A NEW ROLE FOR THE AIRPORT

THE TRANSITION OF HYBRID AND ELECTRIC AVIATION TO FACILITATE THE PARADIGM SHIFT WITHIN THE INDUSTRY.

MASTER THESIS

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Strategic Product Design
Delft University of Technology

A NEW ROLE FOR THE AIRPORT.

The transition of hybrid and electric aviation to facilitate the paradigm shift within the industry.

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Master thesis
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In collaboration with
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March, 2021

PREFACE.

The master has been an amazing journey, with the epitome in front of you: the final deliverable of my graduation project of the Strategic Product Design master at the Delft University of Technology. The thesis has been conducted almost entirely from my living room, with the exception of twice visiting Schiphol, and drinking coffee with co-graduate students at the university. I am extremely proud of the work you currently have in front of you, where I have pushed my capabilities and research ambitions beyond what I hoped to achieve, which the support of a number of people helped me with.

From day one, I have been welcomed it the Innovation Hub and have been supported by my colleagues. Every morning during a standup meeting, I could share my plan and ask questions, which enabled me to advance in my research. I am especially thankful to you Jan, my company mentor, whom sent me daily inspiration and articles with the latest news and developments in the industry, making me look at findings in a new light. On top of that, daily messages and weekly meetings to support me and answer whatever questions I had, whether it be topic related, introducing me to stakeholders, or discussions about the future of aviation and career paths.

Then there is my supervisory team of Erik-Jan and Jeroen, whom have been there to help push the boundaries of what my project could deliver. Their positive critical perspectives and directions they inspired me to look into have shaped this project to its full potential. Thank you Jeroen, for asking critical questions making me reflect on choices I made in the project. Thank you Erik-Jan, for pushing and inspiring me in directions I had not imagined to take.

At last, I would like to thank my friends and family. Thank you Denne, for supporting me everyday and listening to my thoughts and stories. While this thesis merely covers the past six months, you have been there since day one. Thank you housemates, whom made working from home enjoyable and provided a balance between study and social activities. Thank you family, whom have advised and believed in me and my choices.

I am grateful for the people around me, and I am certain that their support will shape my future ambitions to its full potential.

Enjoy the read!

Victor Verboog
March 10, 2021

EXECUTIVE SUMMARY.

For the past decades, aviation has had a fair amount of incremental innovations, such as improved traffic management, optimization in conventional aviation technology and process developments. With the global sustainability ambitions, new technologies and innovations have been in development by a vast amount of parties. Electric aviation is one of these innovations within the developing sustainable aviation industry.

Therefore, the scope of the project revolves around electric aviation, executed in collaboration with Royal Schiphol Group (RSG) and its Innovation Hub department. The Innovation Hub's main role within RSG is to provide research and set in motion radical innovations to be implemented, of which Sustainable Aviation. The research questions within the scope are therefore defined as follows:

What are the current developments in the electric aviation industry?

And how can RSG facilitate the transition towards sustainable aviation within the aviation industry?

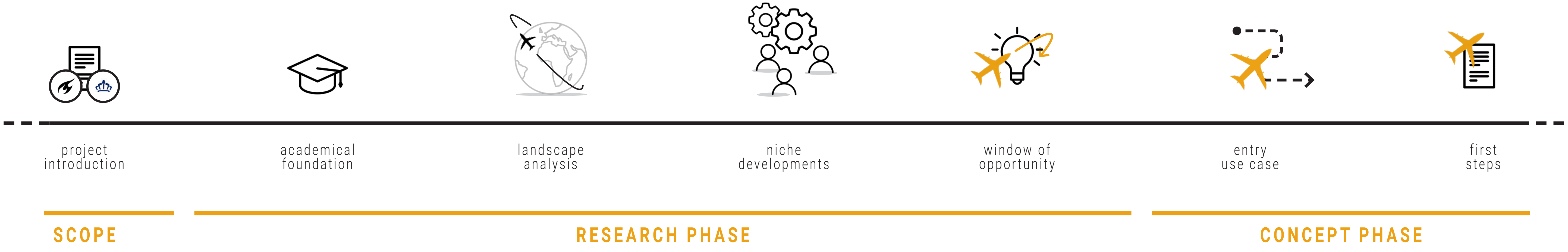
Geels' (2002) system transition theory serves as the foundation for the research approach, structuring the thesis in two phases accordingly to the research questions which define the scope; research and concept phase (figure 0). Within the research phase, the landscape drivers have been analysed, depicting a sustainability pull through global sustainability ambitions and a technology push through the developments in the battery technology. With these developments, multiple niche innovations have emerged over the past years, consequently making electric aviation feasible for specific use cases. The most prominent parties developing these niche innovations are Heart Aerospace, developing a 19 passenger electric aircraft with a range of 400 km, and Eviation Alice, developing a 9 passenger electric aircraft with a range of 815 km.

The socio-technical (ST) system transition towards sustainable aviation is the goal of electric aviation. This transition is enabled by the interaction of technology and people. Based on this, the landscape cultural trends have been analysed and used as a basis for the comparison of the use of modalities within the mobility industry. Thus, deriving a potential ideal use case for electric aviation of 300-400 km, potentially increasing in range depending on the battery developments in the future. The current expectation is that batteries increase in energy density from 260 Wh/kg to 600 Wh/kg by the end of the decade. This range is the foundation for the entry use case, the concept of the thesis.

The range of 300-400 km is one of six metrics used to develop the entry use case. The others are passenger substitution potential, network potential, location in the Netherlands, innovation resources and viral factor. In line with RSG its values, network potential has been the deciding factors when choosing the entry use case, with other potential entry use cases available when altering the deciding factor. This entry use case is between Amsterdam, Copenhagen, Oslo and Stockholm, as this has both a high passenger substitution potential with a critical strategic motive. Scandinavia aims to implement electric aviation on their airports, enabling a higher certainty and willingness to collaborate towards the development and implementation of electric aviation.

With this entry use case, several bottlenecks emerge. As a pioneer in the sustainable aviation industry, RSG has a seven step plan to overcome these bottlenecks, of which creating a coalition of industry stakeholders collaborating in researching and developing the electric aviation industry. With this actionable plan, RSG has the ability to accelerate the transition towards a sustainable aviation industry, as well as progress in the research for the implementation of electric aviation.

▼ Figure 0. Thesis phases based on the project scope.



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READING GUIDE.

Interested in specific topics?
Simply read the following chapters.

TECHNICAL FEASIBILITY OF ELECTRIC AVIATION

3.2	Previous battery technology
4.1	Overview of electric initiatives
4.2	Upcoming battery technology
4.3	Range of electric aviation
6.3	Entry use case
7.1	Technical & operational bottlenecks
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8.1	Further research directions

SUSTAINABILITY OF ELECTRIC AVIATION

3.1	Industry ambitions and goals
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5.2	Comparing ICE, BEV, train, electric and kerosene aircraft
6.3	Entry use case & CO_2 reduction
7.1	Bottlenecks influencing the substitution
8.1	Further research directions

ABBREVIATIONS.

• AAS	Amsterdam Airport Schiphol
• BEV	Battery Electric Vehicle (electric car)
• CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
• FAA	Federal Aviation Administration
• ICAO	International Civil Aviation Organization
• ICE	Internal Combustion Engine (conventional car)
• IPCC	Intergovernmental Panel on Climate Change
• KiM	Kennisinstituur in Mobiliteit
• LGW	London Gatwick
• LHR	London Heathrow
• LTO	Landing and take-off
• MLP	Multi-Level Perspective
• Modality	Mobility modality, type of transport mode
• NASA	National Aeronautics and Space Administration
• NS	Nationale Spoorwegen
• OD	Origin-Destination
• OEM	Original Equipment Manufacturer
• pax	passenger
• pkm	passenger kilometer
• R&D	Research & Development
• RSG	Royal Schiphol Group
• RTHA	Rotterdam-The Hague Airport
• SDG	Sustainable Development Goals
• ST	Socio-technical
• TTW	Tank-to-Wheel
• UAM	Urban Air Mobility
• UN	United Nations
• UNFCCC	United Nations Framework Convention on Climate Change
• VTOL	Vertical Take-Off and Landing
• WTT	Well-to-Tank

01

INTRODUCING THE PROJECT.

The first chapter provides an introduction of the project, including the initial brief and scope of the project. Thereafter, it elaborates on the involved project stakeholders.

CHAPTER 1.1

INTRODUCTION.

Introduction
For the past decades, aviation has had a fair amount of incremental innovations, such as improved traffic management, optimization in conventional aviation technology and process developments. With the global sustainability ambitions, new technologies and innovations have been in development by a vast amount of parties. Electric aviation is one of these innovations within the developing sustainable aviation industry.

Therefore, the scope of the project revolves around electric aviation, executed in collaboration with Royal Schiphol Group (RSG) and its Innovation Hub department. The Innovation Hub's main role within RSG is to provide research and set in motion radical innovations to be implemented, of which Sustainable Aviation.

Project assignment
Electric aviation as a technology is novel, and thus many stakeholders within the sustainable aviation industry have a small understanding of what electric aviation entails. Therefore, the scope of the project is twofold; gaining an understanding of the electric aviation industry in terms of feasibility, viability and desirability and applying this knowledge to integrate electric aviation in the portfolio of RSG. With this, the following research questions were formulated;

What are the current developments in the electric aviation industry?

And how can RSG facilitate the transition towards sustainable aviation within the aviation industry?

This means that the overall goal of this thesis divided in two parts; phase one is gaining an understanding of the current developments in the electric aviation industry, and phase two is exploring the opportunities for RSG to facilitate the industry to transition towards sustainable aviation through electric aviation. Consequently, the second phase proposed a concept for the implementation of electric aviation in the current aviation industry. The original project proposal brief can be found in Appendix A.

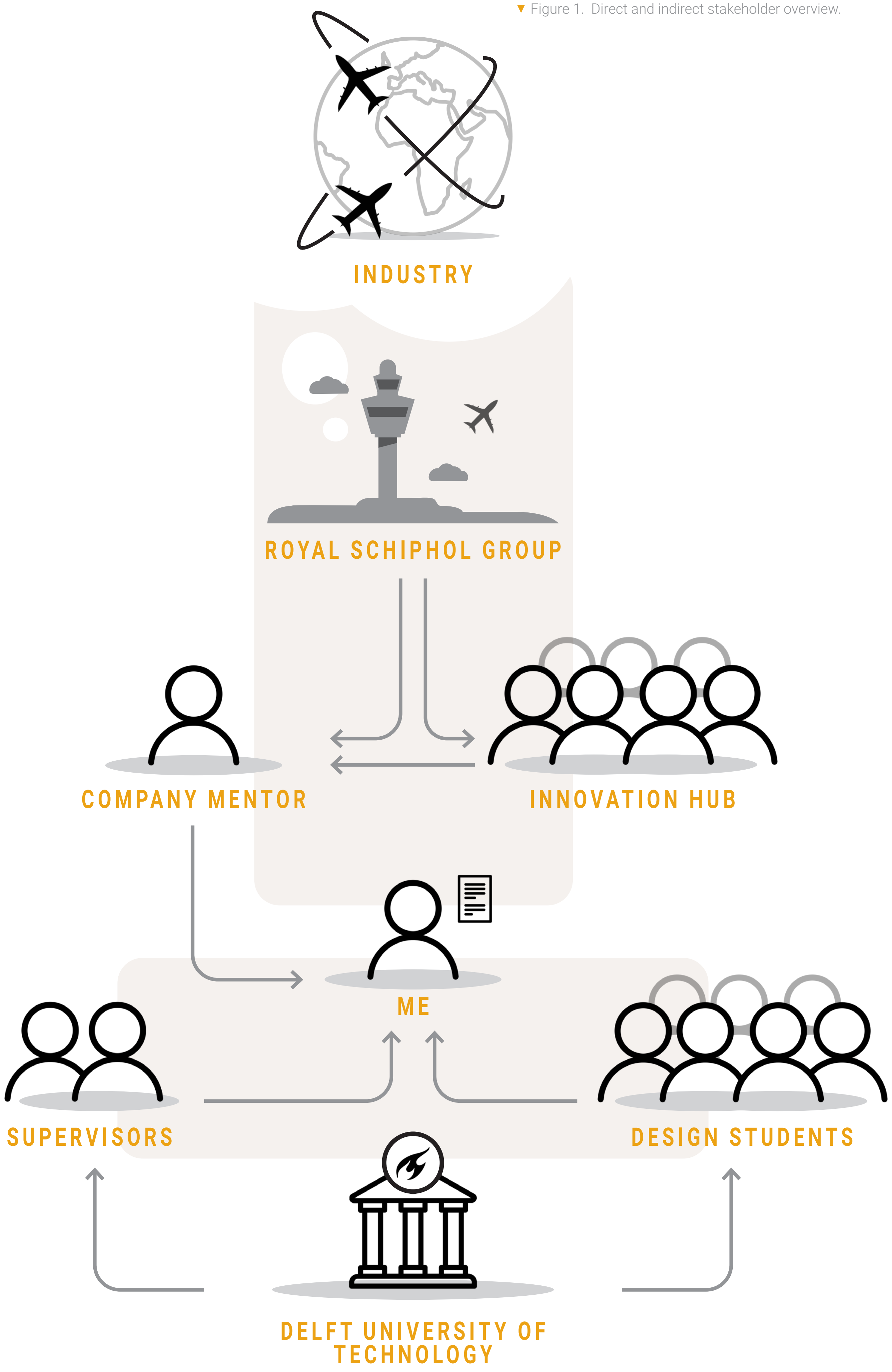
Involved stakeholders
The stakeholders involved can be categorized in two types; direct and indirect stakeholders, each with different interests, shown in figure 1. The direct stakeholders of this project are;

- TU Delft. Its main interest in the project is the knowledge development, of which a Master Thesis is a means. Supervised by two supervisors; Prof. dr. H.J. Hultink and MSc. J. Coelen, both from the faculty of Industrial Design Engineering, department of Design, Organisation and Strategy.

- Royal Schiphol Group. Supervised by ir. J. Zekveld, innovation lead in the Innovation Hub of RSG Its main interest in the project is knowledge development into the electric aviation field, and understanding how it can benefit RSG its value proposition.

The indirect stakeholder is the aviation industry, as electric aviation a novel technology with a low understanding of its future relevance to the industry. This project enables a step in the direction towards a more sustainable aviation industry, by providing a better understanding of the technology and its opportunities, creating legitimacy, which chapter 2.3 will elaborate on further.

▼ Figure 1. Direct and indirect stakeholder overview.



02

THEORETICAL FOUNDATION.

This chapter covers the start of the research behind this thesis, by incorporating socio-technical system transition literature. This literature serves as both research areas in the first chapters, and the reasoning behind the concept and initial steps in later chapters. On the whole, it lays the structural foundation of the thesis.

CHAPTER 2.1

SOCIO-TECHNICAL SYSTEM.

Introduction
At present time, the scope of the project is founded on the research question of: "How can Royal Schiphol Group facilitate the transition towards sustainable aviation through the electrification of aircrafts?"

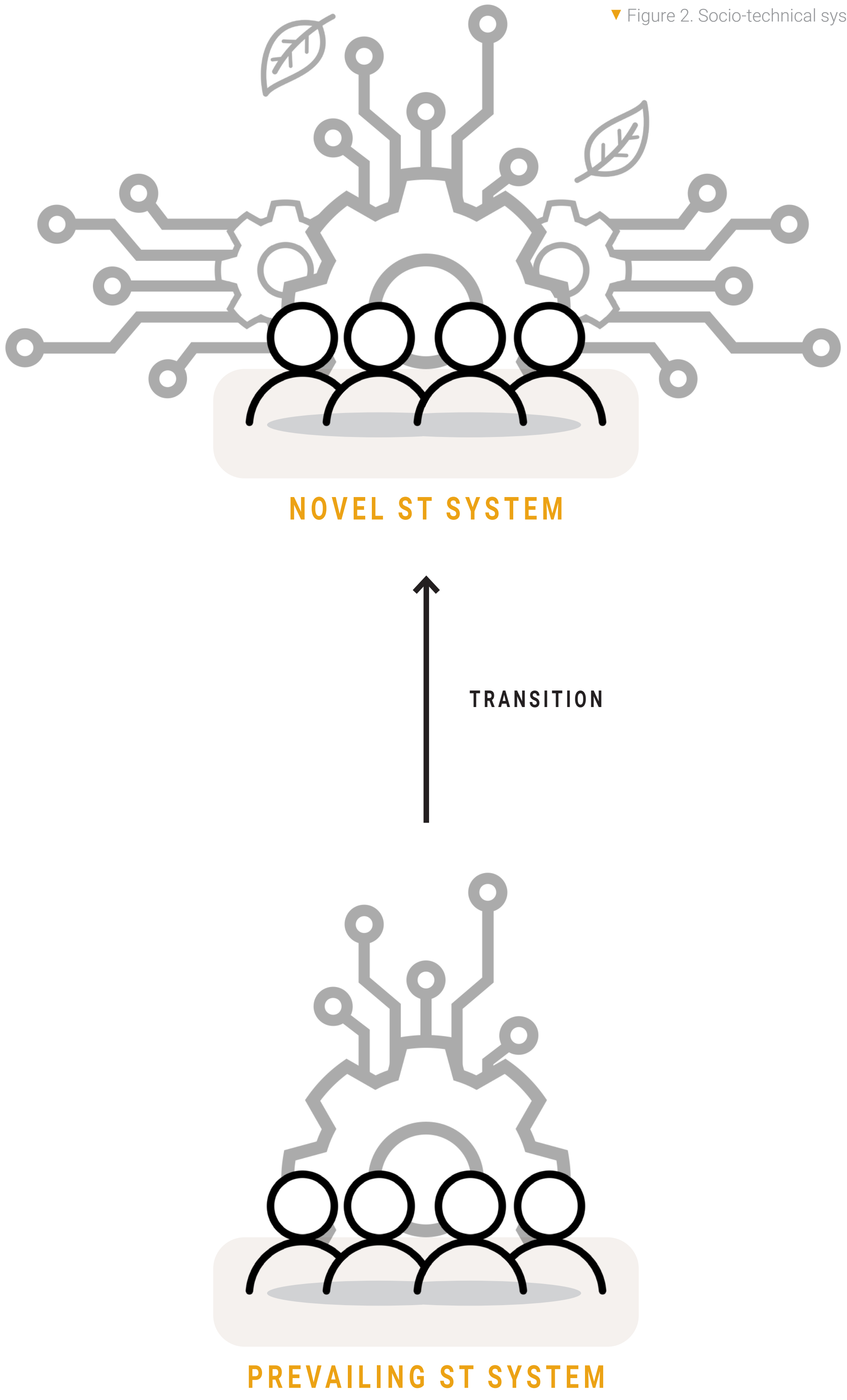
Consequently, there are two sub questions within the scope of the projects to be explored. First, what are the current development within the electric aviation industry? And secondly, how can RSG use these developments to facilitate the transition towards sustainable aviation?

Therefore, the scope of the project is grounded in the overarching subject of transitioning from one socio-technical system towards a new socio-technical system, thus the transition from the current industry towards a sustainable and innovative industry. The current aviation industry and its adjacent influences can be considered as a socio-technical system, and thus be analysed as such. This chapter elaborates on the theory behind socio-technical transition and proposes a means to analyse them.

Socio-technical transition
The problem definition on which this thesis is based on revolves around transitioning the current aviation industry towards a more sustainable one. On an academic level, literature on this subject is available through system innovation and transitions. Currently, the most prominent literature on system innovation is within the socio-technical (ST) system transition, for which sustainable aviation can be categorized into. As argued by Geels (2002), the innovation of a system is the transition from one socio-technical system to another, which goes beyond the product and process level. While technologies are a crucial factor in the fulfilment of societal functions, they do not enable such transitions on their own. Only upon the interaction with social structures and organisations they fulfil functions such as mobility, healthcare and communication. The works of Geels (2002) therefore included the social influence in technological systems, achieving a more complete systemic perspective (figure 2).

The ST system is a combination of multiple actors on various levels, exerting influence on other actors. To put it simply, it's the interaction between technology and people. Each of the actors within the ST system have their own specific role and specific interaction with the technology and people in order for the transition to happen. With these ST systems, Geels (2002, 2010) developed the Multi-Level Perspective framework. This framework categorizes these actors into hierarchical levels and proposes the theoretical structure to frame and analyse the complexity of these transitioning ST systems, which is elaborated in chapter 2.2.

▼ Figure 2. Socio-technical system transition.



CHAPTER 2.2

MULTI-LEVEL PERSPECTIVE FRAMEWORK.

Introduction
The transition towards sustainable aviation is emerging and putting pressure against the established conventional aviation, the current ST system. The Multi-Level Perspective (MLP) framework is a means to provide an overview and analyse the changing ST system.

To understand the complex dynamics of the ST transition, the MLP aims to empirically combine the findings of various literatures into analytical and heuristic concepts (Geels, 2002), especially towards sustainability and resilience (Geels, 2010). The framework hierarchically poses three interacting heterogeneous levels, to categorize the different actors influencing the ST transition; macro-, micro-, and meso-level. (as can be seen in figure 3)

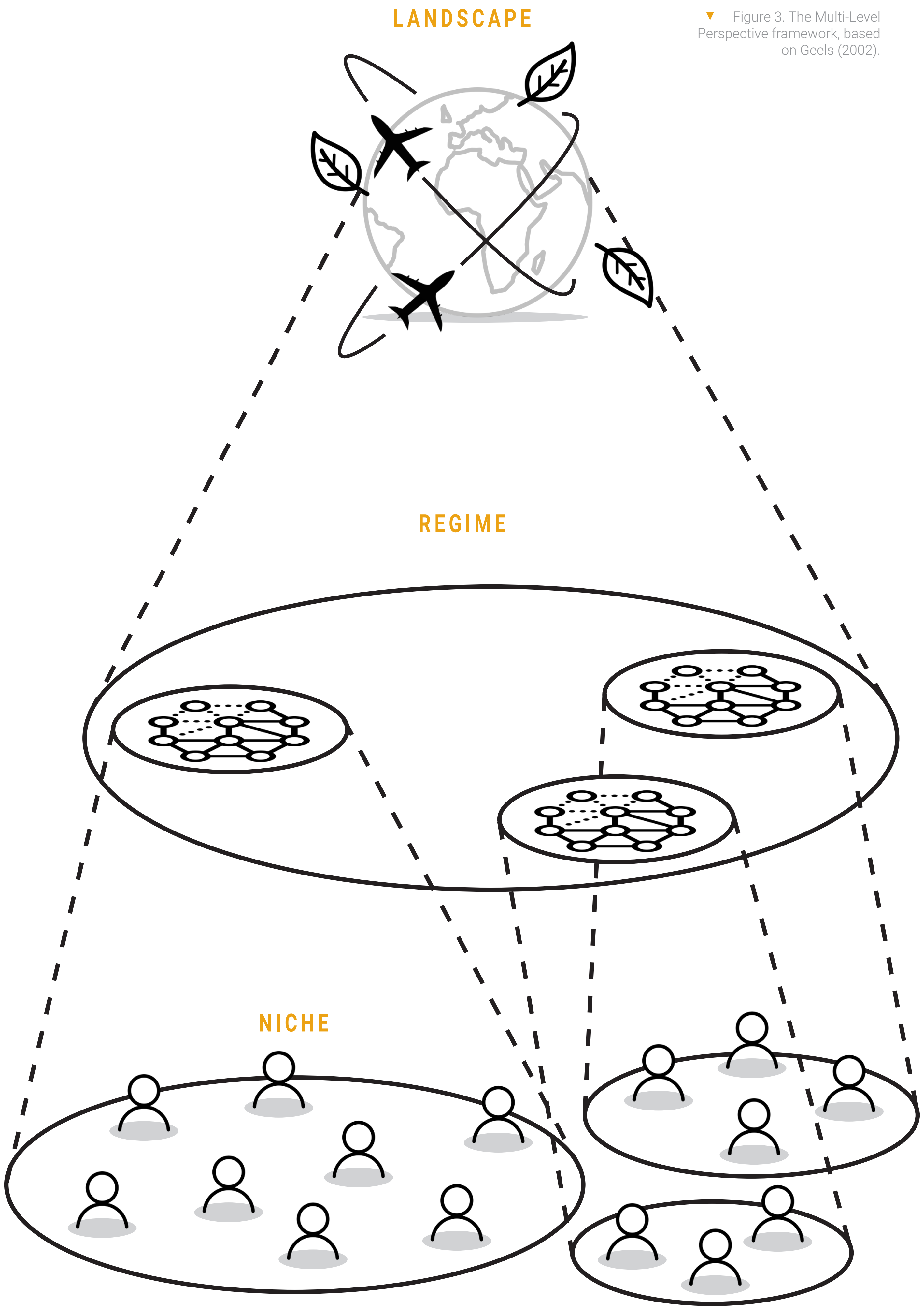
The MLP framework is the literary foundation for this thesis, as the goal of the thesis is to propose a plan to transition towards sustainable aviation by the means of electric aviation. This chapter explores the MLP framework by elaborating on the three levels and concluding with the structure of how a ST transition is enabled.

