. It includes the development of innovation from niche level to technological regime and further to the socio-technical landscape. In this domain, multiple actors are involved to work on a specific goal. New and old entrepreneurs, technology developers, policymakers, influencers (they put pressure on regime actors for rapid development, for example, protesters), these people take actions to drive landscape pressures. They also help to breakout niche market disruptive innovations to regime and gradually supersede the established innovation market. As the discontinuous line between niche and regime shows, these boundaries are less obvious experimentally (Smith, Voß, and Grin, 2010).

The Gray Zone is an intersection of the technology domain and socio-technical domain. We labelled it as a Gray zone in the system development process due to its uncertainty. The shaded region is a dilemma for incumbents where they either identify disruptive innovation or fail to catch the opportunity. If incumbents act on disruptive innovation, they introduce innovation into a niche market as presented by arrow no. 5, gray zone to niche (Figure 3.1).

Chapter 4

Methodology

The research is divided into two sections: the first portion develops a conceptual framework using existing literature, and the second part uses the framework to answer the research questions. The goal is to examine the evolution of the innovation system as a result of the rise of disruptive innovation, which may be accomplished through a case study.

The single case qualitative analysis (Dul and Hak, 2007) is selected to analyze the research questions. The case study method is utilised because this study is based on real-life events (Yin, 2009). The innovation system is not a short time process, it requires years to disrupt one technology and create a new socio-technical system. Therefore, this research is focused on an *ex ante* analysis to discuss the possible outcomes based on the available theories and literature.

The case study is a time consuming method (Geels, 2005). Sufficient subject related data needs to be collected through various sources. The collected information here is mainly based on secondary sources. The research utilizes this selected case data as well as other related information to answer the research questions. The selected case for our research, a start-up in the Hydrogen trucks sector i.e. Hyzon Motors Europe, is a joint venture of Hyzon Motors and Holthausen clean energy. Hyzon motors builds Hydrogen trucks for the heavy vehicle transportation market. All available Hydrogen trucks are in their demonstration phase. We chose Hyzon because Hyzon's Hydrogen trucks are mature enough to enter into the market.

The analysis of the first research question involves finding out key characteristics of disruptive technology, this would be realized through the literature survey on previous disruptive technologies and an analysis on whether Hydrogen fuel cell trucks correspond to these characteristics. A similar approach can be observed in work of C. Christensen, Raynor, and McDonald, 2015, with the analysis of the disruptive nature of the Uber taxi model. The first question can be answered using data about Hydrogen trucks (technical specifications) that has been collected from Hyzon Motors' official web page and other published web articles.

Second question deals with the role of entrepreneurs in innovation system development. Since Hyzon is already an entrant in the market, it will be helpful in analyzing the strategy of the firm and the role of the entrepreneurs at the micro-level. For this analysis, data is collected from a few secondary sources, such as media reports, press releases from Hyzon and Holthausen, press interviews, podcasts, and published news articles.

The first two sections discuss base elements of system innovation i.e technology and entrepreneurs, whereas the third section of research relates to the development of the STS. This question is analyzed through a study of data collected from secondary sources about the selected case, government plans, and ongoing activities in the energy industry regarding Hydrogen fuel. Required additional information is also compiled from various sources. The most common method used to analyze development of a radical technology is MLP theory. MLP is most commonly used in the investigation of radical innovations that replace current STS (Geels, 2007). Because radical and disruptive innovations have similar features, such as first appearing in a niche market and subsequently replacing current technologies, we have considered this technique for the examination of disruptive innovation development. Data collection from various sources for the purpose of this analysis is summarized in the table 4.1.

Source type	**Number of Sources**	**Sources**
Companies' official webpages	6	Tesla Motors, DAF Trucks, Ballard Power Systems, Hyundai Motors, Volvo Trucks, Horizon- Fuel Cell Technology
Web articles, Blog posts	18	energypost.eu, itstillruns.com, Climate & Capital media, Reuters, NRDC: The Natural Resources Defense Council, Utility Dive, Logo Agro & Chemistry: About Biobased Business in a Circular World, H2 View, deVolkskrant (in Dutch), FreightWaves, electrive.com: industry service for electric mobility, Economie Groningen (in Dutch), Clean Technica, Bobit Business Media: Heavy Duty Trucking, Fuel Cells Works, MotorAsk.com, ActNews NU.nl, Vliegende start voor Hyzon (in Dutch), Transport Dive, Tech Crunch
News channels interviews	3	CNBC Television, Cheddar News, AusBiz TV
Podcast	1	Outrage + Optimism
YouTube channels (interviews)	2	FreightWaves, Knext Energy
Research reports	2	Deloitte China 2020, Hydrogen Roadmap Europe, Outlook for a Dutch Hydrogen market, The green Hydrogen economy in the Northern Netherlands
Organizations webpage	4	European Union (ec.europa.eu), NortH2 Consortium, Columbia Climate School, International Energy Agency (IEA)

Table 4.1: Summery of data collection

Chapter 5

Case Study Analysis

5.1 Background

Research in the generation and utilization of Green Hydrogen energy across multiple industries has been carried out in the Northern Netherlands. This case study, focusing on the use of Green Hydrogen in the logistics industry, has been carried out on Hyzon Motors Europe B.V, which is a joint venture by Hyzon and Holthausen Clean Technology B.V, for the commercial production of Hydrogen-powered trucks for the European as well as international markets. Hyzon Motors has announced its European headquarters in the Dutch province of Groningen. In their partnership, Holthausen Clean Technology B.V. will work on the production of Hydrogen FCEVs (Editorial Office, 2020),whereas Hyzon works on fuel cell power trains. Since the formation of this joint venture, Hyzon Motors Europe is a new entrant in the transportation sector, therefore this case could give more insights into the study of emerging technology, the role of entrepreneurs in diffusion of this technology into the market, and their strategic alliances that support the development of the Socio-Technical system.

5.2 Case Study Analysis

5.2.1 Technological Domain

Emergence of Hydrogen Trucks

The established technology, IC (Internal Combustion) engine vehicles have locked-in in the current transportation environment (Klitkou et al., 2015). This opposes the entry of fuel cell technology in the current market. Hyzon Motors, a Horizon fuel cell technology spin-off business, is developing and bringing Hydrogen trucks to market. Since they were not initially involved in the fossil fuel automotive industry, they might be considered outsiders. However, the established incumbents in automotive industry, such as Daimler AG and Ford Motor Company have been developing fuel cell vehicles in collaboration with Ballard Power Systems (Wert, 2007). Hyundai Motor Company is also introducing Hydrogen trucks throughout Europe (Eckert and Revill, 2021). Such insiders are also looking at developing and marketing Hydrogen trucks. In Hydrogen trucks development, both insiders and outsiders are now involved and working towards a common goal, 'Decarbonization.'