Landscape (Macro level)
The macro level is described as an exogenous landscape level, embedding macro-cultural changes and contextual developments in cultural deep structures (Geels, 2002). In the context of electric aviation, this means regulations, industry and infrastructure, technology, environment and culture. The macro level stimulates and exerts pressure on the two other levels.

Niche (Micro level)
Micro level, also called niche, is the origin for radical innovation. The actors within the niches develop configurations that work, called innovations (Rip and Kemp, 1998). Although these technological novelties are the origin of innovation, there remains a strong need for pressure on meso-level by the macro-level to let these innovations break through and create windows of opportunity for a ST transition (Geels, 2010). Both the macro and micro level are de-stabilizing factors within the existing ST system.

Regime (Meso level)
Actors on the meso level, also called regimes, stabilize and promote the ST transition. They ensure that innovation happens incremental along predictable trajectories. As Kemp (1994) explains, prevailing technologies have already had evolutionary improvements, allowing them to adapt and properly fit in the existing ST system. Archibugi (2003) goes a step further and argues that the prevailing policies support the existing ST system, but much less stimulate the novel ST system. Geels (2010) calls this lock-in mechanisms. On one hand this results in the rigidity in the regimes, and on the other hand this results in the stabilization of innovations caused by the predictable incremental trajectory changes. As previously mentioned, landscapes and niches originate de-stabilizing factors within the existing ST system. Regimes fulfil the role of stabilizing these factors incrementally, enabling the transition towards a novel ST system.

Phases of transition
The stabilization happening in the regime level is enabled by the linkage between the levels. The interacting processes result in the transition, which are defined as regime shifts. (Geels, 2010) The emergence of innovation happen in the niches, where the actors nurture radical innovations into the said configurations that work by Rip and Kemp (1998). But these novelties do not break through effortlessly. Geels (2005) argues that, in order



▼ Figure 3. The Multi-Level Perspective framework, based on Geels (2002).

for the radical innovations to break through and cause a systemic transition, four phases need to be walked through. He calls these phases the four phases of transition (figure 4).

The first phase is the result of the emergence of the radical innovation, enabled in the context of the existing ST system. This happens in the niche, where the design of the innovation is not definitive and the actors experiment on shaping the concept before developing the innovation in the second phase.

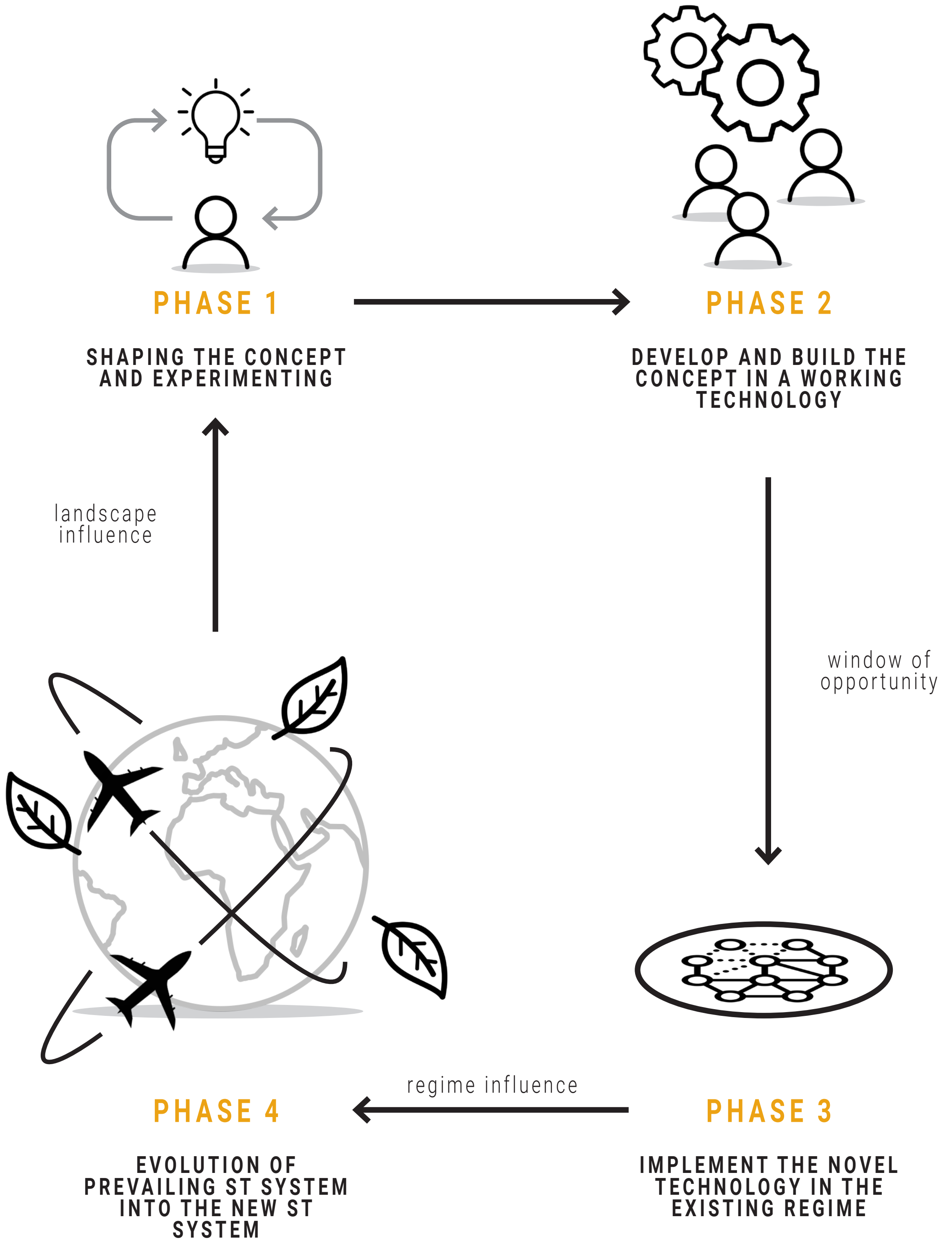
For the second phase, the actors nurture, experiment and develop configurations until the result is definitive and working. Within this phase, the radical innovation stabilizes and takes shape, driven by a community of actors.

In the third phase, the innovation breaks through and competes with the existing regime. The breakthrough is dependent on many internal drivers and external circumstances, called ‘windows of opportunity’, happening in all three levels (Geels, 2005). The windows of opportunity are the result of changes in landscapes and defects in regimes. Changes in landscapes puts pressure on the established regimes to transition and thus stabilize the ST system. Think of changing regulations, industry targets, or a shift in user preferences and thus a change in culture. Defects in regimes are the result of the existing technologies not (properly) solving occurring problems, driving novel innovations to take over and flourish. Note that these windows of opportunity are not the result of a single factor, but are the combination of simultaneous developments at multiple levels reinforcing each other.

At last there is the fourth phase. Within this phase, the regime is implementing the novel innovation, influencing the regimes in the system. Consequently evolving the prevailing ST system and thus shaping the novel ST system. As previously mentioned, this happens incrementally due to the lock-in mechanism within regimes. Geels (2010) argues that, in order to overcome these lock-in mechanisms and facilitate the transition, organizations should balance the exploitation of existing technologies and the exploration of novel ones. Upon the stabilization by the regime and thus finalizing the transition of the new ST system, a feedback loop occurs. The regime influences landscape developments, through shifting regulations, culture, technology and industries. Consequently, this enabled new windows of opportunity for niche innovations, resulting in a constant innovation loop, and thus constant transitioning ST systems.

These four phases of transition are the basis for the transition towards sustainable aviation, which consequently is the foundation of this thesis elaborated in the next chapter.

▼ Figure 4. Four phases of transition, based on Geels (2002).



CHAPTER 2.3

LITERARY INCORPORATION.

Introduction
The theoretical foundation laid in the first two sub chapters serve as the basis for the research direction and layout of this thesis. The phases covered in chapter 2.2 serve as an outline, resulting in a logical research structure and a conclusion in line with the exploitation of the window of opportunity which chapter 5 dives into. The current chapter elaborates on the structure of the thesis, shown in figure 5.

Thesis structure
As per Geels (2010), for a regime shift to happen, four phases of transition need to happen before full scale implementation. Before we move to those four phases, we need to gain an understanding of the current aviation industry and the shift in the prevailing landscape covered in chapter 3. Meaning, understanding the de-stabilization of the ST system and diving into the paradigm shift caused by changes in industry ambitions, which are putting pressure on regimes and niches.

Through these changes in industry ambitions, the four phases by Geels (2010) are set in motion. The first phase often happens below the radar of a regime, as this often entails individual actors in niches exploring user and market needs and ways to answer these needs with a concept, influenced by landscape factors.

The second phase is developing these concepts in viable products, readying them for a product-market fit. This is also the start of the research within the project scope. Innovative initiatives in this phase start to move on the radar of regimes. Chapters 4 and 5 cover research into these initiates and the desirability through the window of opportunity (and thus product-market fit) of these initiatives.

Chapter 6 focusses on stepping into the third phase, the enablement of an entry use case for the developing niche innovations and the exploitation of the window of opportunity. Chapter 7 elaborates on this entry use case and lay the outline of initial steps for Royal Schiphol Group to take for the innovation to enter the fourth phase: implementation within the regime, thus flourishment of the innovation and causing the current regime to evolve. Hekkert et al. (2007) differentiates seven functions that need to take place in innovation systems, leading to successful technology development and diffusion, thus in line with Geels' (2002) fourth phase of transition.

1. Entrepreneurial activities, which are innovative developments in the niche level.
2. Knowledge development, aligned with the third phase of transition by Geels (2002), where research and development increase technological performance by the means of learning curves.
3. Knowledge diffusions, sharing knowledge within a network of stakeholders to align visions, goals and resources.
4. Guidance of the search, with activities indicating input for resources to positively affect the direction of the technological change.
5. Market formation, developing a niche market for actors to understand and diffuse the new technology, often called early adopters in diffusion theory.
6. Resource mobilization as financial and human capital.
7. Creation of legitimacy and counteract resistance to change.

While function 1 is comparable to the first and second phase of Geels (2002), function 2 to 7 are comparable to factors within the third phase of Geels (2002). (Hekkert et al. 2007)

These functions are especially well-suited for those first steps towards electric aviation, as Hekkert et al. (2007) focusses on sustainable technology development, which is the empirical field he bases these functions on. This fourth phase will not be feasible for the foreseeable future as there are currently too many uncertainties within the developing regime, which will become evident later in the thesis. A first step in the direction of this phase is possible, which will be proposed in chapter 7.

▲ Figure 5. literary incorporation in the structure of the thesis.

But, as mentioned previously, before we dive into the phases of transition we must gain an understanding of the background behind the current landscape developments and the electric and conventional aviation industry. This is covered in the next chapter.

CHAPTER 2.4

KEY TAKEAWAYS.

- The MLP framework serves as a structure for hierarchically categorizing factors influencing innovation transitions.
- We can divide three hierarchical levels in this framework; landscape, regime and niche. Each level is needed in the transition from one ST system towards a new one.
- Geels (2010) came up with four phases in which an innovation transition happens, building forth on the MLP.
- The structure of this paper is based on the four phases of transition, resulting in gaining an understanding of the industry innovations from phase two, and proposing an entry use case for RSG to transition towards the third phase.

03

LANDSCAPE BACKGROUND ANALYSIS.

As mentioned in chapter 2, before diving into the current niche developments, it is crucial to understand the trigger which caused the transition within the industry. This chapter gives an insight in these drivers, putting forward the cause and what it has led to up to 2020.

CHAPTER 3.1

THE INDUSTRY AND ENVIRONMENT.

Introduction

Aviation as we know it is currently shifting from its normal pattern, causing a paradigm shift within the industry. The reason for this paradigm shift is the change in regulations and global ambitions in the area of sustainability. This chapter puts the focus on providing insights in the origin of these changes on landscape level, in order to gain an understanding why aviation, the current ST system, is evolving.

Regulations and regulators

The start of this paradigm shift is climate change. Back in 2009, the combined global research on climate change stated that a rise of 2°C is the limit which endangers the current ecosystem of the world (Mommers, Vroomen, & Asbury, 2020). Six years later, in 2015, the United Nations Framework Convention on Climate Change (UNFCCC) developed the Paris Agreements. In these agreements, a new and more ambitious goal is stated: having the global rising temperature limit at 1.5°C, as this could result in major negative impacts on health, day-to-day activities and income, food and water supply, and economic growth (IPCC, 2018). These agreements lay the foundation of goals set in the aviation industry by various organisations, and has been supported by the 2018 Intergovernmental Panel on Climate Change (IPCC), who published their quinquennial report on the status quo of climate change.

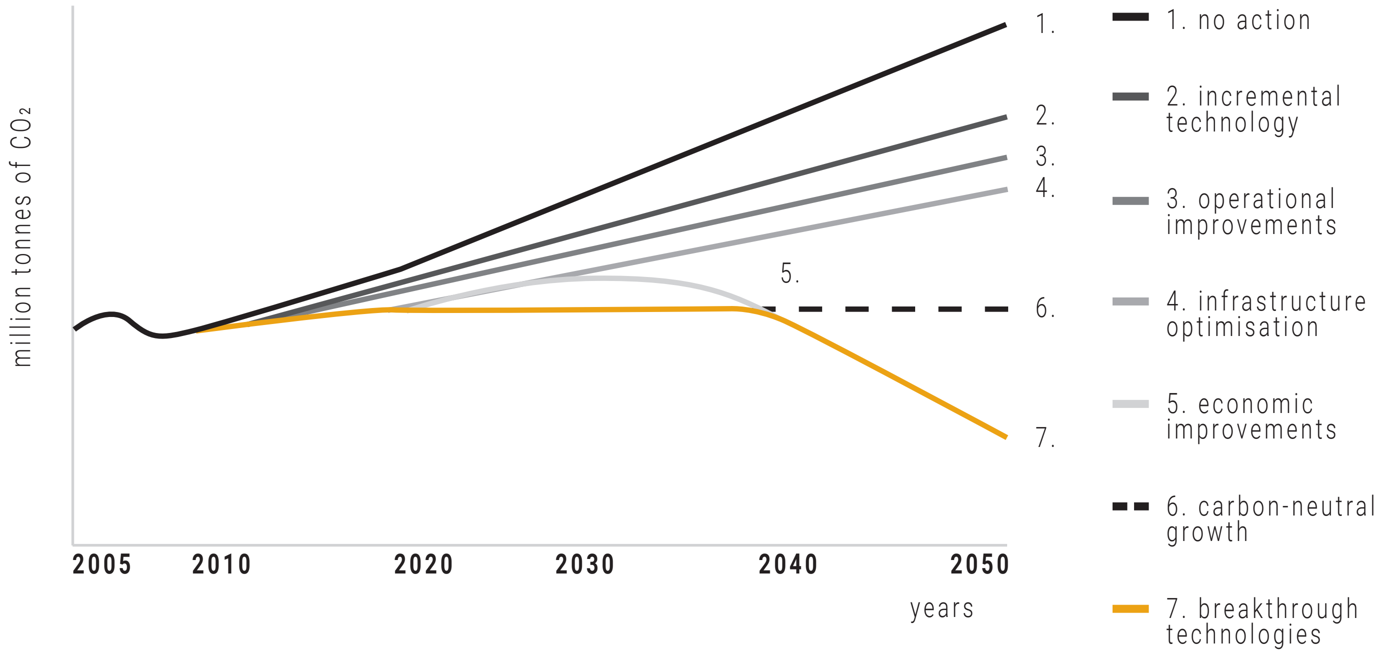
The UNFCC, Paris Agreements and IPCC findings have an immense impact on global level over multiple industries, including the aviation industry. With these findings, the Sustainable Development Goals (SDG) have been developed by the United Nations (UN) in 2015, to be achieved by 2030. The goal of these SDG are meant for a more sustainable future for all by 2030 (United Nations, n.d.). The International Civil Aviation Organization (ICAO), which is a body of the UN focussing on setting the standards within the aviation industry, uses the SDG to develop their own strategic objectives to reach a better and more sustainable aviation industry, with initiatives such as the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) (ICAO, n.d.).

Figure 6 provides an overview of the relevant bodies whom shaped the sustainability goals and ambitions. Note that Royal Schiphol Group has similar ambitious goals compared to the global targets by the IPCC. As of now, the aviation industry causes 3% of the global CO_2 emissions, to be increased to 24% by 2050 if nothing changes. (figure 7) Therefore, with all these initiatives and ambitious goals, the global aviation ecosystem is working towards the sustainable net-zero CO_2 emissions by 2050 ambitions to stay below the 1.5°C ceiling.

IPCC	ICAO	GOVERNMENT	RSG
GLOBAL TARGETS	INDUSTRY TARGETS	DUTCH TARGETS	COMPANY TARGETS
2030 -45% CO_2 for all sectors compared to 2010.	**2030** 2% annual fuel efficiency improvement.	**2030** CO_2 levels equal to 2005.	**2030** Aviation CO_2 equal to 2005.
2050 -100% CO_2.	**2050** 50% CO_2 reduction compared to 2005.	**2070** -100% CO_2 aviation.	**2050** -100% CO_2 aviation.

▲ Figure 6. Landscape and regime sustainability targets (Schiphol, 2020).

▼ Figure 7. Schematic CO_2 emissions reduction roadmap. (IATA. 2013). CO_2 emissions versus years.



CHAPTER 3.2

DRIVER OF NICHE INNOVATIONS.

Introduction
One of the developments within the sustainable aviation industry is the electrification of aircrafts, which falls under the scope of the project. But note that electric aircrafts is no novelty within the industry. The first manned electric powered free flight aircraft dates back to the 1970s. Now over 50 years later, electric aviation starts to become relevant. The reason for this is twofold, caused by landscape push and pull factors.

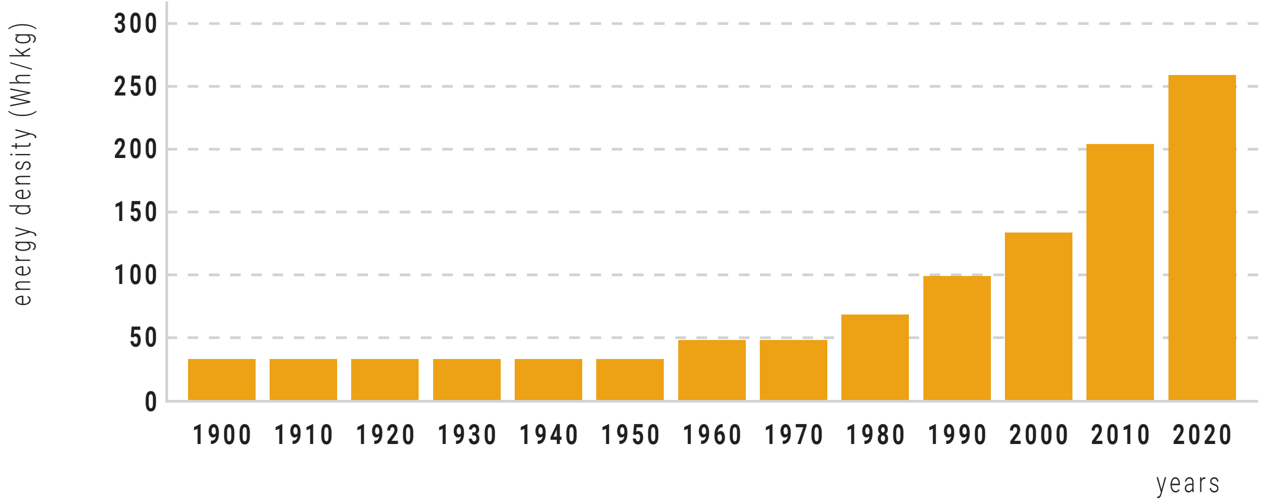
Sustainability pull
The factor causing a landscape pull is sustainability driven, as covered in previous chapter. The global aviation industry is committed to achieve a net-zero CO_2 emissions by 2050, which means that all parties within the industry take actions to work towards the ambitions set by the industry. Because of this demand, initiatives have risen to achieve these sustainability goals such as alternative fuels, new aircraft designs, more efficient motors or even changing business models towards other modalities. The electrification of aircrafts is merely one solution to be researched, but a very relevant one.

Battery innovation push
On the other hand, there is a landscape push through technology, mainly in the battery sector. As chapter 4 will cover, batteries are the single most important enablers of the electric aviation developments. And the metric which drives the batteries to success is its energy density (in Wh/kg).

The first rechargeable (also called secondary) battery was a lead-acid one in 1859, invented by Gaston Planté. Since then, people have been looking for ways to implement batteries for different use cases. The lead-acid batteries which were available usually had an energy density of 35-40 Wh/kg up to the 1950s. As shown in figure 8, the developments in battery innovation have stalled until the second half of the 20th century, where new batteries had been discovered and experimented with. From this point on, there has been a constant increase in growth in the past 50 years. The most recent technology is Lithium-ion batteries which increased the energy density to 100-160 Wh/kg, which were commercialized by Sony in 1991 (Kyria Ltd, 2017). In the first half of the 2010s, the energy density of batteries grew to 200-240 Wh/kg, and in the second half it reached 260 Wh/kg. Between 1991 and now, multiple parties have built successful companies around batteries. Tesla is a good mobility example in the adjacent automotive industry; having developed a car around a battery with an energy density of 260 Wh/kg (Reuters Staff, 2020).

Besides the feasibility aspect, the economic viability is increasing as well. The energy cost of a kilo Watt hour (kWh, the energy unit of electricity) has fallen by 90% past 10 years. The investments in sustainable aviation technology has risen; the French government offered a €15 billion bailout package as a result of the pandemic for the aviation sector. This included €1.5 billion which has to be spend on research and development of alternative fuels and hybrid-electric short haul aircrafts. (Reuters event, 2020) In the electric vertical-take-off-and-landing (VTOL) aviation industry, investors spent over $3.0 billion in the last five years on startups, aerospace and automotive companies. (McKinsey seminar, 2020)

The relevance of the electrification of the aviation industry in the 2020s is thus a combination of the technological feasibility, economic viability and sustainable desirability. Although many sustainable alternatives to the modern-day aviation climate impact are being explored by the industry, this thesis focusses its exploration on hybrid and electric aviation and its applicability for RSG. Chapter 4 dives into the different sustainable alternatives, exploring the niche innovations currently achieving a certain technological readiness and gain an understanding in the potential of these innovations upon further development.



▲ Figure 8. Battery innovation timeline, based on Chen-Xi, Z., Hong, L. (2011) historical battery timeline.

CHAPTER 3.3

KEY TAKEAWAYS.

- The global industry has set ambitions to reach the sustainability goal of net-zero CO_2 emissions by 2050.
- The driver for niche innovations is the mentioned sustainability pull and the technology push in the battery innovation niche. These battery innovations have enabled use cases in the adjacent automotive industry and are currently shaping the electric aviation industry.
- The metric which enables batteries to be successfully implemented for different use cases is energy density Wh/kg.
- The energy density of commercialized batteries have risen to 260 kW/kg up to 2020.

04

NICHE INNOVATION DEVELOPMENT.

The landscape developments resulted in two drivers which have been covered in the previous chapter; a sustainability pull and a technology push. These drivers enabled innovations in niches to become relevant and to develop. Chapter four gives an overview of those niche innovations in the electric aviation market and in the adjacent battery market. Finally, it provides a perspective for which electric aircrafts can fit in the current ST system.

CHAPTER 4.1

FUEL AND AIRCRAFT INITIATIVES.

Introduction
The scope of the project defined in chapter 1 is the developing electric aviation industry. More specifically, how the electric aviation aspect fits in the future of mobility. Electric aviation is but one of the many developing technologies enabled by those drivers covered in chapter 3 as an alternative to conventional aviation fueled by kerosene. This chapter covers the basis in terms of alternative sustainable fuels, including biofuels, synthetic fuels and hydrogen fuel, to understand how electric fuel compares to other developing fuels. Figure 9 provides a schematic overview of these fuels. It then provides an overview of the current niche innovation initiatives in the electric aviation industry, including several prominent hydrogen players.

Biofuels
The fuel that is produced by using biomass as its main component is called biofuel. This is different from kerosene, which is produced through the fossilization of geological components, and is thus not only a finite resource, but also a fuel which emits emissions when utilizing it.

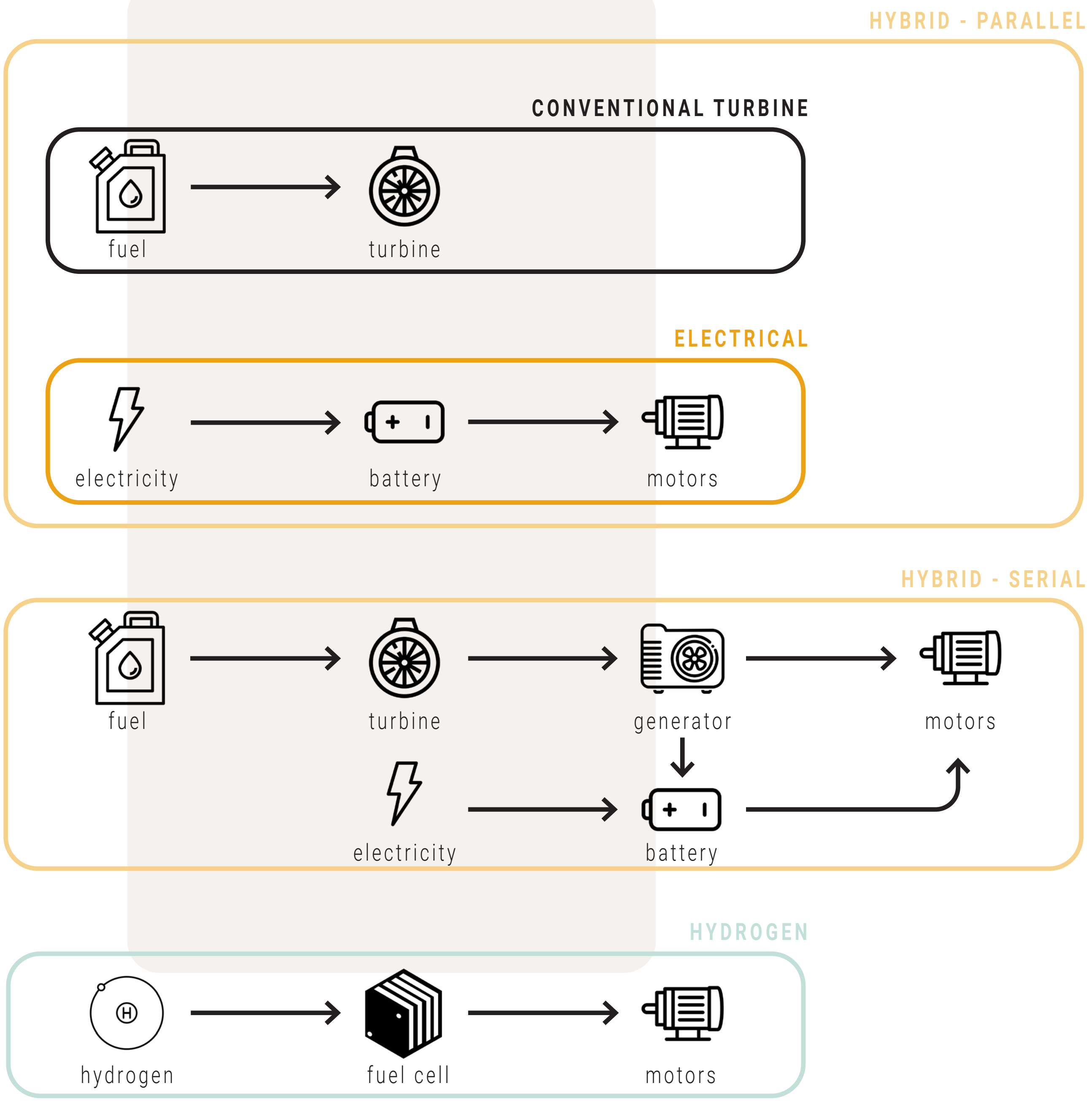
In this day and age, biofuels are available and able to be used in current processes and aircrafts. The technology is mature enough and certified to use at scale. Based on a Royal Schiphol Group research, the emission reduction potential of CO_2 is between 40% and 85%, depending the blend mix percentage. (Royal Schiphol Group, 2020)

Synthetic kerosene
For this fuel, biomass, coal or reformed natural gas converts to two products called hydrogen (H_2) and carbon monoxide (CO). These two gasses are converted by the Fischer-Tropsch (National Energy Technology Laboratory, n.d.) process to synthetic oil and synthetic fuel. This process is almost zero-carbon based, as the product CO is a waste product, and H_2 is made by splitting water into H_2 and oxygen (O_2) by a process called electrolysis. The downside of the process is the energy requirements to produce synthetic kerosene: the energy needed is 4.6x the energy it delivers (McKinsey, 2020).

As synthetic kerosene is a fuel comparable to kerosene, it can be injected in the combustion engine of an aircraft. Thus, it enables the usage in modern-day aviation operations. On the other hand, the production of synthetic kerosene is not yet scalable, as the technology and renewable energy sources still needs to be developed. Based on the research by Royal Schiphol Group, the emission reduction potential of CO_2 is between 50% and 100%, depending the blend mix percentage and the source of electric energy used in the production of the fuel. (Royal Schiphol Group, 2020)

Hydrogen
At last, hydrogen is created by either steam reforming fossil fuels, or through the electrolysis of water. Hydrogen is therefore very similar to synthetic kerosene, as the H_2 is one of the products needed to create synthetic kerosene. As the fuel is stored as a gas under high pressure or as a liquid, it cannot be injected in the conventional combustion engine. From the tanks in the aircraft it is converted into electricity to be used in the electric propulsion engines.

In itself, hydrogen is an incredible potent fuel: it is 3x more potent than kerosene, as its energy density is 33.6 kWh/kg compared to the 11.9 kWh/kg of kerosene (Flyingmag, 2020). And, dependent on the source of production, it can be up to 100% CO_2 emission free. But the downside is the volume of the gas and thus the storage, which



▲ Figure 9. Schematic overview of different energy systems in aircrafts (McKinsey Seminar, 2020).

is inconvenient for the current aircrafts and thus not feasible. On the other hand, liquid hydrogen tanks have a greater feasibility potential than their gas counterparts (Collins, J. M. & McLarty, D., 2020). The downside of liquid hydrogen is the energy need to produce it: the energy efficiency to convert electricity to H_2 is 60-75%, converting it back to electricity has an efficiency of 60% (McKinsey, 2020).

In order for hydrogen to become feasible, the technology and infrastructure needs significant developments. Only then it has the potential to become a leading propulsion system for medium-range flights. Net-zero aviation is not feasible with hydrogen propulsion, but it has the potential to reduce up to 65% CO_2 equivalent emissions. (McKinsey, 2020)

Hybrid-electric

Electricity as a fuel is a much simpler fuel than it's kerosene, biofuel, synthetic fuel of hydrogen counterparts. To simplify the process, electricity is stored in a battery inside an aircraft. Upon utilizing it, it can directly be converted into propulsion energy for the aircraft to take-off and fly, as can be seen in the schematic overview in figure 10. This figure shows the different fuel systems and the components within. From these different systems, the simplest for manufacturing and maintenance is the electrical system. Hybrid-electric systems is more complex, as it combines both conventional and electric systems.

As developing new aircraft is a capital and time intensive venture and the Federal Aviation Administration (FAA) takes several years (5-9 years) to certify new aircrafts, an interim solution of electric aviation is the development of hybrid-electric aircrafts, which take less time to certify (3-5 years) (Federal Aviation Administration, 2019). With this technology, you can modify existing aircrafts and replace engines with electric motors. This enables flying part of certain missions electric, which results in both a 10-30% total reduction in energy usage and CO_2 emission when using electric propulsion during landing and take-off (LTO) (Zaporozhets, O., Isaienko, V., & Synylo, K., 2020). Also note that electric propulsion LTO reduces noise pollution, which has been a local recurring issue around airports.
The hybrid-electric aviation industry is currently in development, with different players exploring the applications of this technology. It is expected that beginning of the decade multiple parties will receive FAA certifications for their hybrid-electric aircrafts, which means they are commercially ready. As this is an early-stage industry, the industry is not yet fully scalable, but is expected to enable large scale implementation end of the decade, due to innovations in adjacent markets such as the battery industry. Experts say that, for 100 seat hybrid-electric aircrafts to become feasible, batteries are needed with an energy density of 800 Wh/kg (China Aviation News, 2019). Chapter 4.2 elaborates on the specific battery developments.

Full-electric

Full electric is the desired technology to be implemented commercially. The technology is novel, and its opportunities are currently not fully understood (Brelje, B. J., & Martins, J. R. R. A., 2019). This means it is therefore not yet feasible in 2020 and will not be feasible for the larger part of the general and commercial aviation soon.

The potential of the full-electric aviation is removing all non-CO_2 impacts and the reduction of 100% in CO_2 emissions, if the electricity produced and used for charging is done by renewable means. NASA (2020) calculated that, on a global

scale, the potential of full-electric aviation will substitute 15% of the commercial aircraft fuel use and eliminate 40% of the global LTO-related NOx emissions.

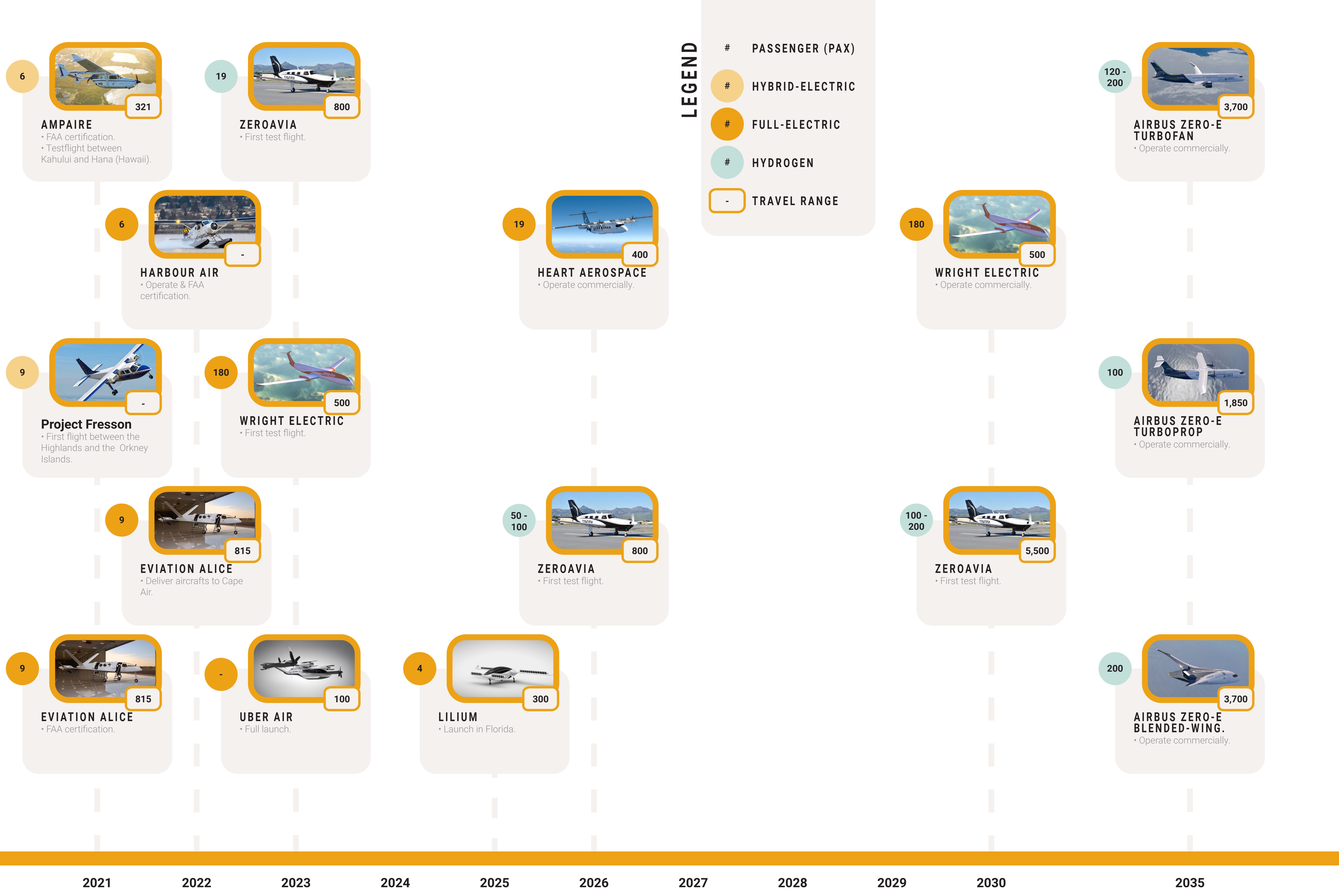
Even though it is not yet feasible in 2020, it will be feasible before 2030 for a limited amount of specific use cases. These use cases are limited by the number of passengers (pax) and the range of the flight. On short haul flights, under 1,000 km, with a relatively low pax, maximum of 19 seats, full-electric aviation is feasible this decade. Similar to hybrid electric aircrafts, experts say that in order for a 100-seat full electric aircraft to become feasible and thus viable commercially, batteries are needed with an energy density of 1,800 Wh/kg (China Aviation News, 2019).

Developing niche initiatives

Based on this research, we are able to conclude that (hybrid) electric aviation is feasible in the foreseeable future. Currently, the biggest challenge in the aviation industry is reducing CO_2 emissions to net-zero by 2050. Hybrid and full electric aviation have the potential to do so, but on relative short-haul distances. Therefore, what we can expect from hybrid electric aviation is to achieve a range of 321 km for 3 passengers and for full electric aviation to achieve a range of 815 km for 9 passengers, by Ampaire and Eviation Alice respectively. The mentioned aircraft of Ampaire is a mere testbed model, and they are planning to develop a 19 seater hybrid-electric model for a similar range (Ampaire, n.d.). Any milestones for this aircraft are yet not available. For hydrogen propulsion system, it seems that ZeroAvia is aiming to achieve a range of 800 km for 10-20 passengers.

On the other hand, established players in the market are aiming for the second half of the decade. Wright Electric in collaboration with EasyJet is aiming to develop a 180-seat full-electric propulsion jet with a range of 500 km, to test in 2023 and to commercialize by 2030. Airbus aims for commercialization by 2035 with hydrogen electric propulsion aircrafts, for passenger ranges of 100-200, and travel ranges of 1,850-3,700 km.

These players are currently the initiatives with the highest potential to be developed and implemented within the hybrid-electric, full-electric and hydrogen aviation industry. These aircraft innovations will help the industry get a step closer to their sustainability ambitions. Figure 6 shows the overview of the most mature and highest technology readiness initiatives in the sustainable aviation industry, plotting their type of fuel, pax, range and their milestones. Note that this is the perceived foreseeable future in the aviation niches. There are two adjacent niches which are going to play a major role in the electric aviation industry maturity; battery and engine developments, the ability to have more energy available on a flight and the ability for energy to have a higher efficiency upon consumption.



LEGEND

- # PASSENGER (PAX)
- # HYBRID-ELECTRIC
- # FULL-ELECTRIC
- # HYDROGEN
- - TRAVEL RANGE

2021

6 · 321 **AMPAIRE**
- FAA certification.
- Testflight between Kahului and Hana (Hawaii).

9 · - **Project Fresson**
- First flight between the Highlands and the Orkney Islands.

9 · 815 **EVIATION ALICE**
- FAA certification.

2022

6 · - **HARBOUR AIR**
- Operate & FAA certification.

9 · 815 **EVIATION ALICE**
- Deliver aircrafts to Cape Air.

2023

19 · 800 **ZEROAVIA**
- First test flight.

180 · 500 **WRIGHT ELECTRIC**
- First test flight.

- · 100 **UBER AIR**
- Full launch.

2024

2025

4 · 300 **LILIUM**
- Launch in Florida.

2026

19 · 400 **HEART AEROSPACE**
- Operate commercially.

50 - 100 · 800 **ZEROAVIA**
- First test flight.

2027

2028

2029

2030

180 · 500 **WRIGHT ELECTRIC**
- Operate commercially.

100 - 200 · 5,500 **ZEROAVIA**
- First test flight.

2035

120 - 200 · 3,700 **AIRBUS ZERO-E TURBOFAN**
- Operate commercially.

100 · 1,850 **AIRBUS ZERO-E TURBOPROP**
- Operate commercially.

200 · 3,700 **AIRBUS ZERO-E BLENDED-WING.**
- Operate commercially.

▲ Figure 10. Overview of the aircraft innovation forecast timeline.

CHAPTER 4.2

ADJACENT NICHE DEVELOPMENTS.

Introduction

This brings us to questioning what the foreseeable future holds besides the perceived initiatives. As mentioned previously, several niche developments have the potential to accelerate or cause radical innovation within the electric aviation industry. The formula to calculate the pax and range of electric aircrafts has been simplified by Ferrier (2015), which can be found in appendix C. While lift to drag ratio and total aircraft weight can be considered incremental optimizations, energy density of the batteries (and thus affecting the battery mass) and propulsion efficiency have the potential for radical innovation.

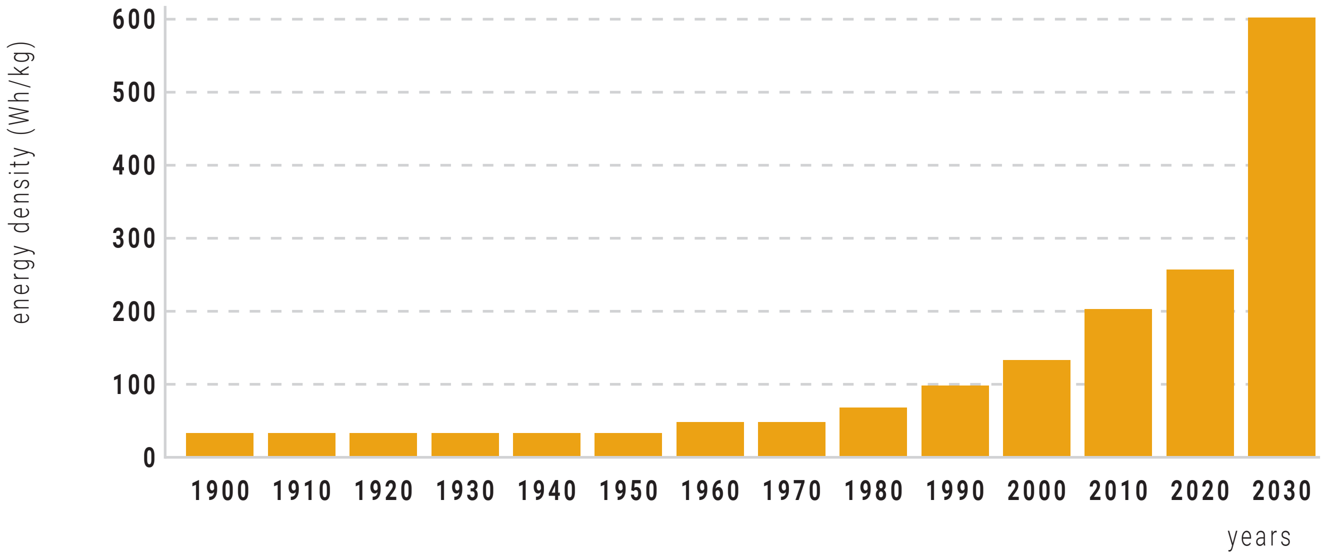
Chapter 4.2 aims to bring an overview of developments within these two niches, in order to understand the potential of these developments upon implementation in the electric aviation industry.

Battery innovation

The crucial criteria in the state-of-the-art batteries are its energy densities. The current batteries are lithium-ion (Li-ion) based and hold about 260 Wh/kg. To give a perspective how it compares to conventional kerosene: kerosene holds about 11,900 Wh/kg, which is almost 50x as much as state-of-the-art Li-ion batteries. On top of that, the batteries have a lifespan of about 1,500-2,000 charge-discharges cycles before they lose their capacity. ZeroAvia CEO Val Miftakhov arguments that, upon full depletion by eight flights (four round trips) a day, the batteries will need to be replaced after seven or eight months which is problematic (Charged EVs, 2021). At last, the downside of the battery as a fuel supply compared to conventional kerosene fuel is the weight factor. Conventional aircrafts become lighter over time when utilizing the kerosene and depleting the fuel tanks. Electric aircrafts do not lose weight over time upon utilizing electricity, as the battery does not reduce in weight when emptying its storage.

Multiple parties expect battery technology to innovate upcoming decade. One independent body who's keen on researching battery technologies is the National Aeronautics and Space Administration (NASA). They expect the energy density of batteries to increase to 300-400 Wh/kg between 2022 and 2025. And for 2030, they expect that 600 Wh/kg is achievable but challenging (NASA, 2017). Other research shows that the future of battery hold energy densities between 750 and 1,500 Wh/kg. (Voskuijl, M., van Bogaert, J. & Rao, A.G., 2018) Based on China Aviation News (2019), energy densities between 1,000 and 1,500 Wh/kg are expected between 2030 and 2035. Figure 11 plots the battery energy density forecast in 2030, upon taking a conservative approach with NASA's battery forecast of 600 Wh/kg. There is a very clear trend depicted in the figure, an exponential growth. Where the energy density developments in the early 1900s were slow, an increase in growth has been taking place in the recent 50 years.

The swiss company Innolith is one of the parties researching and developing new commercial batteries. In 2019 they announced that they have developed world's first lithium-based rechargeable battery with an energy density of 1,000 Wh/kg. (The Engineer, 2019) This would enable short range (up to 1,900 km) air travel, with new electric aircraft initiatives. This battery is based on a conversion type Lithium chemistry technology, which ensures a safer battery as there are fewer ways for the battery cells to fail. On top of that, the battery has an increased lifespan compared to the current Li-ion batteries with over 55,000 charge-discharge cycles. This is between 10 and 100 times the lifespan of conventional Li-ion batteries. According to Innolith, it takes about three to five years to implement these batteries, which is between 2022 and 2025.



▲ Figure 11. Battery innovation forecast, based on Chen-Xi, Z., Hong, L. (2011) historical battery timeline.

Another pioneer in the research of battery technology is the University of Tohoku located in Japan. A group of 70 engineers from this university have started a company called 3Dom, who aim to commercialise a Lithium-metal battery which offers close to twice the amount of energy than current Li-ion batteries. And they expect to do so by 2022. (Financial Times, 2020) 3Dom is partnering with Lavle, whom they will work together to commercialize the 420 Wh/kg batteries (PR Newswire, 2020). Furthermore, the research at the University of Tohoku show that they enabled an all-solid-state Lithium-sulfur battery with an energy density of 2,500 Wh/kg. Though this is probably available in the unforeseeable future, as they do not provide an implementation date for this.

Engine innovation

In terms of engines, the power-to-weight (specific power) and efficiency are crucial. The specific power is a metric used to calculate the amount of power (in Watt) is needed to move a specific vehicle. Thus, the total amount of Watt is divided by the weight of the aircraft in order to calculate the power-to-weight. Within the electric aviation field, current electric motors are under 1 MW. As the electric engines do not have a high-temperature power turbine, they are relatively simpler to construct and maintain (Aviation Today, 2020). This enables the scalability of electric engines, which boosts the feasibility for electric aircrafts.