Analyzing Disruptive nature of Hydrogen Trucks

It is necessary for Hyzon and the incumbents to recognize the disruptive potential of the Hydrogen trucks. Because disruptive innovations have a distinct other dissemination route than sustaining innovations, and both demand different business activities. Before launching developments into the market, entrepreneurs must first decide the sort of innovation. The table 5.1 shows the analogy between technical specifications of trucks equipped with different power generation units that helps to analyze superior and inferior technology.

The primary motivation for the shift is to reduce the amount of carbon in the transportation sector. Over battery trucks, Hydrogen trucks are gaining traction as a promising alternative for fossil fuel trucks. Hydrogen trucks outfitted with fuel cells are powered by electricity (*Mad Money*, 2021) and as a result, they may have certain qualities that are comparable to those seen in battery-electric cars, like Tesla cars (Shipley, 2020), Hydrogen trucks can integrate with software, where performance issues would diagnose through dedicated software and can be designed for driverless transportation. Hyzon motors looking forward to making Hydrogen trucks autonomous for the port (seaports, airports) operations where trucks work within a confined region in fixed routines (Hyzon Motors, 2021h).

The major issue in customer adoption of Hydrogen trucks is their price. Hydrogen trucks cost at least three times more expensive than diesel trucks, the diesel trucks usually cost around 130,000 euros (Geijp, 2021). Compare to Fossil fuel trucks, Hydrogen tanks occupy more space (Thomas, 2009) and have very little fuel storage and range (Table 5.1) On the other hand, battery trucks could be less expensive (Tesla announced its battery trucks cost around 130,000-150,000 euros (*Tesla Semi*, n.d.)) but it led to a compromise of freight load. Heavy-duty battery-powered trucks have limitations on the weight that can be carried because long-range requires larger and heavier batteries (Thomas, 2009). This added weight decreases the pay-

Specifications	**Hydrogen truck**	**Fossil fuel truck**	**Battery electric truck**
Power generation unit	Fuel cell	IC Engine	Battery pack
Fuel	Hydrogen	Fossil fuel (Diesel or gasoline)	Electricity
Exhaust	Water	Green house gasses	No emission
Fuel Storage	Hydrogen tank	Diesel/gasoline tank	Battery pack
Refilling time	Less than 15 min (Molloy, 2019)	10 min (Deloitte-Ballard, 2020)	30 min charging for range ~ 600 km
Energy density	33.6 kWh/kg (Molloy, 2019)	12-14 kWh/kg (Molloy, 2019)	260 Wh/kg (Tesla Li-ion battery pack) (Reuters Staff, 2020b)
Fuel storage	up to 50 kg (Hyzon Motors, 2021b)	300 Gallon (1135.6 litre) (Andrews, 2021)	180-540 kWh, 2-6 batteries (*Volvo FM Electric truck*, 2021)
Range	400-600 Km for GCM 50 tonnes (Hyzon Motors, 2021c)	975–1950 miles (Cunanan et al., 2021)	Upto 300 km for GCM 44 tonnes (*Volvo FM Electric truck*, 2021)
Truck price	estimated 442,000 euro (Oostdam, 2019)	~ 130,000 euro (Geijp, 2021)	216,00 euro (Transport & Environment, 2020)
Fuel consumption	6-8 kg/100 km (12.5 km/kg H2) (Hyzon Motors, 2021b)	6.5 mpg (~3 km/l) (Cunanan et al., 2021; Schoettle, Sivak, and Tunnell, 2016)	0.5 km/kWh (Cunanan et al., 2021; Kalghatgi, 2018
Price per km	80 ct/km	50 ct/km	37 ct/km

Table 5.1: Analogy between the Hydrogen trucks, fossil fuel trucks, and battery electric trucks

load (Climate & Capital team, 2020). The same is illustrated further, for a class 8 heavy-duty truck required to carry 7-8 tons of batteries for the traveling range of 500 miles (805 km). Whereas, Hydrogen-fuel cells weigh about 70-80 kg allowing better performance and a significant increase in vehicle weight for the same range without compromising on carrying additional load (Climate & Capital team, 2020). The Hydrogen truck owners can take advantage of this extra volume and less weight over battery trucks to add more cargo and store more Hydrogen for long hauls.

Gary M. Robb, HYZON's co-founder and chief technology officer *cited the same, "HYZON's approach reduces power-train mass and volume for given power output. This available mass and volume can be used for additional payload and Hydrogen storage allowing our customers to transport more goods further,"* (Climate & Capital team, 2020)

Hydrogen trucks are inferior to fossil fuel trucks but have superior qualities in comparison with battery trucks.

Given that various technologies employ different energy sources, the fuel performance should be addressed as well. IC engines provide power to trucks through the combustion of fossil fuels (diesel or gasoline), batteries store electricity and utilize this energy to drive the motors while trucks are functioning, and fuel cells utilize Hydrogen to generate electricity to drive motors that induce motion in trucks. The energy density [1] of Hydrogen is measured at 33.6 kWh/kg which is three times that of diesel i.e. 12-14 kWh/kg (Molloy, 2019), this means 1 kg of Hydrogen is enough to produce energy approximately the same as the energy of 1-gallon diesel (Molloy, 2019). Whereas Lithium-Ion batteries that Tesla implemented on Model 3 have an energy density of around 260 Wh/kg which is way lower than the other two (Reuters Staff, 2020b). But the drawback of the utilization of Hydrogen gas is its price, which is currently higher than fossil fuel. At the moment (August 2021) green Hydrogen is available in Netherlands priced at about 10 euro/kg (incl VAT). For transport or distribution trucks the consumption of Hydrogen could be vary between 6-8 kg of Hydrogen per 100 km (Hyzon Motors, 2021b). This gives cost of driving Hydrogen trucks is about 80 ct/km, whereas the cost of diesel in Netherlands is 1.461 euro/l [2] that provides freight operations at 50 ct/km which is almost half the price of driving a Hydrogen truck per km.

Although fossil fuel trucks are better in terms of performance, periodic maintenance is essential to avoid wear and failure of mechanical parts, which is expensive compared to battery and Hydrogen trucks. Periodic oil changing costs $\sim$ 5000 euro (5600 USD) per year (Fleet Equipment Staff, 2020) excluding other service costs. Tesla users pay less on maintenance because there are fewer moving parts in their propulsion system, activities such as engine oil change, expensive maintenance for mechanical components longevity are not essential (Hettich and Müller-Stewens, 2017; Shipley, 2020). Same applies to Hydrogen trucks, there is a decline of maintenance cost by

[1]The amount of energy that stored in a given mass of a substance or system is known as energy density. J.M.K.C. Donev et al. (2018). Energy Education - Energy density [Online]. Available: https://energyeducation.ca/encyclopedia/Energy$_density$.)

[2]Price available from https://www.globalpetrolprices.com/Netherlands/diesel$_{\$}prices/$

40% as compared to fossil fuel trucks (Geijp, 2021). The study conducted by Deloitte-Ballard on fuel cell drayage trucks claimed that there will be a decline in Total Cost of Ownership (TCO) over the next 10 years (Deloitte-Ballard, 2020).