A European Union funded demonstrator called ASuMED is currently developing a superconducting engine. The power-to-weight of this motor is 20 kW/kg, with an efficiency over 99% (Engineering, 2019). This is much higher compared to the modern-day electric engines with an efficiency of 80% (Schäfer, A. W., et al., 2019). Therefore, the electric engines have the potential to be upscaled to 10 MW. These superconducting engines enable the scalability of the electrified commercial aircraft industry in the distant future, as the literature of these innovations is yet purely academic. Implementation of these engines in the electric aviation industry forecast will therefore not be included.

With the niche innovation initiatives overview of (hybrid) electric aircrafts in chapter 4.1 and the adjacent niche developments of the battery innovations in chapter 4.2, an overview can be provided of the possibilities and opportunities of the electric aviation industry.

CHAPTER 4.3

INNOVATION HYBRIDISATION.

Introduction

Within the ST transition literature, Geels (2002) describes a phenomenon called niche-cumulation to enable innovations to break out of the niche- into the regime-level. This phenomenon consists of two mechanisms: market growth and hybridisation. We have seen market growth in the electric aviation (and thus sustainable aviation) market and the battery market in chapter 4.1 and 4.2 respectively. This chapter covers the second mechanism called hybridisation. Geels (2002) describes hybridisation as "new technologies in their early phase that physically link up with established technologies, often to solve particular bottlenecks. Thus, old and new technologies do not immediately compete head on, but form some sort of symbiosis."

When looking at electric aviation and understanding the hybridisation of it based on Geels (2002), it is not the technology per se that becomes hybrid. The existing technologies to be considered are the current existing modalities in the mobility industry, meaning the car, train and conventional aircraft. This is what this chapter focusses on, understanding how electric aviation forms a symbiosis with current modalities, and thus could potentially substitute current non-sustainable conventional aviation.

Up to 2030

As can be observed from the map in figure 12, three ranges are relevant in the future. Staying within the scope of the thesis, the benchmark range of electric aviation is expected to be at 400 km (figure 12, a). Heart Aerospace is the leading electric aviation startup in Scandinavia, whom have set the most ambitious goals of the industry: all domestic flights to be substituted by full-electric aircrafts by 2030. Meaning Heart Aerospace will play a significant role in this ambition. Other initiatives, such as Lilium or Uber Air, have Urban Air Mobility (UAM) use cases rather than commercial aviation on international trajects. Meaning, they are designed and developed to serve as a taxi by air rather than an aircraft moving between airports. UAM startups have use cases up to 300 km, with a VTOL feature enabling interesting and specific use cases. Think of overcoming short-range geographical obstacles such as a sea (between the Dutch Antilles, to England from the Netherlands, or even summer travels towards vacation destinations such as Mallorca or Ibiza) and mountains (Scandinavian mountains and fjords) or emergency use cases such as regional VTOL ambulances.

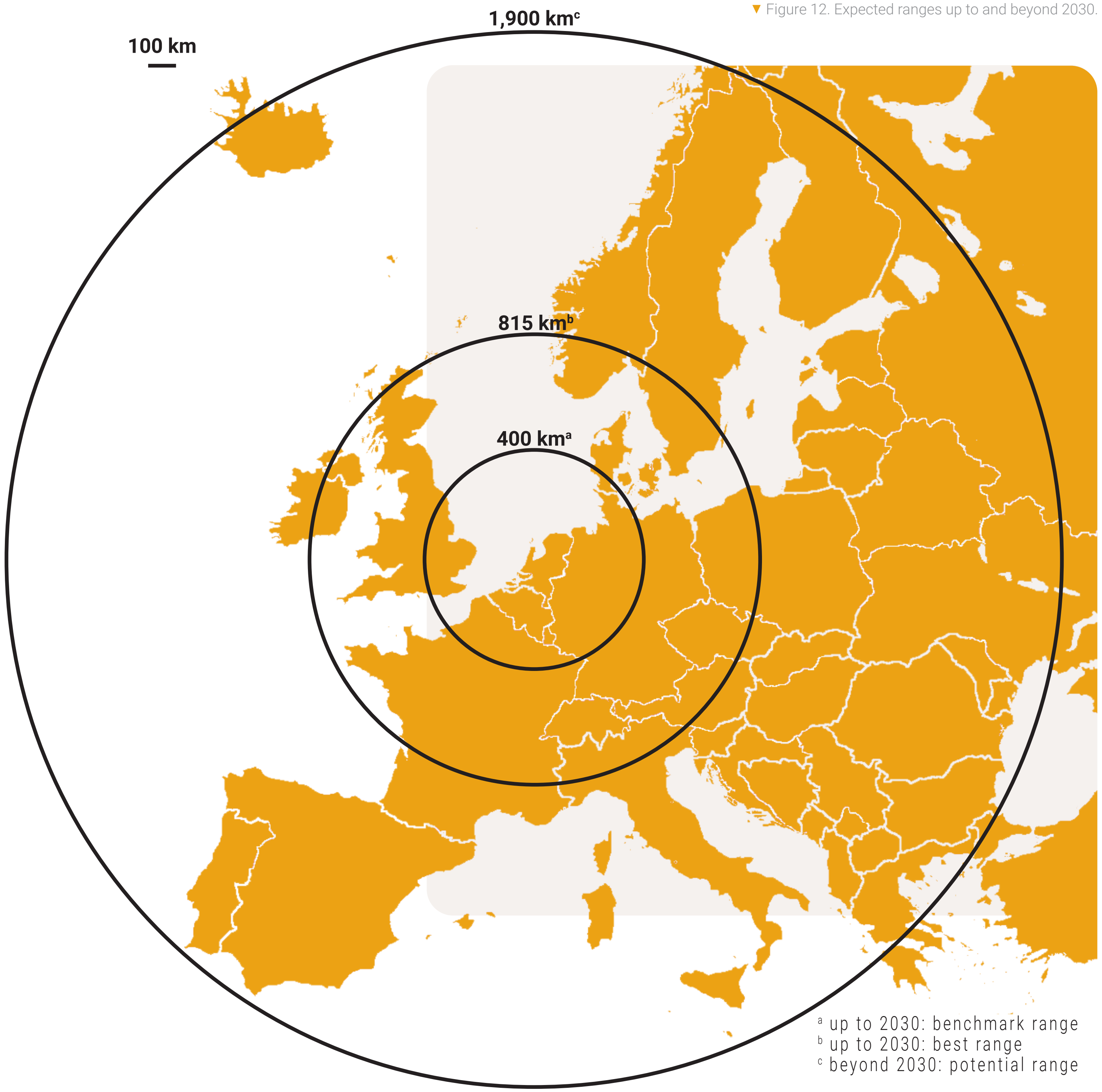
For commercial aviation, we can expect a feasible benchmark range of 400 km by 2030. Many prominent destinations for aviation are within this range, such as Hamburg, Frankfurt and London. Within the benchmark range, we can expect and dive into different traject possibilities.

But then there is also Eviation Alice, considered the best player in the market with range as metric (figure 12, b). An Alice aircraft has a range of 815 km, based its current technology with batteries having an energy density of 255 Wh/kg, the current standard for 2020. A total of 164 suppliers have worked on the project, reasoned by the disrupting potential of the aircraft. This is also the reason why Clermont Group is backing the project. On top of that, Cape Air, the largest independent US regional airline, have released the acquirement of a double digit number of Alice aircrafts to be added to its fleet. Currently, Eviation has set to commercially deliver their Alice aircrafts in 2023.

Beyond 2030

At last, the potential range. It is expected that the battery energy density increases to 600 Wh/

▼ Figure 12. Expected ranges up to and beyond 2030.



[a] up to 2030: benchmark range
[b] up to 2030: best range
[c] beyond 2030: potential range

kg at the end of the decade. While Eviation Alice has a range of 817 km with the current feasible technologies, the implementation of the these batteries and engines would increase its range over 1,900 km based on Ferrier's (2015) equation to calculate aircraft range (figure 12, c). This would significantly increase the amount of destinations electric aviation enables.

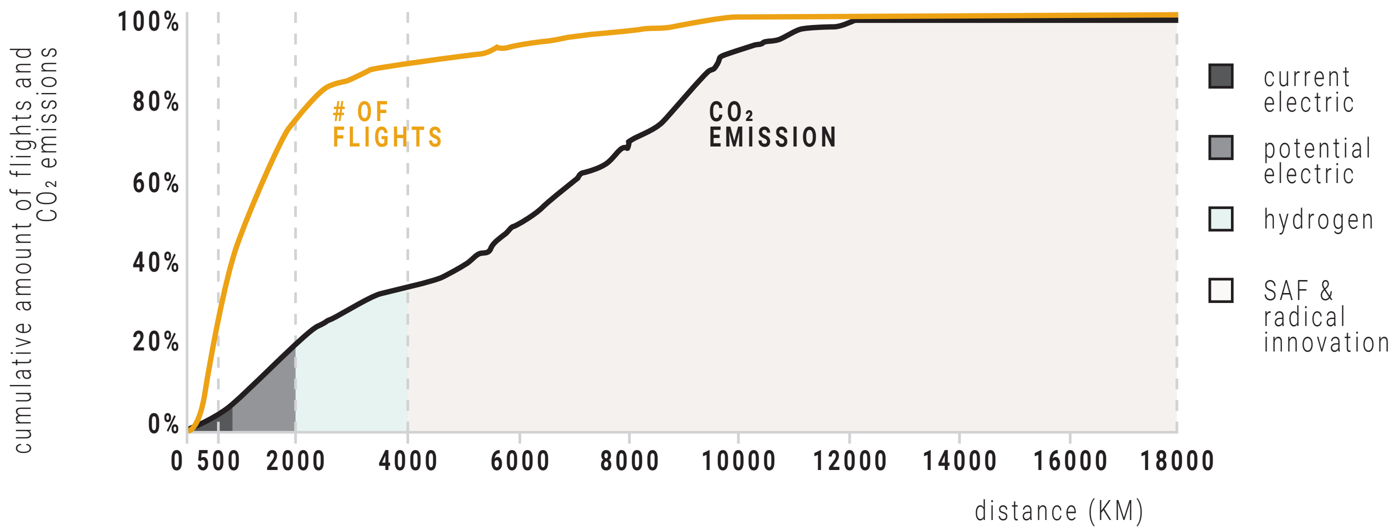
Pax versus range

While a battery with a higher energy density increases the range of an aircraft, it also has the potential to use decrease the weight of the batteries while maintaining the total energy capacity. This allows for the substitution of aircraft range into additional pax. This is a fair dilemma current aircraft manufacturers are facing. Arguably based on Geels' (2002) hybridisation, a stronger bottleneck for both the viability and sustainability of electric aviation is range rather than pax for two reasons.

The first reason is the issue revolving around certifying aircrafts. Aircrafts with a pax below 19 receive different certifications than aircrafts above 19 pax. This influences the timescale at which these aircrafts can be implemented, and thus influence the rate at which the industry ambitions can be met. On top of that, when using the specifications of an Alice aircraft, when reducing 50% the battery weight and therefore also its range, it allows for an additional 19 pax on the flight. Besides certification, replacing the current batteries with denser ones is a process less complex than redesigning an aircraft to allow for more pax. It is therefore more beneficial to enable an Alice aircraft to reach a range over 1,900 km and a Lilium Jet to reach a range over 700 km, rather than redesigning the plane to allow for more passengers. Appendix C elaborates on the calculations regarding pax versus range.

The second issue is the substitution potential. Figure 13 shows the percentage of conventional flights to be substituted for an electric counterpart in Europe. This is a vast amount of flights, but a relative small reduction in percentage of CO_2 emission. The data unveil that 75% of the flights are under 2,000 km, and they only emit 18% of the CO_2 gasses. This means that the remaining 25% of the flights, those whom travel more than 2,000 km, emit 82% of the CO_2 gasses. Above 2,000 km but up to 4,000 km ranges, we will need to rely on hydrogen based innovations. Above 4,000 km, the current foreseeable solution is sustainable aviation fuels and radical industry innovations. (NLR, n.d.)

All in all, this allows electric aviation initiatives to be used for ranges up to 400 km considering the benchmark, and up to 815 km considering the best player in the electric aviation industry. With this feasibility aspect, the base of a window of opportunity is framed. Upon reflecting landscape trends influencing the current mobility industry, and the interaction of people within the ST system, the window of opportunity is completed in chapter 5.



▲ Figure 13. Royal NLR 2020. DDR2 and BADA 3.14 (Schiphol data). Flights and CO_2 emissions versus distance in Europe in 2018.

CHAPTER 4.4

KEY TAKEAWAYS.

- There are currently many promising initiatives in the niches with a foreseeable commercial technology readiness.
- For these initiatives, a range of 400 km can be considered the benchmark up to 2030, and 815 km the best possible range, provided by Heart Aerospace and Eviation Alice respectively.
- The most crucial metric to drive innovation in the electric aviation industry is improving the energy density of batteries.
- NASA's expectations are an increase in energy density, bringing the batteries to 600 Wh/kg by 2030. Note that compared to other organisations in the industry, NASA's expectations can be considered conservative.
- Combining battery innovation and current initiatives, a range of 1,900 km could potentially be achieved beyond 2030.
- Substituting conventional aviation for electric, could result in substituting 25-35% of the flights (up to 815 km), and up to 5% of the CO_2 emissions. Potentially (up to 2,000 km) beyond 2030, it could result in a substitution of 75% of the flights, and 18% of the CO_2 emissions.
- The other 25% of the flights and thus 82% of the CO_2 emissions will depend on hydrogen fuelling, sustainable aviation fuels (SAFs) and radical innovations.

05

WINDOW OF OPPORTUNITY.

With these innovative electric aviation niches, the transition towards the new ST system of sustainable aviation can be set in motion. Within this chapter, the window of opportunity is framed for which electric aviation can enter phase three of Geels' (2010) four phases of transition; implementation in the regime level. This window of opportunity is shaped by the interaction of people with the novel technology.

CHAPTER 5.1

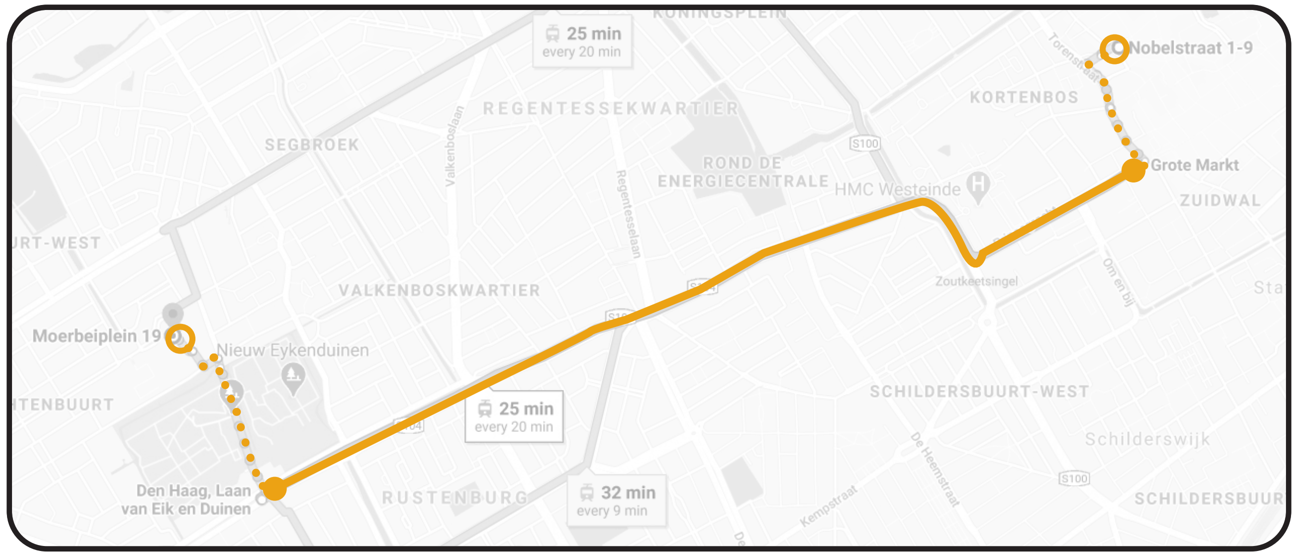
LANDSCAPE CULTURAL TRENDS.

Introduction
As the chapter description stated, these sub chapters aim to forecast the interaction between the technology and people. More specifically, on a landscape level it aims to understand the trend and culture of the people within the aviation, or rather, mobility industry. And with a proper understanding of the trends currently taking place, use it to frame a window of opportunity for electric aviation to be adopted in a regime, and thus in the industry.

This chapter dives into these cultural landscape trends and lays the groundwork to shape this window of opportunity in later sub chapters. Note that there are many trends able to influence and shape such window of opportunity. Experts and literature mention four prominent behavioural trends to have an impact on today's mobility.

Time-based journeys
The first trend covered in this chapter is time-based journeys. While distance (km) is the standard to calculate a travel journey, most consumers refrain calculating with this metric. Time (min) is used to calculate the travel journey. More specifically, time (min) lost (KiM, 2018). This results in two trends: flexibility and travel journeys.

Nowadays, mobility consumers are less bothered by a travel journey when they have the ability to be productive while travelling (e.g. answering mails in the train). Past decades, we have seen a shift towards flexible working spaces: one is not bound to a fixed location to be productive. To give an example, an hour spent travelling in a car is an hour lost, as productivity while driving is small to non existing. An hour spent travelling by train is an hour with the opportunity for productivity. Only before and after the train travel, productivity is come to a halt.



▲ Figure 14. Time based journey, retrieved from Google Maps.

This trend has resulted in the consumer needing a complete overview of the complete journey, and thus needing an individual-centred travel journey. Travels, and thus also aviation travels, are not meant as a means of transportation from city to city, but from A to B. It starts at home and ends at the destined location, as this includes all time spent during a travel journey. (KiM, 2015)

We see this back in travel planner platforms such as 9292 or Google Maps (figure 14). They plan complete journeys from A to B, based on time, mainly show the dynamic transfers within the journey and the time you'll be able to stay in a fixed location, such as sitting in the train. Therefore, upon calculating travel time in later chapters, it is important to take into account the whole journey.

BREVER-law
Secondly, as full-electric aviation enables net-zero CO_2 travels, it could simultaneously push consumers to travel more frequent by plane. Upon more frequent travels, the BREVER-law could emerge as a behaviour pattern.

BREVER consists of the law of maintaining travel time and displacement. On a daily basis, people spend 70 to 90 minutes of their time travelling. This pattern has been existing since mobility modalities have been around. Modalities have increased in speed, but the travel time has not reduced past decades. Either, people tend to live further from their place of work, or the place of work tend to move further away from the urban area (KiM, 2020), resulting in a constant daily travel time.

Mainly home-work travels are affected, but the impact on unique travel journeys such as aviation will be significantly less. Though, it might become relevant for UAM use cases, as this modality is meant as an air taxi, and therefore act as a landside modality enabling day-to-day travels. For commercial aviation journeys, thus infrequent journeys, the BREVER-law impact for the near future will be insignificant.

Flight shaming
Furthermore, a trend over the past few years in mobility is flight shaming, resulting in an increase in demand for sustainable mobility alternatives and thus avoiding the conventional aviation, which mainly impacts the short-haul travels. A 2019 study suggest that for 71% of the interrailer passengers the low carbon footprint was a relevant factor for choosing that means of transport. An increase of 20% compared to 2017 (Abend, L., 2019). The passenger growth of Schiphol suggest an alignment in this trend. As can be seen in figure 15, there is a growth decline in passengers for European flights, while there is a growth increase for the European population. Meaning, while the European population increases, the European travellers insinuate moving in the direction of a growth asymptote. Consider that the results show a correlation, but there are obviously other variables which could have affected the decline in European passenger growth.

We also see this trend back in Kennisinstutuur in Mobiliteitsbeleid (KiM) research. The train enables alternative travel means for the 13 most important destination involving Schiphol, which could potentially result a reduction of 12,000 to 25,000 flights by Schiphol (Savelberg, F. Lange, M. de, 2018). This is a reduction of 2 to 5% in flights from RSG.

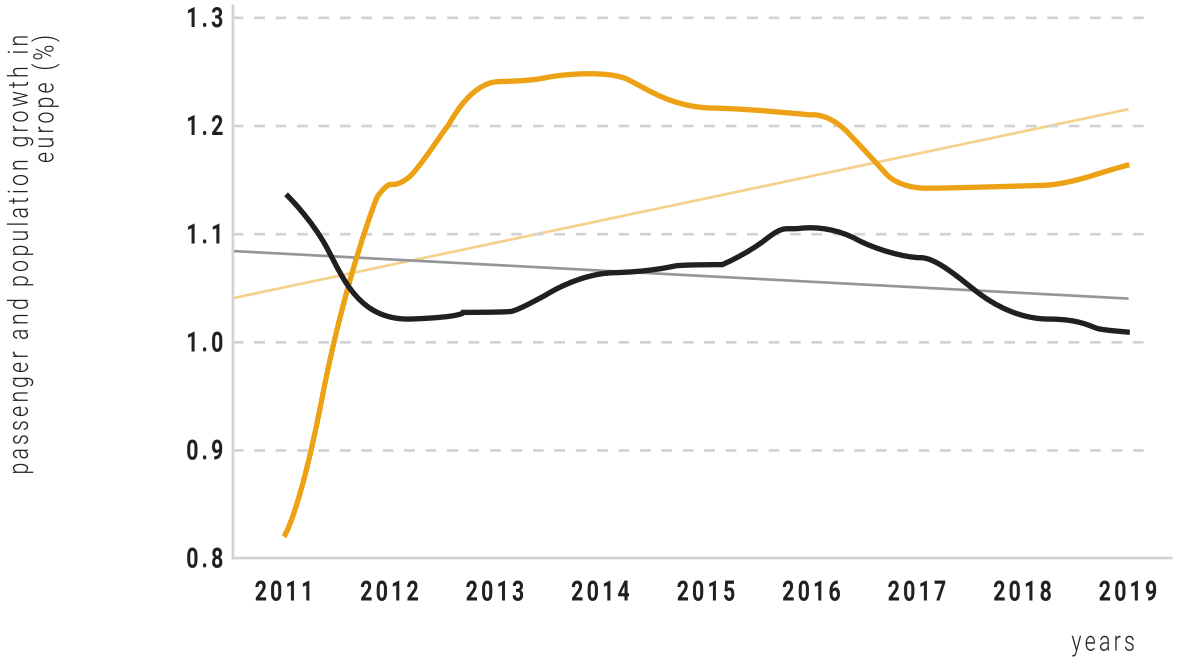
The train could therefore be a valid alternative to short-haul flights, and is thus on a competitive level with electric aviation. The downside of the train is it's rigidity in travelling and scaling the modality, which makes aviation more desirable in the long term. Airports connect directly to all other airports, while train stations need the proper infrastructure to connect to each other. The next chapter compares the modalities on different levels: sustainability, costs, and travel time.

COVID-19 impact

Other behavioural trends are a direct result of the pandemic on society. The KiM (2020) argues that the impact of the corona virus results in people de-urbanising, moving away from the cities, as living in urban areas increases infection risk, and negates the physical need of being at work. As remote working is becoming the new standard, 40-60% of the society expect to continue this work behaviour at home after the corona crisis (Haas, M. de, Hamersma, M., Faber, R., 2020). This is also affecting daily domestic travel patterns, resulting in a wider travel distribution spread over the day, due to regulations or personal choices (KiM, 2020). As mentioned previously, the probability of daily travel patterns influencing the adoption of commercial electric aviation is slim, but could potentially affect UAM propositions.

Haas, M. de, Hamersma, M., Faber, R. (2020) argue that there will also be a reduction in air travel post corona crisis, with an estimated 38% reduction. They state that it could be the result of both the reduced travel desire due to latent risks surrounding COVID-19, but also the reduction of business travels. As 25% of all the flights in the Netherlands are the result of business flights, reducing the amount of business flights inherently reduces the total amount of flights of RSG (Berverling, J. et al. 2020). Moreover, when considering non-business flights, experts argue that people will have a different destination preference. General regulations and conceptions tend to lean towards avoiding longer distance trips and increase the domestic travels, for which other modalities enable those ranges. While the arguments are valid, these KiM reports mostly rest on approaching a forecast by speculations. As of now, the COVID-19 impact on the coming years remains uncertain, but might also provide new windows of opportunities.

▼ Figure 15. Passenger and population growth in Europe past decade. Based on monthly flights from RSG.



Thereupon, a report by McKinsey (2020) argues that a current important variable for choosing which modality to opt for is a reduced risk of infection. Conventional aviation and HSR travel aim to move people in larger groups, while cars and electric aircrafts on various ranges provide individual or small group travels. This is a negative impact for aviation as a whole, but an opportunity for electric aviation which pax is currently limited at 19.

Mobility transition

What we see is a shift in the mobility industry stimulating and thus enabling electric aviation in the transition to the new ST system. New technological initiatives fit in the transitioning mobility industry. Interesting is to understand how they fit in, and whether the different modalities with their specific benefits and bottlenecks compete with each other or have a symbiotic relationship. This is what chapter 5.2 will provide, a comparison of the modalities on sustainability, consumer cost and travel time metrics.

CHAPTER 5.2

MODALITY COMPARISON.

Introduction

Electric aviation therefore fits in the future vision of mobility, enabled by the technology and fitting with society's culture. We have already established that, upon considering the benchmark for commercial electric aviation is set on 400 km, depending on the type of aircraft expandable up to 815 km. For framing a window of opportunity, it is thus key to understand where electric aviation fits in the current mobility industry, linking to the current ST system to form hybridisation (Geels, 2002). This chapter uses three metrics to approach this linkage, which forms the said window of opportunity and gradually transitions the current ST system to the new one. These three metrics are sustainability, consumer cost and travel time.

Sustainability

The first metric to compare the modalities on is sustainability, with the comparable unit of CO_2 per pax km (referred as pkm in the rest of the thesis). Meaning, the amount of CO_2 the modality produces per single passenger per 1 km. Table 1 provides an overview of the different modalities and their CO_2/pkm, based on calculations and approximation found in appendix F. These are based on the Life Cycle Analysis (LCA) methodology, consisting of the phases of manufacturing, maintenance, infrastructure, Well-to-Tank (WTT) and Tank-to-Wheel (TTW). While most of the data can be found from different sources, some data on electric aviation was estimated based on the other modalities in the same domain or adjacent markets. Also note that these numbers are based on direct trajects, without transits, and are industry (short-haul) averages. Modalities generally produce less CO_2/pkm over longer distances travelled, as acceleration raises the average CO_2/pkm on travel journeys.

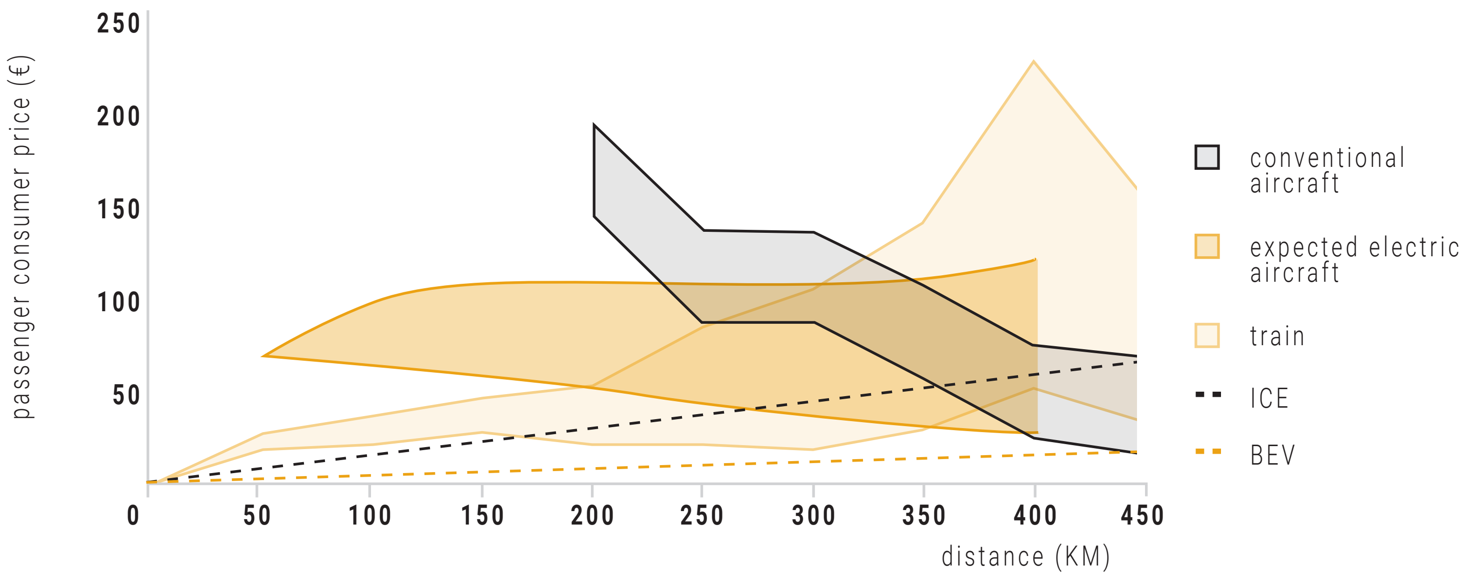
There is a clear sustainability difference between the five modalities, with the train having the lowest carbon emission and the Internal Combustion Engine (ICE) car the highest. The current train CO_2/pkm is based on trains commuting on grey electricity. As the NS, the modality at which RSG competes and synergizes with within the Netherlands is fueled by green energy, the new calculation based on data within RSG arrives at an estimation of half the CO_2/pkm. Furthermore, the average passenger travelling per car within the Netherlands is 1.82 (KiM, 2015). On infrequent travels it is not unusual to travel with more passengers in a car, between 1 and 4. Therefore, the calculations based on 1.82 passengers are also shown in order to give an indication on the sustainability when travelling with a higher pax.

🚆 electric	✈ electric	🚗 electric	✈	🚗
50	89	111	213	244
±25[a]		61[b]		123[b]

[a] Taking into account that NS is fueled on green, low carbon emission, electricity.

[b] 1.82 passengers in the modality on the same traject.

▲ Table 1. Mobility modality comparison, based on appendix E calculations. CO_2 per passenger kilometer.



▲ Figure 16. Price ranges for consumers on different ranges by different modalities.

Consider that the sustainability aspect for the consumer modality choice is not a strong driver, but is a strong driver for regimes to reach their ambitions. Therefore, electric aviation as a modality is not the lowest scoring modality in terms of CO_2/pkm, but enables regimes to pursue this modality as a more sustainable solution than current conventional aviation or car. It is expected that the electric plane's 89 CO_2/pkm will lower in the future, as the current electric aviation industry is an early-stage industry with massive potential for improvements.

Consumer costs

Secondly there is consumer cost. Argued by McKinsey (2020), consumer price is listed as second most important factor for consumers to choose their modality, depending on the travel motive. This has been confirmed by expert interviews, who confirm that cost is the one of the most important factors when planning a trip and choosing a modality. Based on data retrieved from NS international, google flights and plane ticket retailers, estimations have been made to indicate price ranges per passenger on different ranges by different modalities, which have been plotted in figure 16. Both ICE cars and Battery Electric Vehicle (BEV) cars are fairly competitive on ranges under 200 km with the train. Within this comparison, the purchase of a car has been neglected. It is assumed that upon considering the choice of modality and a car is in this consideration, the consumer most likely owns a car beforehand and the cost of it is thus not included. Also on the ranges under 200 km, the train proves to be cheaper in the Netherlands.

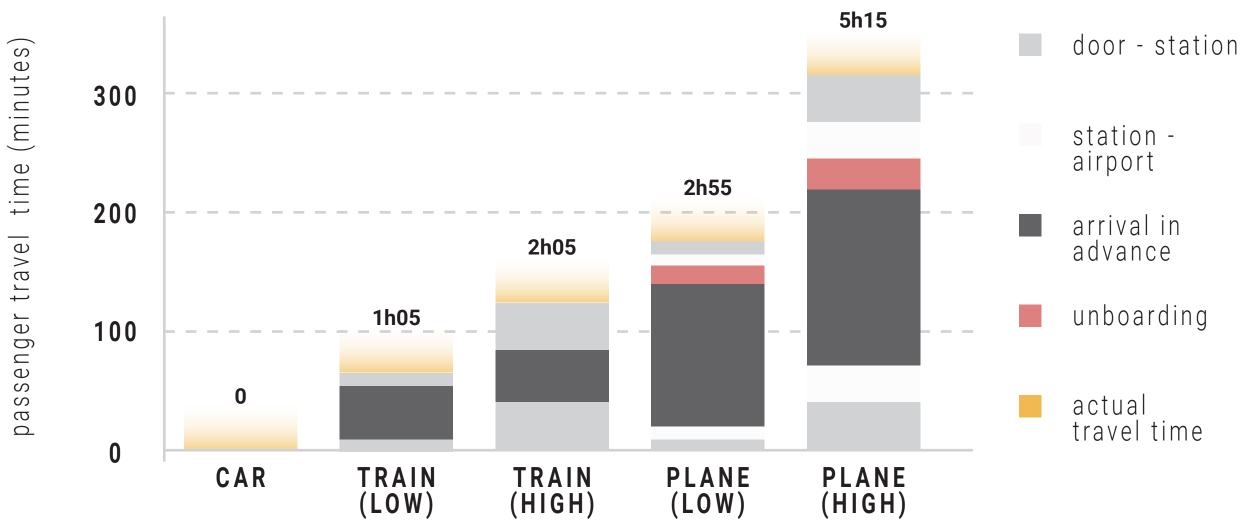
On ranges above 200 km, consumer cost overlap. This is due to multiple reasons, nonetheless this range remains highly competitive and can therefore not be considered the deciding factor.

Travel time

At last the travel time per modality. Sources such as NS, RSG, Google Maps, 9292 and MapItOut have been utilized for assumptions on which the calculations are based.

The data taken into account was travel time between the point of origin and station, between station and airport, the arrival in advance, unboarding, and the actual travel time of the modality. As the travel time differs, optimistic and conservative calculations have been made to display a time range per modality. Table 2 provides the data which figure 17 is based on. Note that these are assumptions based on data from the sources mentioned earlier, and may vary per different use case.

Figure X depicts the conservative and optimistic travel times as low and high per modality, based on the assumptions in figure 14. A car, whether it's a ICE or BEV, is a door to door modality. The additional travel time besides the modality travel time is therefore 0. The train on the other hand, assumed it's an international train travel as



▲ Figure 17. The building blocks of what the travel time consists of for the three different modalities.

electric aviation does not include national travel, has multiple variables to arrive at the total travel time. Also note that average speed of a train is far below the speed at which a train can travel, due to the dependency on infrastructure and the many stops at stations between origin and destination. Finally the electric aircraft, with the highest additional travel time, but the highest travel speed as well. Electric aircrafts are not limited by the infrastructure between origin and destination, and can arrive at their maximum speed decently fast after take-off. The graph of figure 18 is therefore based on the passenger travel time, combined with the speed of the modality (e.g. low electric aviation starts at 175 min, and has an incline of 370 * distance). Appendix F dives deeper in the calculations of the intersection points in the figure.

While the car, whether it's a ICE or BEV, is added in the graph, the expectation for passengers to choose it over train and electric aircraft is slim. A car its use case is often a home-work modality, meaning that the BREVER-law is valid. Upon considering the average speed of a car at 90 km/hr, moving from 50 km/hr zones to 100 km/hr zones and back, and a minimum travel time of 70 minutes, we arrive at a maximum distance of roughly 100 km. While it's interesting to dive deeper in the use case of a car, this range is enough to give an estimation to compare it to an electric aircraft. Note that it remains a competitive modality for ranges above 100 km in specific unique use cases (e.g. excess amount of luggage, specific remote destinations, family size and particular travel motives). Further consumer research could sharpen and strengthen the derived conclusions. I would also like to stress out that these assumptions are based on expected consumer behaviour. Expected consumer behaviour and real consumer behaviour could alter the calculations.

Window of opportunity

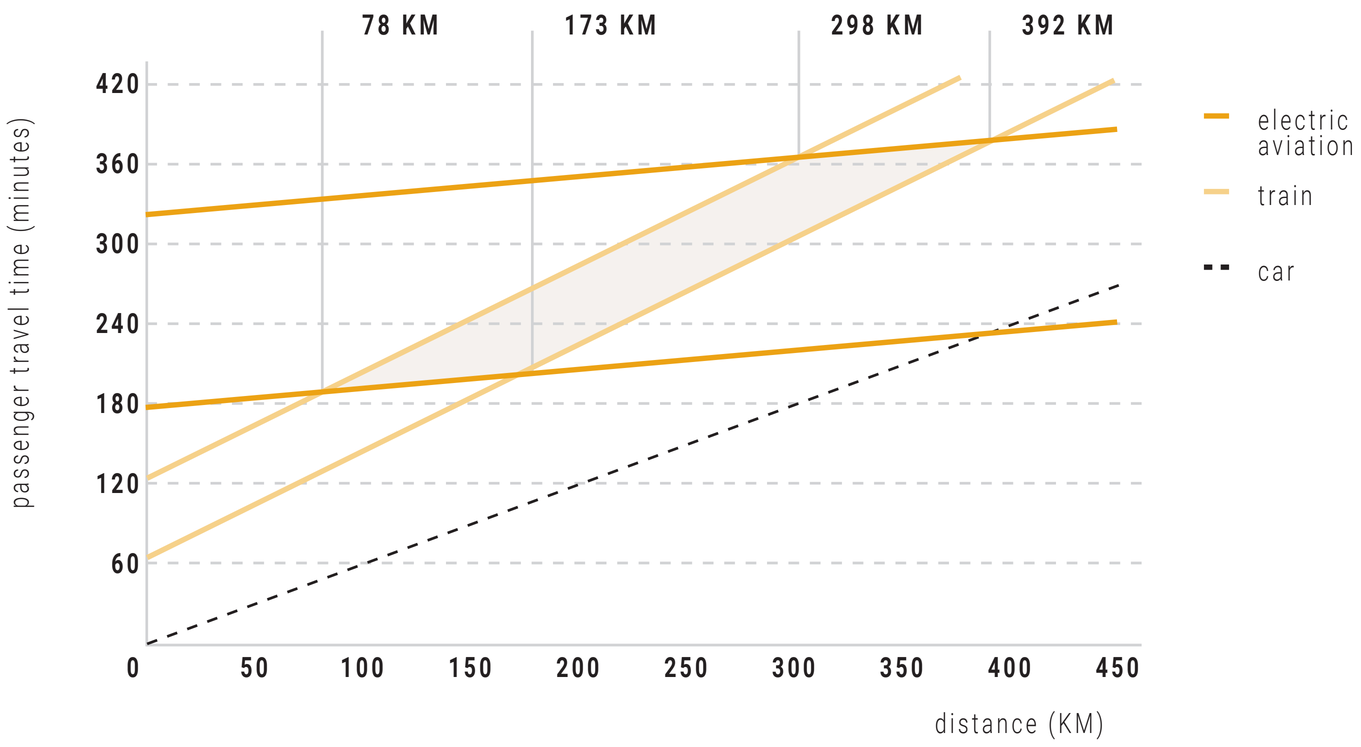
All things considered, based on all three metrics and cultural trends, we can expect a car to be the ideal modality on ranges up to 100 km, and electric aviation on ranges above 298 km. In between, as it's either competitive with other modalities or simply the more sustainable alternative for most use cases, the train would be the ideal modality. When considering a timeline up to 2030, and electric aircraft its benchmark range at 400 km, the ideal metric to link up the existing ST system and the novel ST system would thus be between the ranges of ~300 km and 400 km. This range is emphasized upon specific and unique use cases, which cause train range or travel time to increase compared to aviation ranges and times. E.g. geographic detours or an increased amount of stops, or poor infrastructures in place. Consider the range of 300 km to 400 km Geels' (2002) window of opportunity to enable a novel technology to flourish and enter the third phase; implementation in the regime level. What this also means is that there is not a single solution to reach the aviation industry ambitions, but it is a combination of solutions to enable a sustainable paradigm shift. The transition to sustainable aviation is therefore a transition to sustainable mobility including sustainable aviation.

ASSUMPTIONS*.	MINUTES. (LOW- HIGH)
• Door - station.	10 - 40
• Station - airport.	10 - 30
• Arrival in advance train.	45
• Arrival in advance aircraft.	120 - 150
• Unboarding	15 - 25

SPECIFICATIONS*.	SPEED. (KM/HOUR)
• Average speed train.	75
• Average speed aircraft.	370
• Average speed car.	90

* based on sources: NS, NS international, RSG, Google Maps, 9292, MapItOut and data in previous chapters.

▲ Table 2. Assumptions that lay the foundation for figure 17.



▲ Figure 18. Travel time ranges for consumers on different ranges by different modalities.

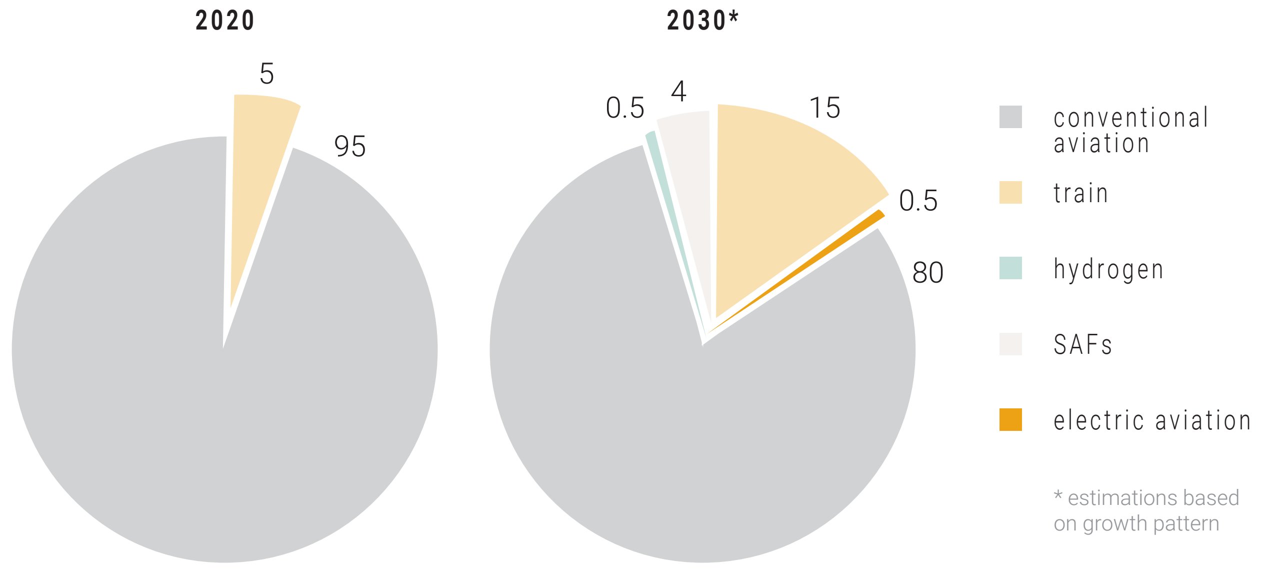
CHAPTER 5.3

TWO FUTURE SCENARIOS.

Introduction
This transition to sustainable mobility will affect the role of the airport. The mobility industry including the aviation industry will aim to replace conventional aviation with sustainable alternatives, be it other modality solutions or SAF solutions. For RSG, this means that their role to facilitate transport for the future mobility industry shifts. For this, there are two future scenarios to consider as an airport of RSG within the Netherlands.

Maintaining the status quo
The first scenario is the maintenance of the status quo. The future of mobility is currently shifting to a more sustainable industry, which disables certain modalities and enables other more sustainable ones. Conventional aviation, which is the aviation we have known past decades, has a less dominant role in this future. The core business model of RSG currently revolves around conventional aviation. As of now, when residing within the scope of the thesis, the alternative between 2,000 km and 4,000 km is hydrogen, enabled beyond 2030. Above that, we can only expect radical innovations or sustainable aviation fuels. But for ranges up to 2,000 km, there is a multitude of solutions, such as the train, car and electric aviation. This means that for RSG, potentially 75% of their flights are substitutable for cleaner modalities at the end of the sustainable paradigm shift, likely to end between 2050 and 2070.

When the current role of RSG remains the same, the probable future for their airports are facilitating flights above 2,000 km by conventional aviation or fueled by SAFs. This reduces their customer base passing through their airports potentially by 75%, consequently reducing profits. Therefore, a more viable path towards both a more sustainable and a more viable future would be transitioning the role of the airport towards a multimodal mobility hub.



▲ Figure 19. The building blocks of the potential mobility future of 2030.

The multimodal hub
The role of the multimodal hub is twofold. The first one is the role of Amsterdam Airport Schiphol (AAS) takes as a hub airport, gathering passengers all over Europe to transfer them at AAS on international flights. But this is a model they are already handling currently.

The second one is the role of AAS, or another airport within the portfolio of RSG, gathering modalities all over the Netherlands to transfer them to European cities and vice versa.

Figure 19 (2020) shows how the current overview of modalities, excluding cars as the data is not available of cars travelling abroad. Then, Figure 19 (2030) shows the potential future including the vast modalities in the mobility industry for RSG to facilitate by 2030. This is an estimation based on the increase niche innovation adoption in the regimes and the decline of the technology, thus the transition towards the new ST system of the mobility industry.

RSG, with vision of becoming the most sustainable airport, should take a pioneering role in this scenario of 2030. Develop sustainable alternatives to conventional aviation and transit towards a new role for the airport: a multimodal mobility hub. This, to facilitate the modalities needed for the transition to sustainable aviation on short-, medium- and long range distances in the field of mobility. The proposition of an entry use case to facilitate this transition through electric use case is up next, based on the metrics defined by the previous chapters.

CHAPTER 5.4

KEY TAKEAWAYS.

- Macro landscape trends are pulling the niche innovation and opening up a window of opportunity.
- When considering sustainability, cost and travel time, a window of opportunity is framed for electric aviation.
- Car excels on ranges up to 100 km, especially in home-work related travel. Between 100 km and 300 km, the train would be the ideal modality due to the low CO2/pkm and travel time. And between 300 km and 400 km, keeping in mind the foreseeable future up to 2030, electric aviation is enabled as the ideal modality.
- For short-haul travel journeys, conventional aviation has a multitude of sustainable solutions. Therefore, RSG should change its role as an airport for short-range aviation towards a multimodal hub, providing a role which gathers passengers from all over Europe at their Dutch airports and transfer them to national destinations and vice versa.

06

REGIME STABILIZATION.

Within the literature of transition theories, the destabilizing levels of landscape and niche enable the first two phases of transition. The stabilizing factor of regimes enable the novel innovations to flourish through windows of opportunity, and thus enter phase three of the transition. This is what this chapter aims to achieve, defining an entry use case as a first step towards this stabilization.

CHAPTER 6.1

REGIME CAPABILITIES OF RSG.

Introduction
The regime-level stabilizes the instabilities happening in the landscape- or niche-level, and through the window of opportunity the entry use case can take place. In order to fully understand how the metrics to define the entry use case for electric aviation within RSG its portfolio came about, an understanding of its capabilities needs to be clear. The capabilities are vital to define the entry use case and recommend the best course of action. These capabilities originate from two aspects: the vision and mission statements from RSG, and the initiatives and operations by RSG aligned with these vision and mission statements.