The production and service of Hydrogen trucks are dissimilar to fossil fuel trucks. The propulsion system for Hydrogen trucks involve Hydrogen tanks, fuel cell, battery (for additional power supply), power control units (PCU), and electric motors. If incumbents are willing to replace their old technology with disruptive technology, *they have to change manufacturing units* to make them suitable for Hydrogen trucks production.

These characteristics exhibit that Hydrogen trucks can rise as a disruptive technology against fossil fuel trucks and also prove to be a dominant competitor for battery trucks. The disruption does not only depend on the features of the product, it also counts on the activities of entrepreneurs to introduce it in the appropriate market. In other words, disruption is not an event but it's a series of events initiated by industrial actors at each stage of system innovation. The disruptive nature of the Hydrogen trucks is summarised in the table 5.2.

Table 5.2: Analysis of Disruptive innovation

Sl. No.	Characteristics	Hydrogen Fuel Cell Trucks	Condition Satisfied
1	New market Innovation (G. Clark, 2003;C. Christensen, Raynor, and McDonald, 2015;Nagy, Schuessler, and Dubinsky, 2016)	Hydrogen trucks require Hydrogen infrastructure	Yes
2	New innovation is cost competitive (C.M. Christensen, 2013)	Hydrogen trucks costs at least three times more than diesel trucks, whereas Hydrogen gas is twice as expensive as diesel.	No
3	Compact in size (C.M. Christensen, 2013)	It can not be determined because even though the size of the IC engine is smaller than the Hydrogen tank and fuel stack unit, it does not affect truck size.	Undetermined

4	Elementary technology (C.M. Christensen, 2013)	Hydrogen trucks drive train has fewer mechanical parts. Equipped with an electric motor, fuel cell, Hydrogen tank, and small lithium battery for additional power supply during high power utilization. The fuel cell which is the core of the Hydrogen trucks has no moving parts, as it works on a chemical reaction.	Yes
5	More convenient to use (Klenner, Hüsig, and Dowling, 2013)	• Hydrogen trucks do not require gear shifts, that makes driving effortless (Hyzon Motors, 2021b) • The fueling of Hydrogen trucks is similar to fossil fuel trucks which is more convenient (and time-saving) for customers.	Yes
6	High cost but having additional performance attributes (Reinhardt and Gurtner, 2015)	• Zero carbon emission: Hydrogen trucks emit water vapors rather than greenhouse gases. • Hydrogen trucks provide a noiseless driving experience (Hyzon Motors, 2021b) because the transformation of Hydrogen to electricity is a chemical process, hence fuel cells do not produce knocking sound which is usually observed in IC engines due to improper air-fuel mixture. • Maintenance of Hydrogen trucks costs 40% less than a conventional vehicle (Geijp, 2021). Because of fewer mechanical parts, frictional losses are much less than fossil fuel trucks. This reduces the TCO of Hydrogen trucks. • Through integration with software, the performance can be analyzed over the internet (Outrage+Optimism Podcast, 2020)	Yes

7	Innovation emerges in a niche market (Reinhardt and Gurtner, 2015;Hüsig, Hipp, and Dowling, 2005;Gibbs and O'Neill, 2014)	Hydrogen trucks have the opportunity to develop into a zero-carbon emission heavy-duty transportation segment where battery trucks can not do well. But due to infrastructure drawback Hydrogen trucks can be potentially grown in small geographical regions where trucks are not involved in cross-boundary applications and customers those have 'back to base' operations.	Yes
8	Emerging markets grow outside the existing resource base (G. Clark, 2003)	The Green Hydrogen market is independent and has no connection with the oil industry, therefore it requires a radical change in existing infrastructure.	Yes
9	Inferior performance than current technology (C.M. Christensen, 2006; Hüsig, Hipp, and Dowling, 2005;C.M. Christensen, 2013;)	The Hydrogen trucks have lower range and smaller fuel storage than fossil fuel trucks (Table 5.1). The unavailability of infrastructure, high fuel price make them unattractive for mainstream customers	Yes
10	New technology impacts the production line (Walsh, Kirchhoff, and Newbert, 2002)	Hydrogen trucks' production line is not as complex as fossil fuel trucks. Due to countable parts in the propulsion system, most of the production operations have to reduce which may lead to sunk cost therefore disruptive technology challenges the established firms to change their production strategy.	Yes

5.2.2 Entrepreneurial Domain

Opportunity Recognition (Intersection of Technological domain and Entrepreneurial domain)

Hyzon motors perceived the opportunity for fuel cells' success in the heavy-duty truck segment.

> *"... we have chosen to set up this business in commercial mobility because of the opportunity for core fuel cell technology that is involved...," Crag knight, CEO Hyzon* (Adler, 2021)

Since Hyzon is a spin-off company of Horizons, their experience and background in fuel cell technology helps Hyzon seek a niche opportunity in the commercial vehicles industry, heavy-duty trucks. For the small passenger vehicle segment, Battery Electric Vehicles (BEV) have already demonstrated their potential (Cheddar News, 2020), however, because of the benefits it provides in terms of driving range and fueling time, technology experts believe that Hydrogen trucks in the heavy-duty market can provide long term zero-emission solutions (Leonard, 2018), Table 5.1 shows the contrast. Heavy-duty trucks have to provide service constantly and consistently on long routes. Crag Knight mentioned in his interview that, in some cases, heavy-duty trucks work 24 hours in 2-3 driver shifts (Adler, 2021). In such scenarios, the fright owners need a zero-carbon emission truck that can function in an identical way to fossil fuel trucks (Adler, 2021). Hydrogen trucks can refuel in less than 15 min, they can fill through a nozzle and pump unit as quickly as fossil fuel trucks (Molloy, 2019). Thus, in heavy duty trucks segment, Hydrogen trucks have novelty in zero carbon emission transportation that match the market need.

Entrepreneurs Role in system Development

At the micro-level industry, entrant firms could not grow and sustain their business for a long time due to competitors' entry or lack of financial ability. Thus identifying and assessing sustainable competitive advantage is necessary (Mullins, 2017). Hyzon motors could get a competitive advantage in the industry with the highest power density fuel cell globally, i.e. 6 kW/L (Hyzon Motors, 2020b). The use of advanced material in Membrane Electrode Assembly (MEA) and metallic bipolar plates used in direct the flow of reactants to MEA that improve the performance of fuel cells (Hyzon Motors, 2021a). These innovations enable Hyzon trucks to compete with niche-level competitors (battery trucks companies and other Hydrogen trucks companies).

Hyzon's main focus is on making a "local Hydrogen hub." In Europe, Hyzon formed a joint venture with Holthausen to serve the European market (Editorial Office, 2020) and the same strategy is applied in the Middle East, through a venture with Modern Group that would focus on locally built Hyzon branded zero-carbon commercial vehicles that is expected to serve throughout Saudi Arabia and the GCC (Gulf Cooperation Council) (Hyzon Motors, 2021i). Whereas Hyzon is partnered with Fontaine Modification in the US for an assemblage of Hydrogen trucks and (Motors, 2021) also launched Hyzon Motors Australia to serve Australia and New Zealand's freight industry (Sampson, 2020).