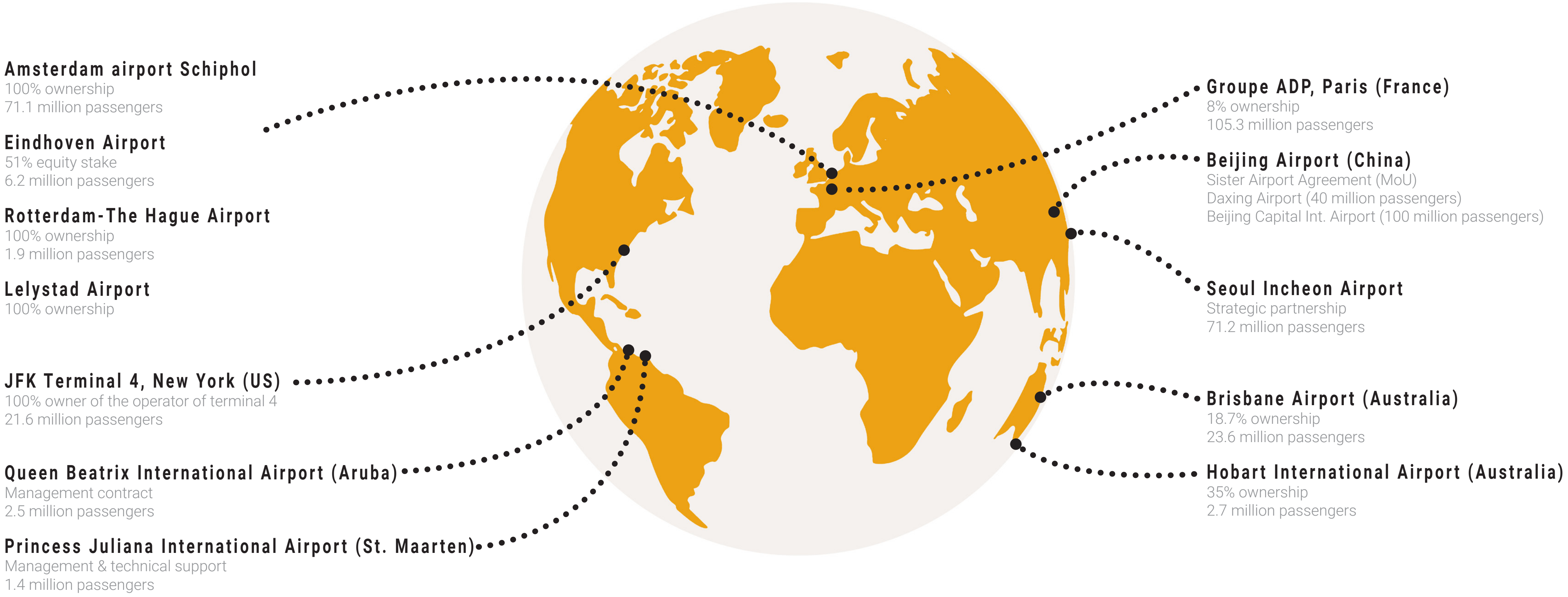
Stargazing into the future
The overall mission of RSG is becoming the most sustainable airport, while its vision is connecting the Netherlands to the world. These mission and vision statement give a great direction for the adoption of electric aviation.

Figure 20 depicts the airports within the current portfolio of RSG. While there are different potential airports within the group for commercial electric aviation to be adopted, we focus on the European market. Mainly due to the fact that the current window of opportunity of electric aviation is 300 - 400 km, and the goal of electric aviation is to facilitate the transition to sustainable aviation. Meaning, the amount of people this modality could potentially substitute, and the network which could emerge with it. The non-European airports have either a low substitution potential, or a low network potential.

Combining the scope of Europe, with the potential range of 1,900 km beyond 2030, the Netherlands are a prime location to facilitate electric aviation journeys throughout western Europe. With this, the alluring perspective for the new role of the multimodal hub and electric aviation becomes:

"Create sustainable opportunity for every traveller to arrive in any European city."

What does this encompass? RSG, based in the Netherlands, offers the ability to travel from and to the Netherlands in a sustainable manner. Whether it is within the Netherlands, through sustainable train transport, or internationally within Europe, through electric aviation. This vision statement



▲ Figure 20. RSG its quality of network. The overview of airports within their portfolio.

also allows for future opportunities outside of the train or aircraft scope to be explored, as this statement promotes the hub function of RSG.

The mission statement, the action oriented goal in line with the vision statement, is a goal set for 2030. Again, for both RSG and electric aviation combined, the mission statement is as follows:

"Accelerating the transition to sustainable aviation by enabling electric aircraft trajects within Europe."

The entry use case will be the first step for RSG as a regime-level organisation to accelerate the transition and become a pioneer in the sustainable mobility industry. This ambitions is aligned by the three capabilities RSG conveys internally and externally: "Quality of Life, Service and Network" (Royal Schiphol Group, 2019), as can be seen in the overview in figure 21 elaborating these three capability pillars.

Network potential

In terms of the transition towards sustainable aviation, electric aviation fits in both Quality of Life and Quality of Network pillars. For Quality of Life, it aims to make aviation and thus mobility more sustainable, in order to reach the ambitions set by RSG. With Quality of Network, electric aviation offers the potential to gain a foothold in a market within Europe which is currently not yet existing but will be by 2030. Connecting both Europeans to the Netherlands and vice versa. For both RSG and the electric aviation industry, it is key that the electric aviation industry not only has the ability for a vast amount of flight substitutions in terms of Quality of Life and thus sustainability ambitions, but also creates a vast Quality of Network for both connectivity and scalability. Network potential is thus a metric to consider when deciding the entry use case.

Quality of Life

The commitments RSG made based on the IPCC 2018, Paris Climate agreement and Dutch targets by the Climate Round Table Sustainable Aviation show a strong focus on sustainability, which have resulted in the goals they aim to achieve; CO_2 emissions by aviation equal to 2005 levels, 14% of the aviation fuels used are sustainable, net-zero CO_2 emissions through own operations, and landside CO_2 reduction of 49% compared to 1990, all by 2030. And for 2050: a net-zero CO_2 emissions aviation sector. (Royal Schiphol Group, 2020)

Based on these sustainable commitments, RSG has developed multiple initiatives. On a regulatory level, while older and more polluting aircrafts receive a sustainability incentive, younger and thus less polluting aircrafts receive a discount. The range of discounts and incentives are between 45% and 180% of the LTO and parking costs for aircrafts at RSG. (Royal Schiphol Group, n.d.) Other initiatives are currently in development and validating phase, under which:

SUSTAINABLE AVIATION

Aviation community developed in order to meet global emission goals. This thesis and thus the topic electric aviation falls under the RSG initiatives.

AUTONOMOUS AIRSIDE

Self-driving interconnecting fleet to enable zero-emission airside displacement. The Taxibot is a project enabling the displacement of aircrafts on airside, enabling a reduction in CO_2.

HEALTHY ENVIRONMENTS

A healthy environment for the communities to live, improving air quality and reducing noise. One of the startups currently collaborating with RSG is DeNoize, developing noise-reducing windows.

FUTURE BAGGAGE

Working towards a disruptive baggage service, making optimal use of the baggage capacity in the airports.

DIGITAL IDENTITY

Personalizing the identity of a passenger, making it connect and interact to its journey. With the current pandemic, RSG is looking into ways to facilitate government policies and developments in security.

MULTIMODAL HUB

The ecosystem enabling new and interconnected modalities seamlessly transition in one another. Hardt Hyperloop and NS are current partnerships aiming to facilitate and promote this.

▲ While interesting to cover more initiatives and elaborating on projects, restrictions do not permit the information for external distribution.

Quality of Network

Having a network of destinations is for RSG essential to achieve the sheer size of passengers that passes through RSG. The vision statement "Connecting your world" is therefore meant to connect the Netherlands to the rest of the world. Enabling passengers from either transfer or Origin-Destination (OD) markets to pass through RSG airports, mainly AAS, is thus the core business for RSG. The partnerships with the Nationale Spoorwegen (NS) align with this goal, to enable international destinations to depart from Schiphol airport and station. An initiative to connect metroline 52 in Amsterdam to Schiphol airport is currently in development, to lower the frequency of trains moving between Amsterdam and Schiphol, and enabling an increase in NS international trajects.

As mentioned in chapter 3.4, electric aviation enables flights up to 1,900 km. The Netherlands have an ideal location to enable journeys through electric aviation, which is in line with the core business of RSG: enabling airlines to LTO and park at their airports.

Quality of Service

This brings us to the adjacent business models: the commercial business models. RSG has an immense portfolio of real estate, for which they offer offices, retail locations and experiences, advertisements, and parking spaces for cars. These value propositions are enabled by the core business model, the quality of network. They offer the passengers of airlines a journey within the airport with the goal of making them enjoy their time at the airport. This enables other companies to flourish around the position of RSG funnelling passengers through their airports.

The quality of service is strongly affected by the quality of network business model. As we have seen in 2020 with the COVID-19 pandemic, which resulted in a decline of 71% passengers passing through RSG, the indirect business models have suffered too. The number of passengers parking at RSG, spending their time and money in the retail experiences on the airports, or even experiencing the advertisements have also declined. The short term effect is among other things a significant loss in profit, and up to a certain degree in revenue. Interesting is to see the long term effect of the pandemic, and upcoming direct and indirect solutions for 2021, with different business models for example.

▲ Figure 21. Overview of the three value and capability pillars of RSG.

CHAPTER 6.2

ENTRY USE CASE METRICS.

Introduction
This brings us to the entry use case to exploit the window of opportunity. Previous chapter covered the capabilities of RSG and how electric aviation fits within these capabilities. This chapter elaborates the metrics revolving around deciding the entry use case, in other words, metrics to decide the two connecting airports and thus the initial traject the entry use case will cover. These metrics have been derived from both research in RSG and the aviation industry, as research in transition literature.

Metrics
The six metrics in figure 22 show and elaborate on the relevance of each of the metrics. Note that two of the metrics are requirements, the 300-400km range and the innovation resources. The others are desires. When sorting these wish metrics on relevance and importance, each of these metrics enable different entry use cases. This also gives the impression that there is no ideal entry use case, which is true. Chapter 6.3 proposed three entry use cases, which are deemed best upon putting specific metrics above others.

Figure 22. The six metrics to provide clear ► arguments for entry use case decision.

The 300-400 km range
This is one of the metrics derived from previous chapters, the window of opportunity for electric aviation as a niche innovation to be adopted into the regime-level. It is relevant for the short term, as beyond 2030 it's expected that this range increases up to 1,900 km.

Innovation resources
An important factor to consider when choosing airports for the entry use case is the availability of resources to innovate, such as people, capital and time. While this is an important metric, all major stakeholders meet this criteria. Smaller stakeholders will be dependent on larger stakeholders having these available resources.

Substitution potential
The goal and ambition of the industry, a sustainability metric. The more kerosene aviation passengers are able to be substituted for its electric counterpart, the higher the reduction in CO_2. The relevance of this metric is high for the short and long term, as sustainability is the driver for the technology.

Network potential
In line with both RSGs ambitions and capabilities, building an electric aviation network is a key factor for the success of the adoption by RSG as a regime and the global adoption of the aviation and mobility industry. The long term relevance is therefore high, and short term relevance (the entry use case) is decent.

Viral factor
As electric aviation is novel, and in order to meet the industry ambitions which is a landscape level type of factor, the stakeholders within the industry, thus the regimes, need to align with the step towards sustainable aviation. The virality of the entry use case needs to be of a certain impact in order to gain widespread relevance and create legitimacy (Hekkert, M.P. et al., 2007).

Location in the Netherlands
At last the location factor for the airport within the Netherlands. Airports fulfil two roles; facilitating origin-destination (OD) flights and transfer flights. OD flights fulfil the need for passengers to travel to desired destinations, often areas with high population densities. The strategically chosen airport for the entry use case therefore needs to meet one of these roles.

CHAPTER 6.3

REGIME ENTRY USE CASE.

Introduction
For the entry use case to have the most impact, mainly two metrics have been considered with the highest relevance; substitution potential and network potential. This chapter covers the entailment of these three entry use case concepts, in the substitutable pax, CO_2 reduction, amount of flights and the amount of energy needed, based on the three entry use case concepts in figure 23 on pages 66 and 67. For this, we consider a conservative approach and a full implementation approach to derive at these numbers.

Entry use case 1
When considering potential passenger substitution the most prominent metric, the traject London Heathrow (LHR) - Amsterdam Airport Schiphol (AAS) becomes the most interesting traject. This is due to two reasons. The first reason is the high yearly traffic between the two airports, where AAS - LHR enabled 1,747,788 passengers to travel between these airports in 2019 (Schiphol, 2019). The second reason is the low competitiveness on this traject for other modalities, as trains and cars are limited by the available infrastructure via France which consequently increase travel time.

In terms of passenger substitution, when considering a partnership with KLM or British airways, commercial electric aviation could have a minimal substitution of 921,103 a year (KLM partnership). As electric aircrafts are smaller than their conventional counterpart, assuming a 19 seat benchmark aircraft, the amount of flights needed to facilitate these passenger travels is 48,479. The difference in CO_2/pkm of electric aviation and conventional aviation enables a reduction of CO_2 by roughly 42.26 kton. At last, the energy needed to enable these flights is 42.6 GWh.

Upon full implementation with full support of society and government on this specific traject, the results are on a different level. This is, assuming all flights between Amsterdam and London are substituted by electric aviation. This brings the total passenger substitution to 4,926,323 a year, enabled by 259,280 flights and thus the CO_2 reduction at 226.02 kton. To enable such an endeavour, an energy supply of 227.8 GWh is needed.

An honourable mention as a connecting airport to AAS would be London Gatwick. Gatwick gives the strategic potential to partner with EasyJet, whom are developing an electric aircraft with Wright Brothers to enable 100 passengers to travel up to 500 km end of the decade.

substitution	0.9 - 4.9 million /year
flights	48 - 260 k /year
CO_2 reduction	42 - 226 kton /year
energy demand	43 - 228 GWh /year

Entry use case 2
The second entry use case is similar to the first one, but from Rotterdam-The Hague Airport (RTHA) instead of AAS. This focusses on both substitution and location within the Netherlands metrics. As previously mentioned, airports fulfil two roles in terms of aviation; OD and transfer flights. For OD, the desired locations of origin and destination are most often in areas with a dense population as this would benefit the larger part of the population within that area. For the Netherlands, that's the Randstad. Transfer flights on the other hand facilitate the gathering of a vast amount of passengers and connect them to new destinations. For RSG AAS fulfils that role, meaning they connect people from all over Europe to intercontinental flights, and people from all over the world to European flights. For either goals, be it OD or transfer flights, the connecting airport would be within reach of the Randstad and AAS, giving RTHA the opportunity to enable the entry use case for electric aviation. What this entry use case enables what the first one didn't, is a connection to Charles de Gaulle airport (CDG).

When looking at the substitution of passengers within this entry use case, we can again consider partnering with KLM as the conservative potential. The total substitutable passengers between RTHA - LHR and RTHA - CDG is 1,525,889 a year, enabled by 80,310 flights a year. This gives a CO_2 reduction of 67.15 kton and a needed energy supply of 70.8 GWh.

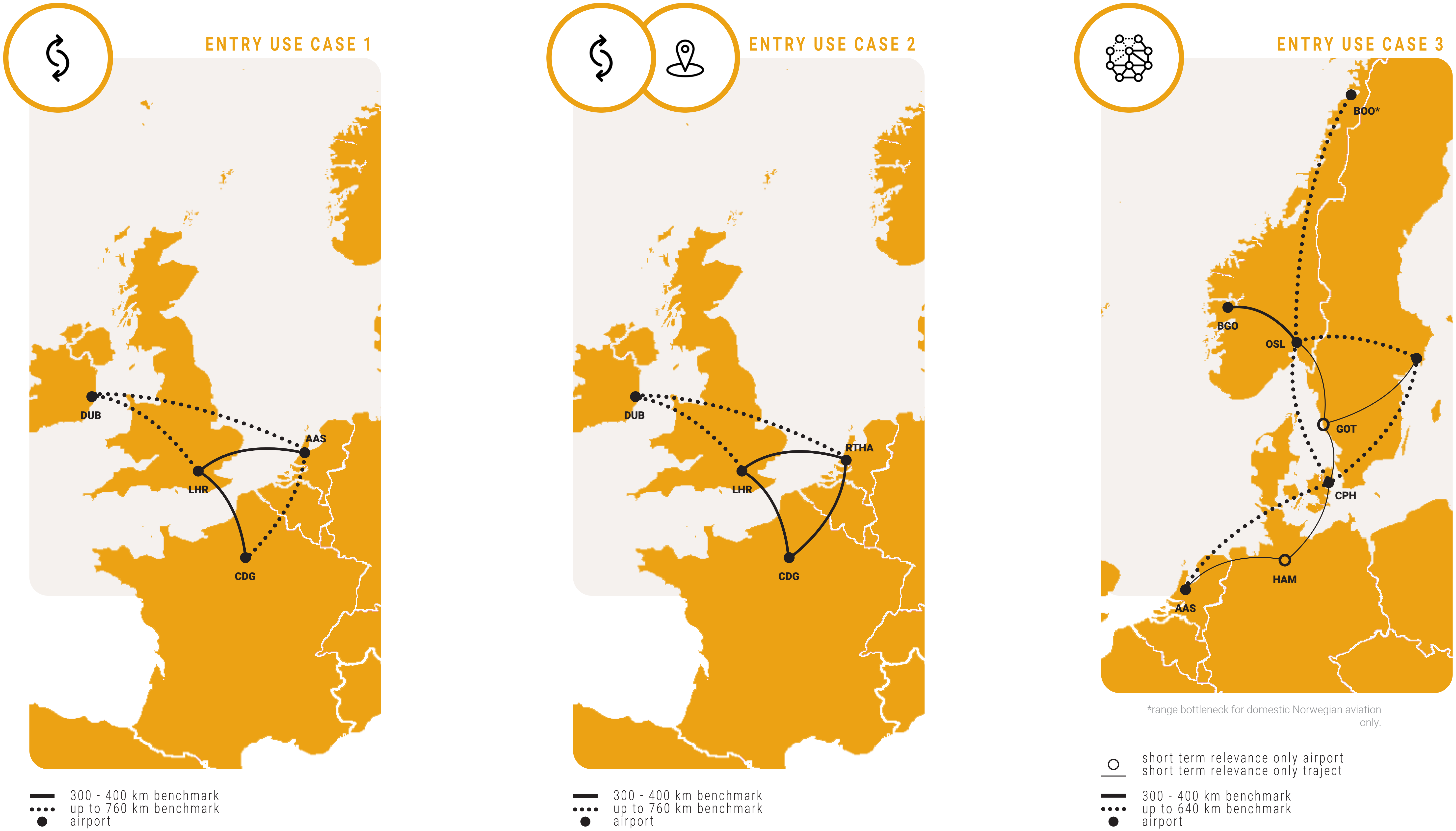
A full implementation for all flight between RTHA and London and RTHA and CDG brings the total amount of passengers at 6,166,112 a year and the total amount of flights at 324,532. The CO_2 reduction would result in 268.6 kton and the total needed energy supply to enable this substitution would be 285.6 GWh.

Note that there is a high modality competitiveness between Rotterdam (for RTHA airport location) and Paris (CDG airport location). The substitution for RTHA-CDG would therefore be more beneficial in terms of sustainability towards the modality of the train instead of electric aviation. This makes this entry use case the least favourable of the three, despite enabling an extra prominent destination on the short term (until the benchmark range increases).

substitution	1.5 -6.1 million /year
flights	80 - 324 k /year
CO_2 reduction	67 - 269 kton /year
energy demand	71 - 286 GWh /year

Entry use case 3
At last the third entry use case. This entry use case focusses mainly on the potential network, while taking into account substitution count. With Scandinavia setting the most ambitious goals for 2030 within the industry regarding sustainability, the certainty for domestic electric aviation within Norway and Sweden is high. The credibility and Hekkert's (2007) legitimacy are already in place for regime implementation. Therefore, connecting to Scandinavia would be close to a no-brainer, in terms of strategic traject. The Scandinavian stakeholders have already mobilized the needed resources and have set the sustainability plan in motion. Meaning, in terms of connecting airport to AAS, the needed airport infrastructure and fleet renewal of airlines will be in place. The Netherlands could serve as a gateway location for western Europe towards Scandinavia, meeting the travel demand in a sustainable fashion. As the train is yet an undesired modality for consumers, the competitiveness against it is low, strengthening the argument for this traject.

The biggest bottleneck specific for this traject are the stops at Hamburg and Gothenburg, as these destinations by itself have a relative low traffic compared to a vast amount of other European destination. This could potentially lower the adoption rate due to consumer desirability. In an ideal situation, these stops would be skipped and only enabling traffic between Amsterdam - Copenhagen - Oslo or Stockholm. This could



*range bottleneck for domestic Norwegian aviation only.

▲ Figure 23. Three proposed entry use cases, based on the metrics in figure 22.

be enabled by either developing temporary fuelling facilities at Hamburg and Gothenburg, or ensuring the acquisition of aircrafts able to bridge the distances between Amsterdam, Copenhagen, Oslo and Stockholm, such as an Eviation Alice. Chapter 7 dives deeper in these bottlenecks.

For the calculations, the cities of Hamburg are not taken into the equation, as my recommendation would be to acquire aircrafts able to bridge the distances between the four cities. In terms of passenger substitution with again KLM as partnering airline, it arrives at 1,739,292 a year passengers between the four cities, and thus 193,255 flights a year. Note that the calculations are thus based on an Eviation Alice instead of an Heart Aerospace ES-19 (which would result in 91,542 flights a year). The reduction in CO_2 when substituting conventional aviation by electric aviation on this traject would result in 190.54 kton. And the energy supply would need to be 246.1 GWh.

Upon full implementation, meaning all traffic between Amsterdam, Copenhagen, Oslo and Stockholm would result in a substitution of 2,697,365 passengers a year, and thus 299,707 flights a year (or 141,967 flights with a 19 passenger aircraft). The potential CO_2 reduction would be 295.5 kton, with an energy supply demand of 381.7 GWh.

substitution	1.7 - 2.7 million /year
flights	193 - 300 k /year
CO_2 reduction	191 - 296 kton /year
energy demand	246 - 382 GWh /year

Recommendation

Based on all the previous information in the past chapters, my recommendation for RSG would be to pursue the third entry use case. The reasoning behind this is its strategic value and certainty, allowing RSG to gain a foothold in the upcoming electric aviation industry and becoming the connecting gateway for sustainable mobility between western Europe and Scandinavia. But, as an avid reader of this thesis might have noticed, there are bottlenecks involving this entry use case and its execution and implementation. Chapter 7 focusses on these bottlenecks, covering the current bottlenecks of this entry use case and proposing the first steps towards overcoming them. These first steps aim to push the electric aviation industry towards implementation within the regime- and landscape-level as per Geels' (2002) four steps of transition, thus implementation within RSG and the aviation industry.

CHAPTER 6.4

KEY TAKEAWAYS.

- Electric aviation fits in RSG its portfolio with its mission statement of *"Accelerating the transition to sustainable aviation by enabling electric aircraft trajects within Europe"*.
- Electric aviation should be in line with the three RSG pillars, Quality of Life, Network and Service. Therefore, the metrics substitution and network potential are deemed the most important.
- With this, three entry use case emerge. Each of them have their own bottlenecks and possibilities. The third entry use case, connecting the Netherlands to Scandinavia, and thus Western-Europe to Scandinavia is recommended at the entry use case with the biggest potential.

07

FIRST REGIME MILESTONES.

Arriving at the climax of the thesis, the first regime milestones. Chapter 7 aims to make the entry use case actionable, giving RSG the ability to proceed with the first steps towards the implementation of electric aviation. This chapter contains the bottlenecks regarding the entry use case and proposes the first actions to take as RSG.

CHAPTER 7.1

ENTRY USE CASE BOTTLENECKS.

Introduction
An entry use case needs to be feasible in order for it to be implemented. Yet, with recommending the entry use case of Amsterdam-Copenhagen-Stockholm and Oslo (further referred as the entry use case), a vast amount of bottlenecks emerge. These bottlenecks are the result of innovation policies maintaining existing technological systems, but much less stimulating the creation of new ones (Archibugi & Lundvall, 2003). Experts differentiate three types of bottlenecks, minimum range, operational transition and policy.

Minimum range
In terms of technology bottlenecks, one is expected to emerge with the entry use case; minimum range needed. Most electric aircrafts in the foreseeable future (up to 2030) have ranges up to roughly 400 km. Chapter 6 argued that Hamburg and Gothenburg would be desired to skip when enabling the destinations of the entry use case, meaning that an aircraft with a minimum range of 640 km would be desired.

As of now, only a single aircraft enables this range; Eviation Alice with a range of 815 km (excluding energy in reserve). For chapter 7.2, my recommendation therefore would be to pursue and stimulate the acquisition of this aircraft. Even though Scandinavia have interests vested in Heart Aerospace, the Swedish electric aircraft initiative with the ambition to substitute regional aviation, Eviation Alice would have its place along side Heart Aerospace and its ES-19 aircraft. Eviation Alice could provide European flights, while Heart Aerospace could provide regional flights, synergizing as a Hub and Spokes model for electric aviation.