> *"Hydrogen trucks are useless without Hydrogen, therefore, to develop Hydrogen infrastructure Hyzon is working with Hydrogen project developers. Hydrogen can not be transferred easily and*

cheaply, therefore Hydrogen adoption of Hydrogen system or vehicle system is going to be locally oriented so best local resource to make Hydrogen should be used to make Hydrogen whether that sun wind landfill gas whatever that local resource present to make Hydrogen cost-effective then they (Hydrogen trucks) can be viable commercial diesel vehicle alternative," Craig Knight, CEO of Hyzon Motors (Pickett, 2020).

To form a local Hydrogen network Hyzon is involved in strategic alliances with local energy companies and OEMs companies. Hyzon is not manufacturing complete trucks in-house. In EU, they are purchasing trucks from DAF Trucks, a Dutch truck manufacturing company, without a diesel engine (Weijer, 2020). They also working with VIVA energy (Hyzon Motors, 2021d), Real Energy (Zero Carbon Alliance, 2021a), and Hiringa energy (Zero Carbon Alliance, 2021b) to build Hydrogen infrastructure in Australia and New Zealand respectively. Hyzon's trucks manufacturing plans highly depend on outsourcing equipment to keep capital expenditure minimum (Motors, 2021). Their focus is only on core technology- fuel cell drive train (Adler, 2020). This approach of Hyzon's earns them a performance-based competitive advantage over niche competitors.

The mass media play a major role in conveying information about new innovations. It is the most rapid and efficient way to reach potential adopters (Rogers, Singhal, and Quinlan, 2014). Like Tesla, Hyzons marketing strategy is also trying to bring media attention to Hyzon's trucks through activity on social media (Appendix A.1) and news channel interviews (Knext Energy, FreightWaves, Cheddar News CNBC News, AusBiz TV), and from the organization of different events such as, "Hydrogen Now- Virtual ride event" (Hyzon Motors, 2021b). This strategy could assist in a more global outreach, for both investors and market.

The selling model of Hyzon's Hydrogen trucks can be seen as a direct sale and leasing service in Europe for rapid deployment of zero-carbon emission commercial vehicles (Hyzon Motors, 2021f). The early adopters of Hyzon's Hydrogen trucks are split into two segments, (1) government, those are bounded to achieve climate goals, and (2) customers, who are interested in decarbonization and have freight operations in limited regions, like New Zealand based energy company Hiringa and Australia based mining company Fortescue Metals Group (Hyzon Motors, 2020a). Since the price of Hydrogen trucks and its fuel have higher cost compared to fossil fuel trucks, a disruptive channel (C. Christensen and Raynor, 2013) like leasing trucks would help to deploy Hydrogen truck fleets.

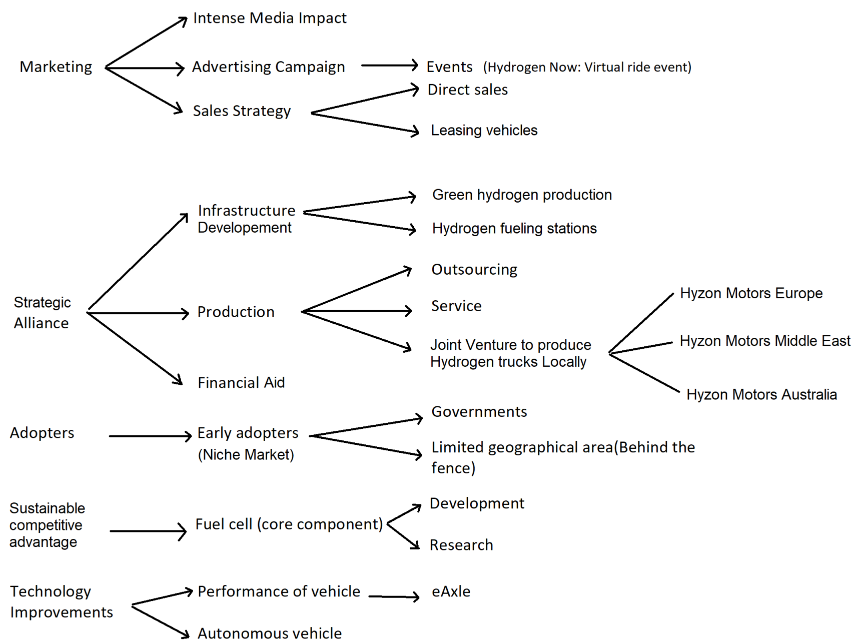

Figure 5.1: Hyzon's Business Strategy

5.2.3 Socio-Technical Domain

Niches (Trivium of three domains)

Hyzon motors identified two niches. First, the technology-related niche, the battery technology can decarbonize passenger vehicles and short-range applications vehicle segments leaving a wide gap in the decarbonization of heavy-duty commercial vehicles. Second, the Market niche, it is a geographically confined region such as Australia, New Zealand where freights are not involved in cross-border operations(Stinson, 2021), and regions where freight operators provide "back to base" service (Stinson, 2021). This strategy allows fueling of a large fleet at a single location by minimum investment in infrastructure (Alamalhodaei, 2021). Hydrogen vehicles markets are similar to the chicken and egg problem, what comes first? Due to the lack of Hydrogen vehicle demand, there are no Hydrogen filling stations, and because of no fueling stations, there is low demand. Tesla recognized the lack of infrastructure in the electric vehicles sector, so they mainly focused on building distribution networks, service, and charging stations (Stringham, Miller, and J.R. Clark, 2015). This helps Tesla to gain market share of BEVs and create their position in the auto sector. On other hand, Hyzon solved this initial problem in two ways, scenarios like New Zealand and back-to-base operations (Adler, 2021).

Technological Regime (Intersection of Entrepreneurial and Socio-Technical domain)

The technological regime is the second stage in STS. The demand from the landscape enables regime actors to work on a sustainable path. Paris Agreement is an outcome of the landscape pressure on regime actors, where several countries pledge to restrain a rise in temperature well below 2 degrees Celsius above pre-industrial level (United Nations, 2015). Following this, The Gemeente Groningen, a lead customer of Hyzon motors, willing to achieve zero carbon emission goals by 2025 in the inner city by replacing medium and heavy-duty municipality trucks (water, refuse, hook lift crane, and delivery trucks)(Hyzon Motors, 2021e). Dutch Province of Utrecht also joined hands with Groningen, to deploy 1800 Hydrogen vehicles and 10 Hydrogen refilling stations by 2025 (Hyzon Motors, 2021g). The Netherlands government have budget plan of 35 million euro per year from 2021 to support Hydrogen infrastructure (Government of Netherlands, 2020). By 2030, European Union targeting to reduce Green House Gases emission at least 40% compare to 1990. (European Council, 2014). In addition, the EU planning to run about 45000 fuel cell trucks and busses on road by 2030 (Fuel Cells and Hydrogen, 2019). The rapid deployment plans by the governments could help transition. The government involvement is significant because 70 percent of clean energy transfer is still government-driven (Birol, 2020). Germany plans to invest 9 billion euros for the National Hydrogen strategy, with the European Union also making a huge investment of about 140 billion euros for Hydrogen deployment (G Economie, 2020). This can encourage more actors to get involved in the development of the Hydrogen Economy.