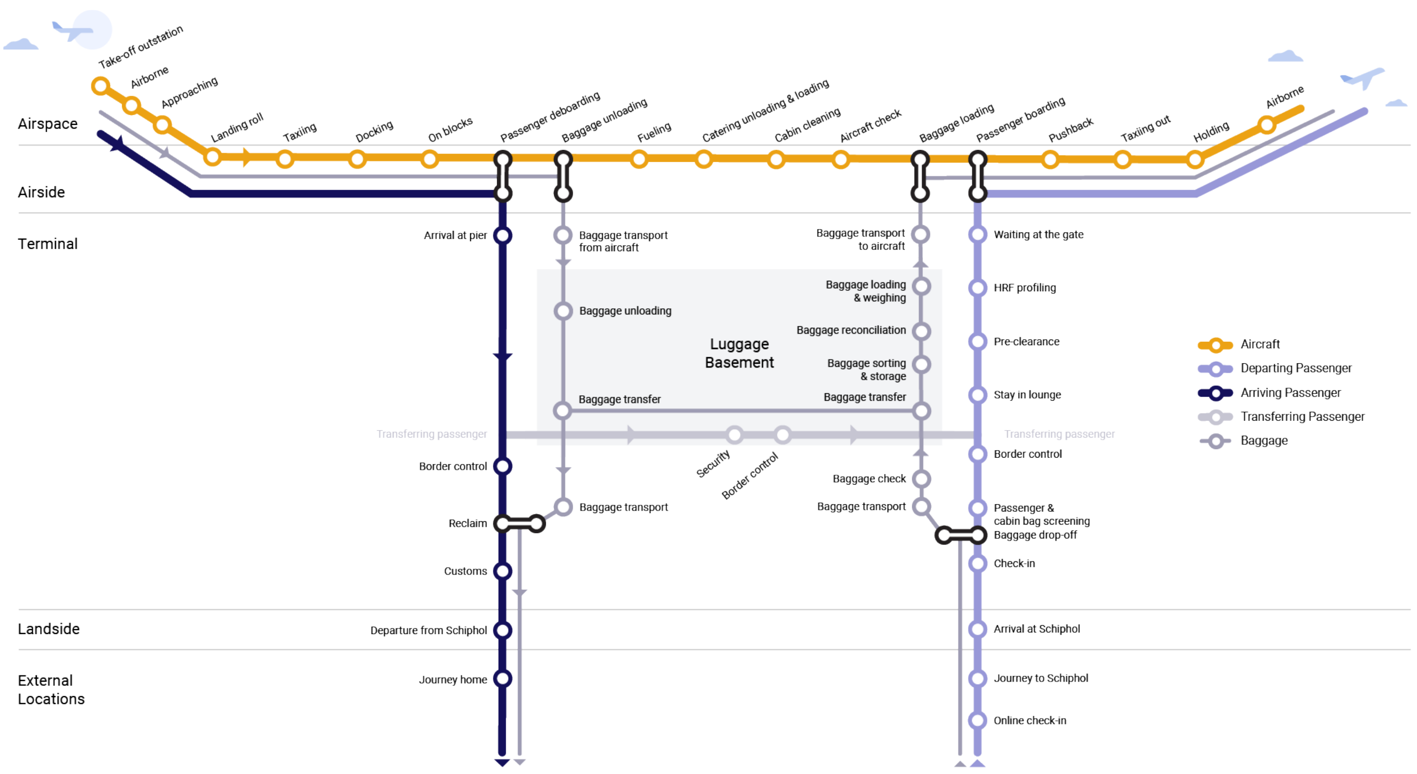
Operational transition
The second bottleneck has to do with the different facilities needed on airside and in the terminal to facilitate electric aviation. The operational bottleneck are; 1. the fuelling of the aircraft in terms of turnaround time and megachargers, 2. the energy supply for the electric aircrafts to facilitate the amount of flights needed, and 3. the airside logistic and management system to facilitate the amount of flights. The operational and logistical process of conventional aviation is shown in figure 24.

When comparing this process to electric aviation, the fuelling on airside and possibly the operational service model on the terminal differ. This last one is not a crucial bottleneck in the current stage of electric aviation, but aim to serve as a possible solution for the facilitation of the amount of electric aviation flights. Fuelling on the other hand is a crucial bottleneck, as airports currently do not have the needed infrastructure to fulfil this task for electric aviation.

The fuelling of an electric aircraft is done by, as the name suggest, electricity. Existing electric chargers are unable to charge electric aircrafts, simply because their power is too low. The electric aircrafts to consider are Eviation Alice with an energy capacity of 920 kWh and the Heart Aerospace ES-19, with an energy capacity similar to the Eviation Alice.

To understand which charger type is needed to fuel 920 kWh, the unit Power needs to be understood. Chargers vary in Power. Meaning, they vary in Voltage and Ampere levels, as these units multiplied result in Power. The chargers we use on a daily basis such as phone chargers, have a voltage level of 5 V and 1 Ampere, putting the Power level to 5 Watt. Car chargers on the other hand, have an increased power output, as the battery of a car is much larger than the one inside a phone. Car chargers such as Tesla's, have Ampere levels between 12A and 48A, and voltage levels of 240V, resulting in power outputs between the 2.8 kW and 11.5 kW, and thus fully charging a Tesla Model 3 (54-75 kWh) in 4.5 to 7 hours. Then there are Tesla superchargers, planned to be adopted as on-the-road fuelling stations,having peak charging rate of 250 kW, with levels up to 480V and 520A. This enables charging a Tesla to 80% in 30 minutes. Moving from the adjacent automotive market back to the aviation market, the feasibility is still not enabled with state-of-the-art superchargers currently available on the market. This is when taking into account the most crucial factor on airside; the turnaround time.

For a successful implementation of electric aviation on an airport, the turnaround time should be on par with conventional aviation. Meaning, the turnaround time should not exceed the 10 and 45 minutes (Telegraph, 2019). As smaller narrow body aircrafts, similar to the Eviation Alice, turn around in roughly 20 minutes, the electric counterpart should turn around accordingly. The fuelling time is based on the speed at which


▼ Figure 24. Internal RSG Concept of Operations (Conops).

an electric aircraft has a full battery. While BEV batteries are between the 50 kWh and 150 kWh, the batteries for electric aircrafts are bigger and denser. An Eviation Alice, with an energy capacity of 920 kWh, will need chargers with a power output of 2.76 MW, thus megachargers.

While this seems rather much, the current innovations are looking promising. In 2018, Chargepoint (2018) stated that they are working on a charging system of 2 MW to support the fuelling of electric aircrafts and trucks (Electrek, 2018). Tesla unveiled in 2019 the ambition to achieve >1 MW charging, to facilitate the fuelling of the electric trucks (Electrek, 2019). Even Daimler stated in 2019 that they are working on a charging system to support 3 MW charging (Electrek, 2019). While the last two are automotive based innovations, they give a proper indication of the feasibility for electric charging.

With this, we arrive at the second operational transition bottleneck; the energy supply. While the kerosene infrastructure is already in place, the electricity supply infrastructure is not. With an Eviation Alice and its 920 kWh energy capacity, and the entry use case with a conservative 193,255 flights a year, the total energy capacity demand is 177.8 GWh. Even considering a scenario of full implementation substituting all flights for the entry use case, an energy supply of 275.7 GWh is needed to support 299,707 flights a year. The shift to a bigger electricity supply is evident, but based on data from 2019, this would mean an increase in electricity demand for RSG of 88.9-137.9% (Schiphol, n.d.) to enable the entry use case

The feasibility of this electricity supply might not be possible currently, but it is crucial for RSG to invest and increase the electricity supply in the coming years in order to enable electric aviation at the airport. Also understand that the kerosene supply would decrease simultaneously.

At last, there is the logistical issue on airside. Calculations from chapter 6.3 show that, in order to facilitate the entry use case, the yearly number of flights could increase with 193-300k, which is 529-822 flights a day, thus 29 - 46 flights an hour (18-hour day). As Schiphol facilitates roughly 500k flights on a yearly basis, this entry use case would mean an increase of 39-60% in yearly flights. This increase is not yet feasible logistically and regulatory, and would mean significant changes in the current operational and logistic management system on airside.

As of now, the foreseeable future either suggest lowering the capacity, while still maintaining a viable and desirable business model, suggesting a shift in the current service model is required to make electric aviation viable and desirable. Or radically optimizing the operational and logistic management systems, meaning that a significant optimization is required in the existing systems. This last scenario would indicate an increase in human capital and possibly airport size, as well as shifting towards a new airport management system. In either scenarios, enabling the flight capacity in the Netherlands is required for electric aviation, which is done through changing landscape regulations through the regulatory parties.

Policies

The third major bottleneck for the implementation of electric aviation in the regime is the landscape regulations. In the Netherlands, in order to limit the emission of CO_2, noise and NO_X a cap on the amount of flight movements have been installed and regulated. As electric aviation significantly reduces these emissions, making it comparable to a train or a BEV, a cap on flight movements might prove unessential for this novel modality. This might open a discussion between regime organisations to alter or provide different regulations on landscape level regarding electric aviation.

These bottlenecks are yet the most urgent obstacles to overcome to facilitate the implementation of electric aviation. The next chapter covers the initial steps for RSG to take in order to overcome these bottlenecks, and accelerate the transition to electric aviation.

CHAPTER 7.2

FIRST STEPS.

Introduction
This chapter concludes the research into electric aviation, and the expected outcome of the scope of the thesis covered in chapter 1. Within this chapter, the first steps towards the implementation of electric aviation are covered, aligned with the functions of Hekkert et al. (2007) leading to successful technology development and diffusion. Finally, the seven initial steps by RSG towards electric aviation and the thesis research are integrated in a final roadmap, giving an overview of the entry use case timeline and expectations.

Seven functions
The seven functions of Hekkert et al. (2007) provide insights in steps to pursue to enable the third phase of transition by Geels (2002). Below are the seven functions covered, specific to the entry use case and bottlenecks of this thesis.

1. Entrepreneurial activities. As mentioned in chapter 2, this function is comparable to the second phase by Geels' (2002) four phases of transition model. Therefore, the stimulation of entrepreneurial activities have already been undertaken and is still happening to push the limits of electric aviation, potentially enabling higher ranges up to 1,900 km beyond 2030.

2. Knowledge development. One of the most crucial functions, as the bottlenecks of chapter 7.1 are mainly under researched. The supply of energy to facilitate the entry use case is not yet in place and the airside infrastructure to provide this even less. Therefore, spending resources in research and development (R&D) activities towards building a knowledge foundation to enable mega charger technology is imminent. On top of this for an airport such as AAS, having the certainty of electric aircrafts using the electric airside facilitation provided by the airport is important before implementing the needed infrastructure. Therefore, developing this knowledge is not a one-organisation job, but will be in collaboration with industry stakeholders.

4. Guidance of the search. With the knowledge development from function 3, a pilot can be set in motion. The goal of this pilot is collaborating with a multitude of stakeholders to understand which knowledge is not well understood yet, in order gain an indication for knowledge direction and resource input.

5. Market formation. This aspect, the development of a niche market, has not been covered in this thesis. A small but promising early adopter for electric aviation would be the business traveller. He has the budget to invest more than the average consumer for a flight, and could desire a higher luxury than the average consumer such as privacy. This is an important aspect for the early stages of the entry use case, as these early adopters are key to advance the diffusion of the novel modality. While it has not been covered in this thesis, and this is an educated speculation of research and expert knowledge, further research is needed to fully understand the initial market formation.

6. Resource mobilization. A fairly straightforward function, arguing that human and financial capital is needed for R&D and implementation to happen. This is one of the required metrics for the choice of the entry use case.

7. Legitimacy creation and counteracting resistance to change. At last, the seventh function. The current regime, have regulations and policies in place to maintain existing technologies and oppose novel ones due to vested interest. Hekkert et al. (2007) argue that forming a coalition could function as a catalyst for change and influence the existing regime to transition towards a new mobility ST system, including electric aviation. As per Hekkert et al. (2007); " If successful, advocacy coalitions will grow in size and influence; they may become powerful enough to brisk up the spirit of creative destruction."

Another, or rather, an additional way to promote legitimacy and counteract the resistance to change is through policies and regulations. Collaborating with the government for novel regulations to enable and even promote electric aviation should be done on three topics as proposed in chapter 7.1. These topics are the limited amount of flight movements from AAS (or other airports in the entry use case), a change in tax and subsidies promoting electric aviation, and a shift in aviation borders in Europe. An underexposed topic in this thesis, as it's outside of the scope, is the European aviation borders, causing flights to alter routes and flight patterns due to existing regulations between countries.

The Coalition
Therefore, the first step into the direction of the implementation of electric aviation should be forming a coalition with the stakeholders in the industry whom desire to pursue electric aviation as a venture towards sustainable aviation. Within this coalition (further referenced as the Coalition) will cover the functions and invest resources in gaining knowledge and developing the technological demand to facilitate electric aviation. Figure 25 provides the first steps to be undertaken by RSG and the Coalition for the facilitation of the transition to electric aviation.

INITIAL STEPS

1. Gather industry stakeholders and form the Coalition. Stakeholders essential within this coalition for the entry use case are airports, airlines, OEMs, governments, research institutes and startups (whom could fall under both OEM and airline).

2. Research & development towards airside infrastructure, mainly the megachargers.

3. Research & development towards the provision of a sufficient energy supply. Currently RSG is collaborating with Eneco, communicating the endeavour of increasing the energy demand would be a valid step.

4. Consumer research for the development of the niche market, thus developing the market for the early adopters of electric aviation on the entry use case. This also includes research into a shift in service model enabled with the novel modality.

5. Developing & implementing a shift in current aviation regulations for electric aviation regarding tax and subsidies.

6. Developing & internationally collaborating a shift in current aviation regulations for electric aviation regarding European aviation borders and flight patterns.

7. Opening the discussion and collaborating on the development of changing regulations and policies regarding the limit on the number of flight movements at AAS with the government and other involved stakeholders.

▲ Figure 25. Initial steps for RSG to take to accelerate the implementation of electric aviation.

08

CONCLUDING THE PROJECT.

As this thesis is coming to an end, an overview of the limitations and relevance will be covered within this chapter. Consequently, there is a discussion and a reflection sub chapter to complete the thesis.

CHAPTER 8.1

DISCUSSION.

Introduction

The thesis has enabled the understanding of the current electric aviation industry. With a topic as big as electric aviation, a person could spend years researching and find new knowledge, making it evident that there remain domains not covered in the thesis or even knowledge gaps. The steps proposed in chapter 7 are founded on the research conducted in this thesis, meaning that there are limitations due to the time limit of the project.

Resource depletion

In the final weeks of my project, during a meeting with a stakeholder within NLR, I discovered that resources for the development and building of batteries deplete faster than they are delved from mines. This came to light globally when Telsa shared its vision on the implementation of their BEV, where experts argued that the resource demand to facilitate this would cause a resource shortage in the future. While the automotive industry is an adjacent market, it has direct impact on the feasibility for electric aviation in the future, as the modern-day batteries contain the same components. In the literature, it is referred as the Jevons paradox, stating that upon the increase in efficiency for a resource, the rate of consumption of that resource rises due to increasing demand (Polimeni, J.M. & Mayumi, K., 2015). As of now, there is little information known about this limitation, but it would have benefited the feasibility aspect of the thesis.

Hydrogen

Secondly, intentionally left out of the scope is hydrogen powered aircrafts. The topic of hydrogen is as big as the topic of electrical aviation. While still incorporating a rough indication of the opportunities of hydrogen in the aviation overview including ranges, pax and milestones, it was too large to incorporate in the thesis itself.

Other modalities

Thirdly, the detailed incorporation of different modalities. One novel modality which has proved valuable for specific use cases is Hardt Hyperloop. In order for a full assessment of what the future holds for the mobility industry, Hyperloop would have generated an interesting perspective on short range travels. While my personal belief is that Hyperloop as a modality is too rigid and would not arrive at its full potential within Europe due to many stops between cities, other stakeholders believe the opposite. Thorough research within this modality could prove fruitful in the assessment of the future of mobility.

Another is the train. The thesis has touched upon the train as a modality and its synergy with electric aviation. Research into the impact of scaling the train as a modality and the potential indirect transition of current train passengers to electric aviation is untouched upon within the thesis, which could impact the transition or use cases for electric aviation in the future.

Both the modalities of train and Hardt Hyperloop are exciting topics, influencing the viability for electric aviation in the future.

Consumer research

The steps in chapter 7 contain consumer research. As an industrial designer with a specialization in strategic product design, I am well experienced with conducting consumer research. While chapter 5 contains a basis for consumer research, it has a limited amount of insights. Richer insights within consumer research would be their willingness to travel during or post pandemic, and their willingness to travel with an electric aircraft.

RSG currently resides in an early stage of knowledge development on electric aviation, therefore it is arguable whether conducting thorough consumer research prior to exploring the current window of opportunity would prove valuable as other explorations were more urgent. Nonetheless, it would enable novel insights in the window of opportunity, or be the start of further research. Therefore, it is included as the initial next steps for RSG to research, as this could shape the niche market for the entry use case.

All in all, these four limitation form interesting new research domains for RSG to explore, enriching the available information with new insights and potentially strengthening or altering the direction in which electric aviation should be developed.

CHAPTER 8.2

REFLECTION.

Introduction
The aim of this thesis was to gain an understanding in the electric aviation industry and its corresponding developments. Based on this research, looking for opportunities for RSG to facilitate the transition towards sustainable aviation through electric aviation.

Phase one of the thesis conducted extensive desk research and interviews with experts to gain a complete overview of the electric aviation industry, together with its feasibility, desirability and viability. Based on this, a window of opportunity emerged, enabling an entry use case for RSG in phase two to exploit the electric aviation developments as well as accelerating the transition towards sustainable aviation. With this, new knowledge gaps emerged on the subject, which consequently resulted in the end with the proposed first steps for RSG to undertake.

Problem statement
The results of the projects have been in line with the research questions derived from the problem statement of the project brief. Rapidly after the initial research and expert interviews into aviation and its electric innovation developments, it became clear that there was a strong need for knowledge and understanding on the subject. Not only for RSG, but aviation as an industry. Information, academic literature and organisational knowledge was fragmented, with many stakeholders having different opinions and visions regarding electric aviation.

Therefore, this thesis aims to give a comprehensive understanding of electric aviation, and map concrete opportunities for electric aviation with actionable next steps for RSG to take. This last argument was not included in the project brief, but discussed with all three supervisors in the early stages of this thesis, as my personal goal of this thesis was developing a concrete and actionable plan for RSG for further activities on this topic.

Relevance for RSG and the industry
The relevance for RSG is mainly in gaining an understanding in the direction of which the electric aviation developments take. RSG as a group of airports do not have direct benefit of understanding what the future will hold for electric aviation, but it does enable them to speculate on airside development needs and invest resources, research and development in them. Moreover, it also became clear that the transition towards a new aviation industry, arguably a novel ST system, is enabled by collaborating with all the stakeholders within the industry. For RSG to become the most sustainable airport, it'll need to take a pioneering role in this transition.

This is what makes it also relevant for the industry, gathering the fragmented knowledge to gain a full understanding of the current feasibility, desirability, and viability. Understanding where the developments enable , if the need within the industry is large enough, and whether there is a market and strategic value for it. Finally, the proposal of a coalition, to align visions of different stakeholders within the industry and accelerate the transition.

Relevance for academic literature
While the literary foundation has been incorporated in the final stages of the thesis, it has been proved useful and relevant. It has served as the backbone of structuring the knowledge within this thesis. Additionally, the steps taken for research directions and concept development have had a subconscious basis of transition theory, which enabled the finetuning of the knowledge and its logical structuring. All in all, it did not enable the development of new knowledge within this academic field. As per Geels (2002), for system transition to become visible, it takes decades to perceive it and thus analyse. Nonetheless, the thesis did validate the value of the academic literature.

Personal learning goals
At the start of the thesis, I formed four learning goals:

1. Applying my capabilities in research to develop a value proposition for RSG in the aviation sector.
2. Manage a project from research and ideation until concept.
3. Become an in-depth expert on sustainable aviation innovation and innovation management.
4. Dive into the Innovation Hub way of working methodology.

Arguably, three of the four personal learning goals or rather ambitions have been reached. The second goal used to have implementation instead of concept, which seems unrealistic at the end of the thesis. As previously mentioned, the topic of this thesis is immense, while the knowledge on this topic is limited and yet underdeveloped. I am glad that my supervisors pointed this out, setting realistic expectations for the thesis that I had in mind.

Nonetheless, during the thesis new goals and ambitions emerged, in line with this implementation phase removed from the four mentioned learning goals. Thus, my ambitions evolved, and shape the direction to pursue post graduating from the TU Delft. I believe that a scale-up or a traineeship in a large corporate organisation enable learning the development and implementation of concepts in the market and adjusting accordingly. Thus, becoming my new learning goal and ambition.

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10

APPENDICES.

APPENDIX A

PROJECT BRIEF PROPOSAL.

start date 12 - 10 - 2020

12 - 03 - 2021 end date

INTRODUCTION **

Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

Background: With the increased importance and acknowledgement of climate change in the aviation industry past decades, change and solutions to tackle climate change have become urgent. In order to keep the rising temperature below two degrees celsius, the UN developed the Paris Agreement including Sustainable Development Goals (SDGs) [1]. Expected with the Paris Agreement is to both strengthen the global response to climate change and strengthen the ability to cope with the impact of climate change [2]. The current emission through the aviation industry is two to three percent of the worldwide CO_2 emission [3]. Therefore, the response of the aviation industry is investing its developments in (1) the reduction of CO_2 emissions through aircraft and engine design, (2) technology and supporting development of sustainable aviation fuels [4] and (3) better travel route management [3].

Client: Based on the UN's SDGs, Royal Schiphol Group (RSG) has developed their own share of sustainability goals to be reached: looking into ways to reduce the CO_2 emission through flying. As the demand for mobility is increasing and aviation is an efficiënt way of travelling, RSG is looking into aviation fuel alternatives such as hybrid and electric flying [5]. Within this field, RSG is looking into the business value of these alternatives to enable and facilitate the transition to sustainable electric flying. Benschop, CEO of RSG, argued three criteria which play a key role for the implementation of such a solution: (1) it should be related to the emission goals, (2) it should contribute to the current investments towards increased sustainability and (3) the international role of the Dutch aviation must remain intact [3].

Project Goal: The aim is to develop an overall strategy to help RSG in its transition to make aviation more sustainable within the hybrid/electric aviation innovation field. This entails a scope defined by the following deliverables:
1. In-depth research by identifying and categorizing hybrid/electric aviation modalities.
2. A value proposition of hybrid/electric aviation for RSG in 2030 and it's strategic relevance to the current business & service models.
3. A concrete concept entailing this value proposition.

References:
[1] UN. (2020). Climate Change. Retrieved September 6 from https://www.un.org/sustainabledevelopment/climate-change/
[2] UNFCCC. (n.d.). The Paris Agreement. Retrieved September 6 from https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement
[3] Royal Schiphol Group. (2019). Schiphol CEO Dick Benschop: 'Zero emission aviation is Mission Possible' https://news.schiphol.com/schiphol-ceo-dick-benschop-zero-emission-aviation-is-mission-possible/
[4] Safran. (2019). The Sustainability of Aviation. Retrieved September 6 from https://www.safran-group.com/media/sustainability-aviation-20190618
[5] Royal Schiphol Group. (2019). Annual Report 2019. Retrieved September 5 from https://www.annualreportschiphol.com/xmlpages/resources/TXP/Schiphol_web_2019/pdf/Schiphol_Annual_Report_2019.pdf

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Initials & Name VJC Verboog Student number 4466640

Title of Project Transition to sustainable aviation

Personal Project Brief - IDE Master Graduation

TUDelft

PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

The goal of this project is to create an overall strategy for RSG to make aviation more sustainable through hybrid/electric aviation. This leads to the problem definition: What are the current developments in the electric aviation industry? And how can RSG use this to facilitate a transition towards sustainable aviation through enabling hybrid/electric aviation?

As of now, the scope of the project is to highlight where the biggest opportunities lie for RSG and develop a value proposition for RSG in terms of hybrid/electric aviation. These opportunities will be the starting point of the project frame. Therefore, the first phase of the project is to research the current developments and capabilities within the electric aviation industry. The second phase is exploring how RSG can use those developments and capabilities in order to create a business value proposition for 2030. Consequently, based on this value proposition, develop a concrete concept for the facilitation of the transition to sustainable aviation, taking into account both RSG's strategic fit and capabilities.