> *"That offers producers and the logistics sector an incentive to go green," says Holthausen, Director of Hyzon Motors*(Translated from Dutch) (G Economie, 2020).

One of the main reasons holding back the commercialization of BEVs and FCEVs is the lack of infrastructure (Ligen, Vrubel, and Girault, 2018). Hydrogen trucks and battery trucks make use of electric energy to drive motors but due to differences in utilization of electricity, they require different infrastructure (Ligen, Vrubel, and Girault, 2018). The emergence of fuel cells could bring radical change in infrastructure, thus establishing Hydrogen production systems, storage units, supply chains, and fuel stations (Ligen, Vrubel, and Girault, 2018). This is demonstrated in the Figure

5.2. The STS system for Hydrogen trucks was developed referring to Geels, 2005. Figure shows anticipated STS for Hydrogen trucks in transportation in order to analyze what elements are changing and what elements are benefited from present STS. As Craig Knight stated, the supply of Hydrogen is not cheap and easy (Pickett, 2020). Since Hydrogen is less dense (14 times lighter than air) it is difficult to transport (Tae, 2021). Hydrogen can be transferred in two ways: in the liquid state by cooling it to about $-253°C$ or in the compressed gas form (Cho, 2021). But transporting liquid Hydrogen is more expensive than transporting gaseous Hydrogen (Mulder, Perey, and Moraga, 2019). Currently, Hydrogen can be transported via pipelines, rail or by road transport (Mulder, Perey, and Moraga, 2019). The transportation of Hydrogen gas through tube trailers can carry up to 1000 kg per truck, it is suitable for smaller quantity supply (Mulder, Perey, and Moraga, 2019). On other hand pipelines are suitable to transport large quantity of Hydrogen over long distance. In spite of the fact that initial cost of pipelines are high, the transportation of large amount of Hydrogen (up to 9000 kg/h) and the low operating expenses make the costs per kilogram of Hydrogen transportation minimal (Mulder, Perey, and Moraga, 2019). Over longer distance a 120 bar Hydrogen pipeline with a 35 bar input pressure will cost between 0.04 and 0.16 cents per 100 kilometers (Wijk, 2017). A cheaper and faster alternative is utilizing existing gas pipelines (Wijk, 2017). On large scale, the transportation of Hydrogen employing any method eventually costs much less than power transmission lines (Fuel Cells and Hydrogen, 2019).

Deployment of Hydrogen trucks won't change user behavior and market much, because Hydrogen trucks can deliver the same goods with the same driving skills as Fossil fuel trucks. This demonstrates that Hydrogen trucks are disruptive on the supply side but have little impact on demand. Hydrogen trucks can refuel in less than 15 min, they can fill through a nozzle and pump unit as quickly as fossil fuel trucks (Molloy, 2019). In addition, the policymakers don't have to make new transportation laws for driving Hydrogen trucks but they could implement robust laws regarding carbon emission on the existing transport system that makes more actors inclined towards the Hydrogen transition. During transportation and storage of Hydrogen, to prevent undesired effects, some new regulations are made by policymakers. Currently, Hydrogen trucks are equipped with compressed gas storage tanks that are using nominal work pressure 35 Mpa and 70 MPa only (ITF, 2020). Other regulations also include, but are not limited to, Hydrogen quality, specifications of vehicle refueling connecting devices (ITF, 2020).

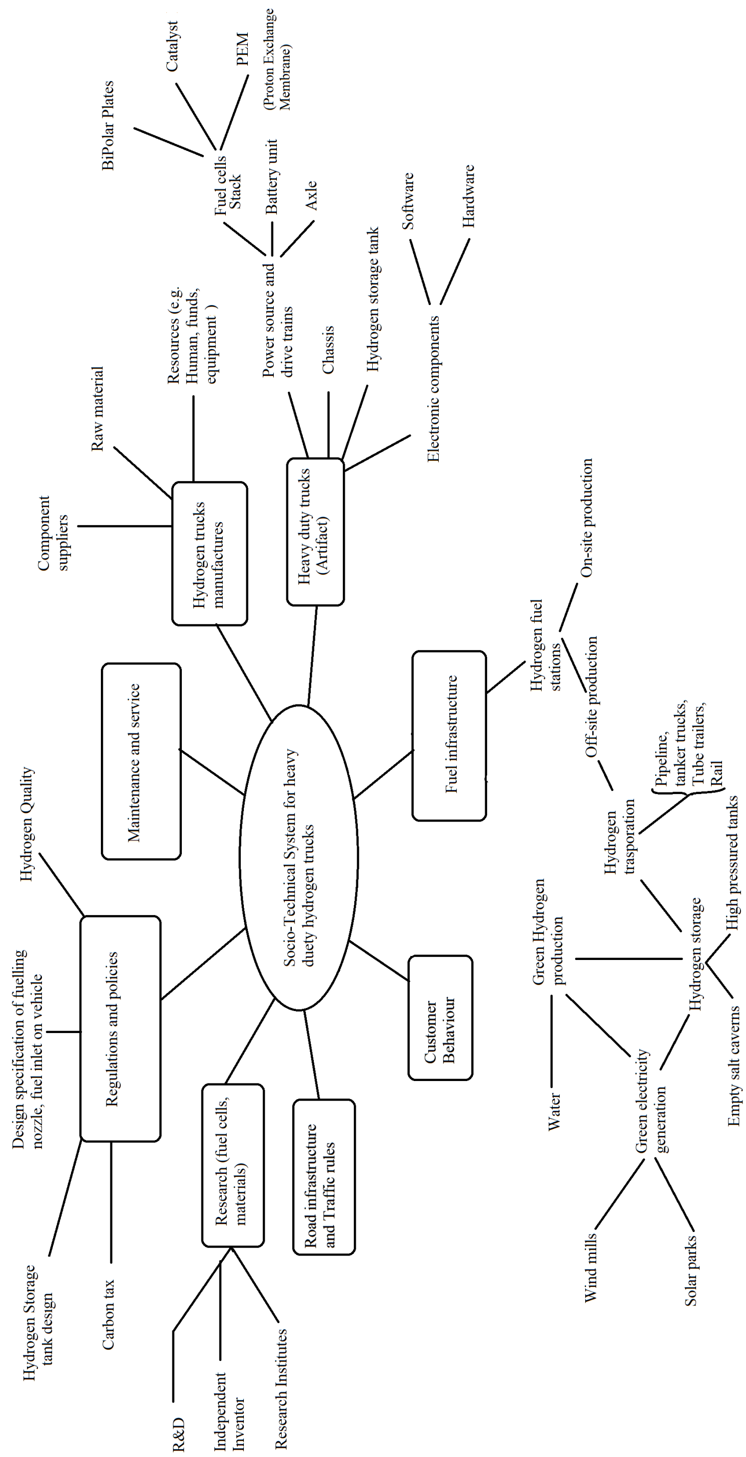

Figure 5.2: Socio-technical System for Hydrogen trucks

5.2.4 Gray Zone (Intersection of Socio-Technical system domain and Technological domain)

Due to the high-cost of Hydrogen trucks and the low presence of infrastructure, at present, the Hydrogen trucks market seems unattractive, and therefore, not many large companies are adopting the innovation. The incumbents like Daimler Truck AG and Volvo Group formed a joint venture to manufacture Hydrogen powered heavy duty vehicles, but it is expected that their first heavy-duty FCEV would run on the roads around 2025 (Randall, 2020). According to a study, such delay could affect gaining market share. At the same time, Hyundai entered into niche competition with their heavy-duty truck 'H2 Xcient',(Reuters Staff, 2020a), and Volkswagen Group has demonstrated their trucks in Norway (NU.nl, 2020). Analyzing the threat and need for transition, the oil giants are now diverting their investments towards decarbonization. For example, NortH2, a consortium of Shell, Gasunie, Groningen Seaport, province of Groningen, Equinor, and RWE are aiming to build Europe's largest green Hydrogen project in Netherlands (Energy Industry Review, 2020).

It is difficult to run two businesses at the same time in a single organization (Markides, 2006). Such scenarios can be avoided by starting a new independent organization that has no interactions with the mainstream business (C. Christensen and Raynor, 2013). In light of these challenges, the Daimler Group has separated Daimler Truck AG as an independent company from its business, providing full entrepreneur freedom and independent chairman of the supervisory board (Manthey, 2021).

Chapter 6

Discussion

Three research questions mentioned in chapter 1 referred to three domains of conceptual framework. These are further divided into propositions to understand the evolution of the innovation system. The development of this framework was based on propositions, therefore the argument of propositions could provide the affirmation for the path showed in conceptual framework (Figure 3.1).

Technological domain

It is indeed true that hydrogen trucks will raise as a disruptive innovation for fossil fuel trucks. Raising issues of climate change and demands for carbon-free transportation would bring innovation mainstream market. The answer to the first research question is based on three definitions of disruptive innovations, the original definition given by Christensen (cheaper, simple, and smaller), the definition given by Christensen and Raynor (new-market disruption), and the definition given by Walsh and his co-authors (disruption of manufacturing methods). Table 5.2 demonstrates that hydrogen trucks satisfied 8 characteristics out of 10. The change in propulsion system does not affect the size of the trucks therefore this condition is undetermined. The characteristics of hydrogen trucks partially match with the Christensen definition, whereas a good match is found between the other two definitions. Hydrogen trucks fulfill the definition provided by Walsh and his co-authors (Walsh, Kirchhoff, and Newbert, 2002) i.e. its ability to attack manufacturing methods and production lines of incumbents that were established through years of experience and continuous improvement. In terms of range and fuel carrying capacity hydrogen truck are still far behind compare to fossil fuel trucks where 300 gallon tank capacity can cover approximately 3000 Km (these values are based on author's assumption (Andrews, 2021). This makes innovation unattractive for mainstream customers. The cost of hydrogen trucks and hydrogen gas is much higher, it is not a cost-competitive solution for average customers. Currently, these trucks are only available for affluent customers but further development in fuel cells and hydrogen infrastructure would make hydrogen trucks more affordable to the large non-consuming segments of the population. On limited production, the price of fuel cells dropped by 65% in a decade (Pocard, 2020). Consequently, it is expected to be price drop about $70 - 80\%$ on large scale production (Pocard, 2020) that could make hydrogen trucks more affordable for a large segment of consumers. According to (C. Christensen, Raynor, and McDonald, 2015) theory, hydrogen trucks can disrupt an existing market, they create an entirely new value network that serves as a new market disruption. The hydrogen trucks are not sustaining innovations thus it is important to take necessary disruptive actions.

Disruptive innovations originate outside the existing technology domain that demonstrated by arrow 1 in the Venn diagram. However, this is only partially true, because both start-ups and incumbents are involved in the development of hydrogen trucks. The entrants like Hyzon are outsiders for present technological base i.e. fossil fuel automotive industry, the insiders like Daimler, Ford, and Hyundai are also trying to introduce their products in the market. Usually disruptive technologies emerged from inside are developed in R&D organizations of incumbents. This shows of disruptive innovation can emerge from inside as well.

> *Revised Proposition 2: Disruptive technology emerges from outside as well as inside of the Technological domain.*

Since technology circle in the Venn (Figure 3.1) itself relates to an existing technological basis, therefore, there is no need for modification.

Intersection: Opportunity Recognition

The proposition 3 holds true. The recognition of an opportunity serves as the starting point for an entrepreneurial enterprise (Bodde, 2004). Hyzon motors (actor) recognized the potential of Hydrogen trucks (technology) to start a new auto company that produces zero-carbon commercial vehicles. The business opportunity in hydrogen trucks fits into the demand-pull type since there is a need for a potential alternative for decarbonization of the road transportation sector. In this type entrepreneurs first, analyze market necessity and introduce products that have some special technological feature to satisfy demand (Byers et al., 2011) Hyzon recognised decarbonization trend, quick fuelling and better range market need, and utilization of fuel cells in heavy duty trucks. This is inline with the proposition 3.

> *Proposition 3: Entrepreneurs seek opportunities when they simultaneously involved in social trend, market need and technological innovations.*

The proof of proposition also provide validation for entrepreneur domain intersecting at opportunity recognition and regime, in the Venn diagram (Figure 3.1). The involvement of entrepreneurs in STS helps to analyze trend and market needs, while involvement of entrepreneurs with technology help to find potential solution satisfy those needs.

Entrepreneurial Domain: Role of Entrepreneurs

The commercialization of disruptive technology requires innovation in the business model (Hopp et al., 2018), The business activities of Hyzon motors' at the micro-level demonstrate an innovative business model. Yet in some fields, they reflect Tesla's business model. Hyzons commercialization activities show five business driving elements, Marketing, Strategic alliance, Adopters, Sustainable competitive advantage, Technology improvement. Continuous technology development and sustainable competitive advantage are assists to stay ahead in the competition. Marketing and niche market identification assists to gain market share . Finally, strategic alliance supports to development of trucks production units, hydrogen production and supply, and helps to raise fundings. Hyzon's locally oriented business model not just concentrating on production of hydrogen trucks but also supporting to build local hydrogen infrastructure and economy. The proposition 4 supports the building of system at niche level.

> *Proposition 4: Entrepreneurs are system builders with a distinct business model who incorporate innovation into niche.*

The activities of Hyzon suggest the strategy to bring technology into niche which also indicated by arrow no 3 in the Venn diagram (Figure 3.1). Hyzon identifying niche market and creating niche as well by involving in the infrastructure development as shown by arrow no. 4.

Socio-Technical Domain

Intersection: Niche

Niche is a region where all three domain intersect. Prior researches claimed that, disruptive innovation requires niche spaces to grow under the established innovation. Hydrogen trucks are disruptive innovation they have less success at mainstream market. Further development in terms of cost reduction and performance enhancement require to attract non-consumption. Niches found by Hyzon helps to fulfill disruptive innovation requirements. Thus the niche requirement of disruptive technology domain fulfilled by entrepreneurial domain and development activities push innovations from niche to regime level in Socio-technical domain. This argument could support proposition 5 and claim as true.

> *Proposition 5: Niches are a Trivium that brings together the innovations, entrepreneurs, and socio-technical system.*

Intersection: Technological regime

The entrepreneurs or actors play a major role in the transition. Their influence on niche and regime in system building demonstrated in the Venn. But it is not possible to affirm role of entrepreneurs in the regime due to hydrogen trucks are still in demonstration phase. Therefore proposition only claims the activities of regime elements at niche level. The socio-technical system transition comprise co-evolution of some elements but not all. As previously stated that present fossil fuel infrastructure can be use in hydrogen supply such as gas pipelines network, tanker truck, trains but appropriate modifications need to be made to become suitable for transporting pressurized hydrogen gas. In the Figure 5.2 The gray blocks show which elements aren't going to change. The road infrastructure and traffic rule are not required to make new. Also user practices won't change much they do not require any special skills or license to drive hydrogen trucks. The existing knowledge of driving make customers to adopt innovation quickly. As a result, it is possible to take advantage of the existing network with certain amendments. Thereby, it supports the proposition 6,

> *Proposition 6: The current network facilitates the transfer of innovation from niche to regime.*

Although, the argument supports the proposition 6, it is dependent on the technology.

Socio-technical landscape

For radical transition, the socio-technical landscape has a major impact on the niche as well as regime level. The landscape change has direct and indirect influence on niche actors. As a result of Climate change like extreme weather conditions, rising temperature, these landscape changes pressurize regime level actors (policymakers) and niche level actors (inventors and innovators) to adopt a green solutions. Governments hydrogen programs encourage entrepreneurs to work on sustainable technology (Bodde, 2004).This can be observed in case of Hyzon and Holthauzen joint venture. Moreover, regime incumbents, decarbonization enthusiasts are investing in start-ups. For example European energy giant TOTAL SE is investing in Hyzon motors to promote hydrogen transition (Randall, 2020) and integration of Hyzon with special purpose acquisition company: Decarbonization Plus Acquisition Corporation (DCRB) for large financial gain (Motors, 2021). The landscape pressure also creates opportunities for entrepreneurs i.e. the demand for carbon free solution. New opportunity seekers like Crag Knight and his team, as well as their collaborators are taking benefits of these opportunities. The Government provided subsidies and the awareness of sustainable transition between the customers, generate demand at niche level. For example Australian mining company, New Zealand's energy company. These evidence suggest the impact of landscape tension on niche level.

> *Proposition 7: The landscape pressure creates a window of opportunity not only at the regime level but also in the niche.*

In the Venn diagram, the reasoning of proposition 5 demonstrates the convergence of three domains at the niche. The proposition 6 argued that present regime elements such as policy makers, infrastructure, early actors and adopters (Governments, decarbonization enthusiastic) may help to launch and develop innovation in niche markets in an indirect way. The interaction between niche and regime creates indistinct boundaries which is showed in the Venn diagram with discontinuous line. The landscape pressure creates window of opportunity in niche spaces as well. The verification of proposition 7 confirms the arrows pointing towards niche and regime.

Gray Zone

Earlier literature suggests, the disruptive innovations create opportunities and develop threats among incumbents at the same time. It is a dilemma for industry incumbents whether to invest in their sustaining product or disruptive innovation (C.M. Christensen, Anthony, and Roth, 2004). Even though incumbents know the future potential of hydrogen trucks they are not enthusiastic about switching diesel engines to fuel cells (Park, 2021) because the low profits could not satisfy the financial requirement to run an established business successfully. Therefore this phase of the innovation system can be referred to as the Gray zone in Figure 3.1, where incumbents could not recognize future potential and ignore the innovation, whereas some incumbents prefer to wait for market growth for example Daimler and Volvo joint venture. On other hand, Hyundai analyze the opportunity and take immediate actions to introduce their product in the niche market (Arrow no. 5 in Figure 3.1). This argument supports the proposition 8 as well as position of gray zone in conceptual framework.

> *Proposition 8: The Grey Zone is a dilemma that incumbents confront in the innovation system when determining whether to invest in disruptive innovation or current technology.*

As the literature on disruptive innovation showed the importance of identifying innovation type, that decides what actions should take to grow the business. It also decides that what path technology would take. Disruptive innovation originally appeared in a niche market as a non-competitive alternative to mainstream innovation. The following is the path that technology takes: hydrogen trucks were emerged in the technological domain. Hyzon motors (actor from the entrepreneurial domain) recognized a potential market in heavy-duty transportation for hydrogen trucks. They identified a niche market as well as creating a new market through the strategic alliance. Because changing climate threat (landscape pressure) enabling the governments (regime level actors) to interact with niche level actors. In a niche market, as further development occurs in fuel cells and infrastructure, the minimization of hydrogen trucks costs would attract average consumers. As a consequence, innovation will go from niche to regime level, including more producers and consumers in the process, eventually displacing mainstream technology. This provide proof for the proposition 1,

> *Proposition 1: The development of the innovation system is path-dependent on the nature of the innovation.*

In summery, all proposition found to be true which also supports the validation of the framework. The proposition 2 is partially true but it could not affect the firmness of conceptual framework. The proposition 3 is true and also confirms the intersection phase in Venn diagram. Proposition 4, supports the important role of entrepreneurs in system building. They find opportunity, put them in niche market. This as well reflect in conceptual framework, the intersection of entrepreneurial domain with other two domain demonstrate the area of activities that entrepreneurs undertake. Furthermore, niche is Trivium where all three, product, actor, and system meets. The proof of proposition 5, niche as a trivium give framework solid structure. The proposition 8, is not a part of selected case but it is a important for incumbents. The proof of proposition 8 supports the concept of Gray Zone i.e. intersection of Socio-technical domain and Technological domain. Finally, proposition 1, support the statement that system innovation chose path according to type of innovation. This also supports path demonstrated in framework.

Chapter 7

Conclusion, Limitations and Future Research

7.1 Conclusion

This research has a wider scope in terms of theory building as well as in practice. It contributes to the literature of innovation system, disruptive innovation, entrepreneurship and socio-technical system. This research provides a graphical representation of development of innovation system. The developed framework is well validated with research questions and propositions. Most of the current research reports are concerned with TCO of Hydrogen trucks. Indeed, it is important to understand the financial aspects of the Hydrogen trucks when there is a higher cost involved. However, it is also vital to realize the technological aspects and business model strategies to deploy Hydrogen trucks into the market. The main research goal is to the study "the development of the innovation system that occur on emergence of disruptive innovation." is achieved by analysing three research questions that is discussed further.

The first research question discusses the disruptive nature of the Hydrogen trucks and their success in existing markets. The technological domain assists to find the disruptive nature of Hydrogen trucks. Answer to first research question provided solid proof for the speculation about Hydrogen trucks possibly being disruptive for conventional trucks. The advancement of Hydrogen trucks would create threats for the incumbents. At present, Hydrogen trucks are inferior and have cost barriers, in spite of which a potential profitable market awaits in the coming years. But the success of Hydrogen trucks in current conditions is only possible through government initiatives such as subsidies for early adopters. The analogy between battery trucks and Hydrogen trucks revealed that Hydrogen trucks possess better performance than battery trucks. The well-to-wheel (WTW) efficiency of battery trucks is almost double ($18 \sim 42\%$) that of the Hydrogen trucks ($4 \sim 25\%$) (Deloitte-Ballard 2020), but because of the range anxiety and lower load carrying capacity, batteries are deemed suitable for passenger vehicles and limited range commercial vehicles such as buses, light commercial trucks, and vans. The Hydrogen trucks are suitable for both short and long distance medium and heavy duty trucks transportation industry. This universality of Hydrogen trucks could prove a threat for battery trucks in future for short range transportation as well (see domination of IC engine trucks over battery trucks in past, Mom and Kirsch, 2001).

Although Hydrogen vehicles have progressed, they are still lagging behind fossil fuel trucks in terms of range, fuel storage. Therefore it is not possible for Hyzon to sell their trucks to a large clientele (or mainstream costumers) where freight operations take place over long distances or internationally. In such scenarios where co-evolution of industries are required, Hyzon provided a unique business model i.e. highlighted by answering second research question. The Entrepreneurial domain assisted in analyzing the role of entrepreneurs or actors in advancement of Hydrogen trucks. Hyzon stressed on building a local Hydrogen economy by implementing "Local Hydrogen Hub" model that could help to speed up building infrastructure and also bring down total operating cost of Hydrogen trucks. Hyzon's activities reflect Tesla's business model to some extent. They are similar in the aspects of support infrastructure development through alliancing, extensive media presence, direct sale, continuous improvement in technology. These factors are important to consider when targeting a chicken and egg like scenario. But such business model require large capital to execute plans. One way is creating partnerships with established companies for financial purposes. Hydrogen infrastructure is insufficient to adopt Hydrogen trucks, therefore Hyzon's back to base strategy is only feasible at the moment. Heavy duty trucks are dedicated for heavy cargo and long-range drive therefore unexpected breakdowns are inevitable. The one way to counter such scenarios is to start remote services on wheels like Tesla. Where Tesla has given more value to customers' convenience, their 'Tesla Mobile Service Van' (Mangram, 2012) and Tesla Rangers- A team of Tesla's technicians (Field, 2017) were focused on serving vehicles in remote areas. Since maintenance and repair workshops are not available everywhere, Hyzon should consider implementing such services.

As previously said, entrepreneurs play a critical role in the growth of society and innovation. But for larger transformation more actors should involve in the transition. The third domain i.e. Socio-technical domain discusses the socio-technical system and its elements. The existing elements such as gas pipeline network, road infrastructure, customer's driving skill and knowledge could support the deployment of Hydrogen trucks. Because green Hydrogen production is still minimal and costly, it is not practical to utilize it; however, blue Hydrogen is $2-3$ times cheaper than green Hydrogen (Schroot, 2021), making it a viable option for existing Hydrogen trucks.

Because this is a real-time case study, the major research aim was met until phase of introduction of disruptive innovation. The Hydrogen trucks are yet in initial phase therefore role of entrepreneurs at the regime level could not be determined. But the research has discussed the influence of regime and landscape on niche level based on current activities in the Hydrogen economy. The final phases of innovation system i.e. diffusion of Hydrogen trucks into socio-technical system and co-evolution of other elements are discussed based on available theories and research reports.

This research approach helps to analyze the paths that one could take during the diffusion of disruptive innovation and actions that needs to be undertaken to introduce innovations. The research suggests one way to look at an innovation system through three interconnected domains for better understanding of technology developments. The research approach allows us to study technological aspects, business aspects and societal aspects independently and relate them at intersections. The conceptual framework suggests the influence of entrants on niche and regime, whereas gray zone indicates the introduction of innovation by incumbents. In this manner, the framework could help both entrants and incumbents. The methodology is constructed in a chronological way, thereby making it easy to comprehend the development of innovation and respective activities from emergence to diffusion. The real world case study helped us to analyze disruptive innovation from its emergence and analyze the actions carried out by the firm to introduce disruptive innovation into the market. Research has briefly described all the phases of innovation system using provided conceptual framework. The same framework can be used for facilitating more detailed studies in future.

7.2 Limitations and Future Research

The research approach has some limitations as well. The study is mainly based on secondary sources, a GCM greater than 26 tonnes refers to Heavy duty trucks, therefore variation in companies and weight of trucks shows different performance measures. Therefore the research has limited legitimacy. The framework did not consider a time factor, therefore it is difficult to say how much time would be required for system development. Since during research, we observed much of the firms activities and requirements for disruptive innovation are similar to radical innovation, therefore this framework can be utilized for research in innovation system development based on radical innovation. Researchers can study the validation of the framework for radical innovations to make framework more robust. The Hydrogen truck and battery trucks are still in a demonstration phase, and early conclusions about the future of Hydrogen trucks may not strongly be emphasized. Finally, innovation system do not depend on a single innovation development, there are many invisible hands involved at different states, hence it is possible that development could take various paths during the transition of system. A deeper analysis is required to understand the entirety of the innovation system.

Appendix A

Appendix

Table A.1: Similarities between Tesla and Hyzon business activities

Sl. No.	Tesla Business Model	Hyzon Business Model
1	Intense media attention (Hettich and Müller-Stewens, 2017;Mangram, 2012)	Intense media attention
2	created supercharger stations (Hettich and Müller-Stewens, 2017)	Alliance with local energy companies (Hyzon Motors, 2021d;Zero Carbon Alliance, 2021a;Zero Carbon Alliance, 2021b)
3	Outsourcing: Windshield, airbags, and automatic braking system to save time and money (Stringham, Miller, and J.R. Clark, 2015)	Outsourcing: Chassis, cab, other elements to minimize capital expenditure (Motors, 2021)
4	Sales strategy: Direct sale (Hettich and Müller-Stewens, 2017)	Sales strategy: Direct sale and Leasing hydrogen trucks (Hyzon Motors, 2021f)

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