ASSIGNMENT **

State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in "problem definition". Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, ... In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

My aim is to deliver a strategic transition report including the value proposition and a concept for RSG to facilitate the transition to sustainable aviation. These deliverables consist of an in-depth analysis of market and context, product and service offering, RSG capabilities and technology developments. This analysis will then be turned into a concrete value proposition and concept for RSG to change it's current offering and facilitate the transition to sustainable aviation.

As per the Delft Design Methodology and RSG's Innovation Hub way of working, I will start with a detailed analysis using the DEPEST method to understand current market and context (consumer, company, competitor, context and stakeholder). This will give a broad perspective in what developments and innovations are currently happening and which needs and opportunities these developments entail. Consequently, this will give a clear perspective which innovations and capabilities are crucial for RSG to facilitate the transition to sustainable aviation, and give clear insights in the feasibility of such transition. This is the first phase of the project.

The second phase starts with the synthesis of the research and will be the basis to develop the value proposition. Parallel to the development of this proposition, a concept will be developed using both the synthesis of the research, value proposition and qualitative interviews. These qualitative interviews will be used to develop and test the viability and desirability of the concept internally at RSG. Both the value proposition and the concept will be the starting point in capabilities to develop and for future partnerships and ventures for RSG, for the execution in facilitating a transition towards sustainable aviation.

IDE TU Delft - E&SA Department /// Graduation project brief & study overview /// 2018-01 v30 Page 5 of 7

Initials & Name VJC Verboog Student number 4466640

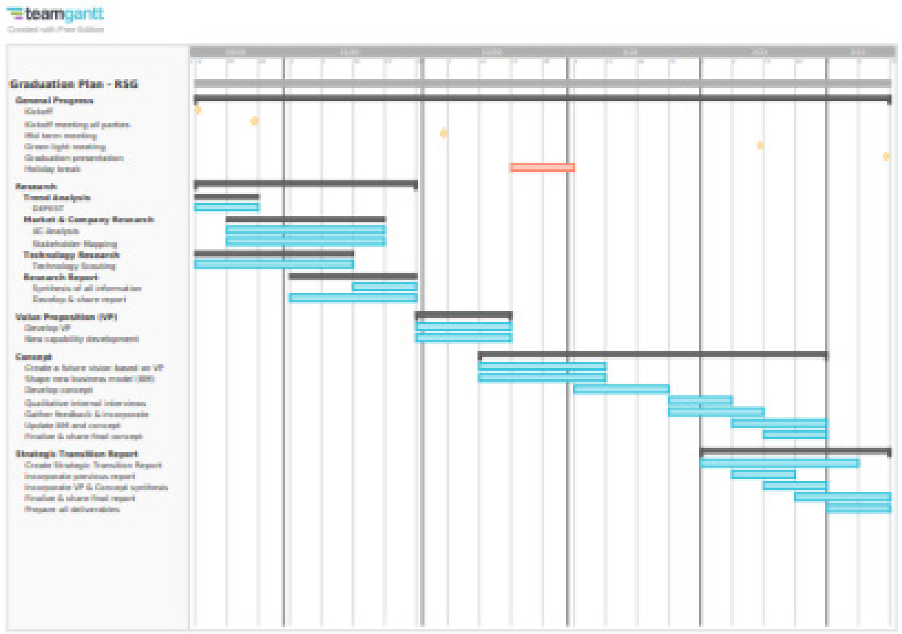
Title of Project Transition to sustainable aviation

PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any, for instance because of holidays or parallel activities.

start date 12 - 10 - 2020

12 - 3 - 2021 end date



MOTIVATION AND PERSONAL AMBITIONS

Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed. Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a specific tool and/or methodology, ... Stick to no more than five ambitions.

These past years I've shaped my ambitions to work in the business strategy field of disruptive technology companies who have a positive impact on the world. Courses in Strategic Product Design such as Design Strategy Project, New Product Economics, Brand and Product Commercialization and Design Roadmapping have given me the capabilities to pursue these ambitions. This is intertwined with entrepreneurship, which has been my main focus in my minor International Entrepreneurship & Development and Build Your Startup, which have given me insights and tools to understand feasibility, viability and desirability of companies and its impact.

This, in my opinion, helps me define overall strategies for companies to focus on both its long-term sustainability and impact. I am therefore eager to implement my knowledge in the innovation branche of a corporate multinational with the influence to make a positive impact.

My personal learning goals are:
1. Apply my capabilities in research to develop a value proposition for RSG in the aviation sector.
2. Manage a project from research and ideation until concept.
3. Become an in-depth expert on sustainable aviation innovation and innovation management.
4. Dive into the Innovation Hub way of working methodology.

FINAL COMMENTS

In case your project brief needs final comments, please add any information you think is relevant.

APPENDIX B

CURRENT INITIATIVES.

PROJECT FRESSON.

PROJECT FRESSON.

Location.
United Kingdom.

Parties involved.
Cranfield University. Cranfield Aerospace Solutions Rolls-Royce. Denis Ferranti Group. Britten-Norman. Warwick Manufacturing Group. Loganair.

Type.
Hybrid electric propulsion system. Britten-Norman aircraft.

Goal.
Island-hopping between the Orkney Islands in UK/Scotland and the Highlands.

Pax.
9.

Range.
no data. Short-haul.

Battery energy density.
no data.

Milestones & readiness.
2021 first flight of the aircraft.

Description.
They received a £9 million from the UK government to realise the 30 month project. The ambition is to claim global first with the introduction of this hybrid-electric aircraft by Loganair and Cranfield University. The first step is the 9-seat aircraft, and the next goal is modifying a current existing 19 seat aircraft with the ambition to design and build a new 19 seat aircraft.

Sources.

- Press and Journal. (2019). Electric plane plan for islands receives UK government cash. Retrieved on October 22, 2020 from https://www.pressandjournal.co.uk/fp/news/islands/1893676/electric-plane-plan-for-islands-receives-uk-government-cash/
- Reuters events. (2020). Aviation plots an electric flight plan despite headwinds. Retrieved on October 22, 2020 from https://www.reutersevents.com/sustainability/aviation-plots-electric-flight-plan-despite-headwinds

AMPAIRE.

AMPAIRE.

Location.
United States, Los Angeles.

Parties involved.
Techstars Accelerator.

Type.
Hybrid electric propulsion system. Cessna 337 Skymaster.

Goal.
Test the aircraft in Hawaii between Maui's main airport in Kahului and Hana.

Pax.
6.

Range.
200 miles. 321 km. Short-haul.

Battery energy density.
no data.

Milestones & readiness.
Testflight in 2021. FAA certification end of 2021.

Description.
Ampaire modified an existing Cessna 337 Skymaster into a hybrid-electric aircraft with an electric motor powered by a battery pack and a conventional combustion engine. Noertker, CEO of Ampaire, says that this hybrid design cuts fuel consumption between 70 and 90%, and decreases maintenance costs between 20 and 50%. Once they passed the FAA certification, passengers will be able to book their first flight with the hybrid aircraft for a 15 minute flight between Kahului and Hana.

Sources.
- Green Biz. (2019). 6 Electric aviation companies to watch. Retrieved on October 26, 2020 from https://www.greenbiz.com/article/6-electric-aviation-companies-watch
- Reuters events. (2020). Aviation plots an electric flight plan despite headwinds. Retrieved on October 22, 2020 from https://www.reutersevents.com/sustainability/aviation-plots-electric-flight-plan-despite-headwinds

EVIATION ALICE.

EVIATION ALICE.

Location.
Israel.

Parties involved.
MagniX. Clermont Group. Cape Air. Siemens. Honeywell.

Type.
Full-Electric propulsion system. Alice.

Goal.
Enable regional affordable and sustainable transport through aviation.

Pax.
9. (+2 pilots)

Range.
870 km. Medium-haul.

Battery energy density.
~255 Wh/kg.

Milestones & readiness.
Expect to receive the FAA certification late 2021.

Description.
With a speed of 444 km/hour, the Alice aircraft is able to achieve a range of 870 km with operating costs of $165. A total of 164 suppliers have worked on the project, reasoned by the disrupting potential of the aircraft. This is also the reason why Clermont Group is backing the project, and Cape Air, the largest independent US regional airline, have released the acquirement of a double digit number of Alice aircrafts to its fleet. Expected to deliver them in 2022.

Sources.
- Eviation. 2020. Homepage Alice. Retrieved on October 12, 2020 from https://www.eviation.co/
- Green Biz. (2019). 6 Electric aviation companies to watch. Retrieved on October 26, 2020 from https://www.greenbiz.com/article/6-electric-aviation-companies-watch

HARBOUR AIR.

HARBOUR AIR.

Location.
Canada, Richmond.

Parties involved.
MagniX.

Type.
Full-electric propulsion system. Havilland DHC-2 Beaver.

Goal.
To operate a full-electric sea-aircraft on short routes.

Pax.
6.

Range.
no data. 30 minute flight. Micro-haul

Battery energy density.
~150 Wh/kg.

Milestones & readiness.
Working to gain certification, and hope to start operating in 2022.

Description.
Harbour Air and MagniX are collaborating to electrify existing certified aircrafts, in order to start operating in 2022. By electrifying the aircraft, they'll enable a 30min flight with reduced noise and air pollution, but also reducing fuel and maintenance cost.

Sources.
- Reuters events. (2020). Aviation plots an electric flight plan despite headwinds. Retrieved on October 22, 2020 from https://www.reutersevents.com/sustainability/aviation-plots-electric-flight-plan-despite-headwinds
- Forbes. (jan 2020). Is Electric Flight Aviation's Next Era of Innovation? Retrieved on October 22, 2020 from https://www.forbes.com/sites/forbesbusinesscouncil/2020/01/10/is-electric-flight-aviations-next-era-of-innovation/#36f43c3e7b7e

ZEROAVIA.

ZEROAVIA.

Location.
United States, California.

Parties involved.
Cranfield Airport. Cranfield University. Cranfield Aerospace.

Type.
Hydrogen propulsion system. Piper Malibu Mirage.

Goal.
A 10-20 seat hydrogen electric aircraft with a range of 500 miles (800 km). 50-100 seat aircraft with a range of 800 km by 2027. And a 100-200 seat aircraft with a range of 5,500 km by 2030.

Pax.
10-20.

Range.
800 km. Medium-haul

Battery energy density.
no data.

Milestones & readiness.
A 10-20 seat hydrogen electric aircraft by 2023.

Description.
In June 2020, they operated a test flight from Cranfield Airport with a Piper M350 with hydrogen fuel cells and gas storage. In September 2020, with project HyFlyer, they executed the test again. The next step will be executing the test from an airfield in Orkney with a range of almost 500 km by the end of 2020.

Sources.
- Royal Aeronautical Society. (2020). High time for hydrogen. Retrieved from October 26, 2020 from https://www.aerosociety.com/news/high-time-for-hydrogen/
- CNN. (2020). This aviation startup is soaring ahead with hydrogen-powered planes. Retrieved on October 23, 2020 from https://edition.cnn.com/travel/article/zeroavia-zero-emission-hydrogen-planes-spc-intl/index.html
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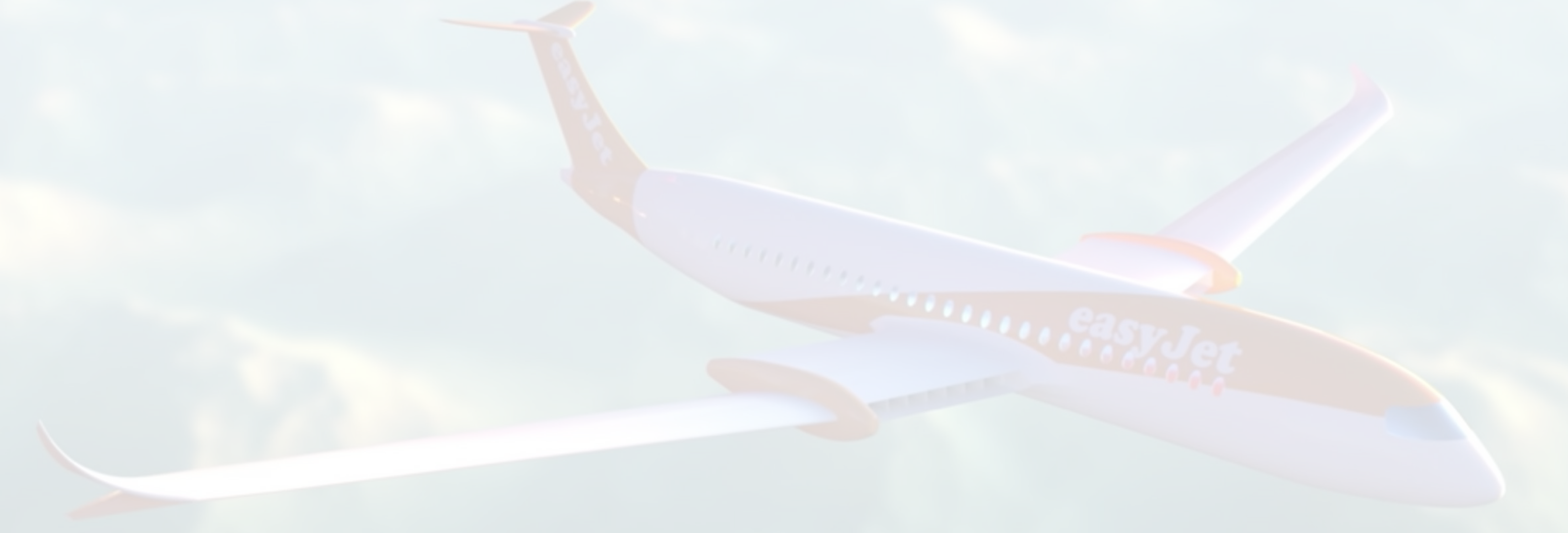


WRIGHT ELECTRIC.

WRIGHT ELECTRIC.

Location.
United States.

Parties involved.
EasyJet. Cranfield University.

Type.
Full-electric propulsion system. No data.

Goal.
Develop a 180 seat full-electric propulsion system jet, with a range of 500 km.

Pax.
180.

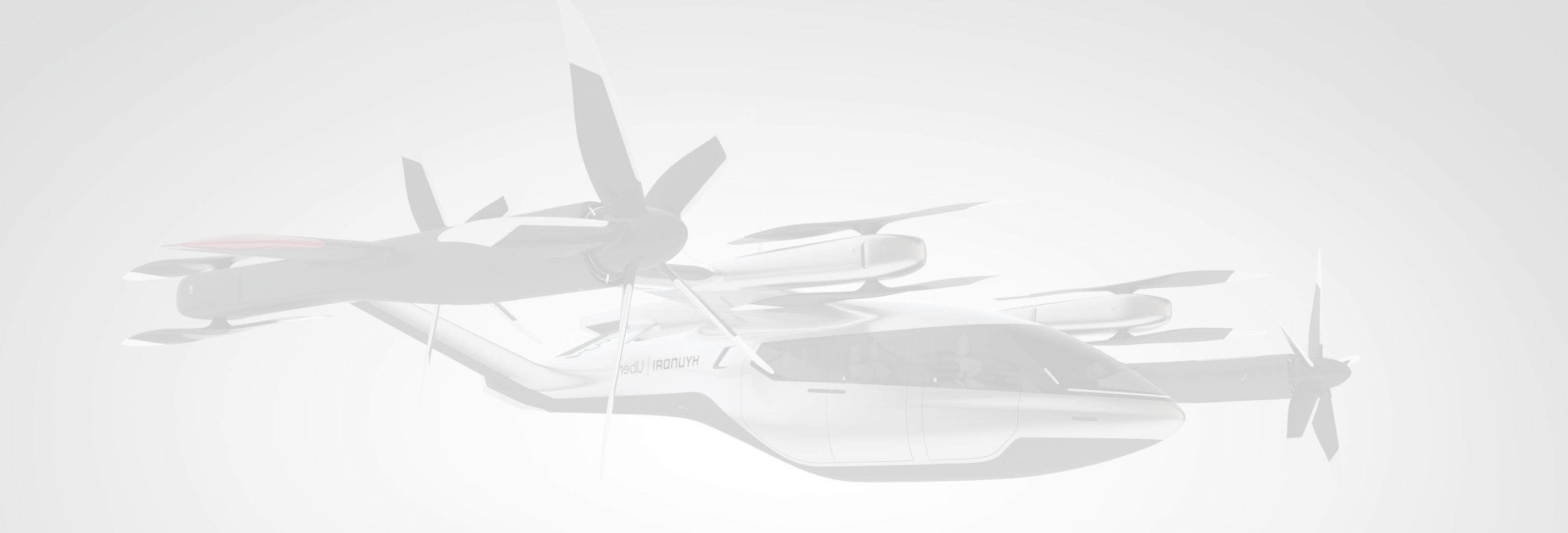
Range.
500 km. Short-haul.

Battery energy density.
no data.

Milestones & readiness.
A 180 seat, 500 km range, test flight in 2023.

Description.
EasyJet and Wright Electric are collaborating on a 180 seat full electric jet. They intend to conduct test flights in 2023, and enter the commercial market by 2030, with short-haul flights such as Paris-London.

Sources.
- BBC. (2020). As electric planes pass another milestone, Future Planet asks how long will it be before they are ready for everyday aviation? And just how far can they go? Retrieved on October 21, 2020 from https://www.bbc.com/future/article/20200617-the-largest-electric-plane-ever-to-fly
- Reuters events. (2020). Aviation plots an electric flight plan despite headwinds. Retrieved on October 22, 2020 from https://www.reutersevents.com/sustainability/aviation-plots-electric-flight-plan-despite-headwinds



UBER AIR.

UBER AIR.

Location.
no data.

Parties involved.
EmbraerX. Hyundai. Joby Aviation. Pipistrel. And more.

Type.
Full-ellectric propulsion system. Hyundai S-A1. VTOL.

Goal.
Start the Uber Elevate service, an Urban Air Mobility (UAM) service for micro-haul.

Pax.
no data.

Range.
100 km. Micro-haul.

Battery energy density.
no data.

Milestones & readiness.
Full launch in 2023.

Description.
Uber Air have demonstration flights planned for 2020, and expect a full launch in 2023. Recently, Uber Air was acquired by Joby Aviation, to take over the potential for an UAM service.

Sources.
- PC World. (n.d.) Uber Elevate and Uber Air Explained. Retrieved on October 28, 2020 from https://www.pcworld.idg.com.au/article/670509/uber-elevate-uber-air-explained/
- Transport Up. (n.d.) Pipistrel 801 eVTOL. Retrieved on October 28, 2020 from https://transportup.com/pipistrel-evtol-concept/
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HEART AEROSPACE.

HEART AEROSPACE.

Location.
Sweden.

Parties involved.
European Innovation Council (EIC). EQT Ventures. Norrsken. Vinnova.

Type.
Full-electric propulsion aircraft. ES-19.

Goal.
To aid to the Scandinavian goal of having an all domestic full-electric propulsion aviation by 2040.

Pax.
19.

Range.
400 km. Short-haul.

Battery energy density.
no data.

Milestones & readiness.
Expect the commercial operation certification by 2026.

Description.
Result from the Electric Air Travel in Sweden (ELISE) project, Heart Aerospace aims to enable domestic short-haul flight. They have already received a €2.5 million grant from EIC and €2 million from EQT Ventures and Norrsken. Furthermore, 8 airlines have already expressed their interest to purchase 147 aircrafts.

Sources.
- Sifted. (2020). Electric planes: not so far-fetched after all. Retrieved on October 22, 2020 from https://sifted.eu/articles/electric-aircraft-heart-aeorospace/
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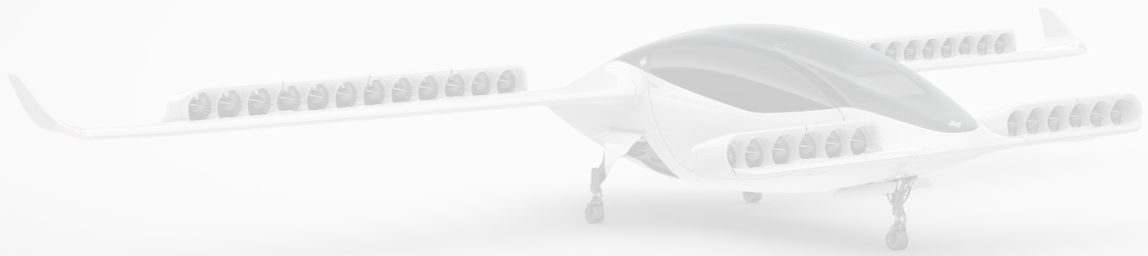

LILIUM.

LILIUM.

Location.
Germany.

Parties involved.
no data.

Type.
Full-electric propulsion engine. Lilium Jet. VTOL.

Goal.
To provide an alternative sustainable mobility for the 300 km range.

Pax.
4. (+ 1 pilot).

Range.
300 km. Short-haul.

Battery energy density.
~157 Wh/kg.

Milestones & readiness.
Aim to launch in Florida by 2025 as an Urban Air Mobility service.

Description.
Lilium Jet is an Urban Air Mobility VTOL type aircraft. Their aim is to enable the air taxi service, by flying passengers 300km in just one hour. Currently they are working on certification and industrialization.

Sources.
- Lilium. 2020. Home page. Retrieved on October 12, 2020 from https://lilium.com/
- Forbes. (2020). Lilium to launch air taxi network in Florida centered on Orlando. Retrieved on November 12, 2020 from https://www.forbes.com/sites/jeremybogaisky/2020/11/11/lilium-to-launch-air-taxi-network-in-florida-centered-on-orlando/?sh=6d368c7073a0

AIRBUS.

AIRBUS.

Location.
Netherlands, Leiden.

Parties involved.
no data.

Type.
Hydrogen-electric propulsion aircraft.
Type 1. Turbofan. Type 2. Turboprop. Type 3. Blended-wing body.

Goal.
Enable sustainable long-haul flights with hydrogen.

Pax.
Pax 1. 120-200. Pax 2. 100. Pax 3. 200.

Range.
Range 1. 3700 km. Range 2. 1850 km. Range 3. 3700 km.

Battery energy density.
no data.

Milestones & readiness.
Expect to enter the commercial market by 2035.

Description.
Airbus aims to disrupt the long-haul flight potential with new aircraft designs which enable flights over 1500 km before refuelling, which enables transcontinental aviation. For this to happen, the aviation ecosystem needs to change in terms of innovation and airport facilitation and infrastructure.

Sources.
• Airbus. (21 September) 2020. Airbus reveals new zero-emission concept aircraft. Retrieved on October 12, 2020 from https://www.airbus.com/newsroom/press-releases/en/2020/09/airbus-reveals-new-zeroemission-concept-aircraft.html

APPENDIX C

RANGE CALCULATIONS.

$$R = E^* \frac{m_{batt}}{m}\frac{1}{g}\frac{L}{D}\eta_{total}$$

Based on the calculations set up by Ferrier (2015) for a basic electric aircraft, I've calculated the range upon the implementation of 600 Wh/kg batteries.

R = distance flown.
E* = Battery specific energy.
mbatt = battery mass.
m = total aircraft mass.
g = force of gravity.
L/D = lift to drag ratio.
ηtotal = propulsion efficiency from cell to airflow.

L/D and ηtotal do not change upon inserting a different battery. The E* does change, and dependent on the total amount of energy supply your aircraft has, the mbatt/m will change.

With a L/D ratio of 19 and an efficiency of 80%, a total aircraft mass (based on Eviation Alice 6350 kg total aircraft mass) of 6350 kg, and a battery mass of 3600 kg. With an E* of 255 Wh/kg brings the range roughly to 817 km. Increasing the battery density to 600 Wh/kg, while keeping the battery weight at 3600 kg, brings the total range to 1,909 km.

Finally, when substituting 50% of the 600 Wh/kg batteries for passengers, the batteries end up on a total of 1800 kg with an aircraft mass of 6350 kg. This brings the range to 987 km, compared to the 1,900 km previously. With an average passenger weight including luggage of 90.7 kg (FAA standards), the remaining 1,800 kg of free space can be filled up by roughly 19 passengers.

APPENDIX D

COSTS.

Conventional aircraft.

Operational fuel use average sub 800 km: 5.9 L/100 pkm. (Lufthansa, date).
Kerosene: 0.19 €/L

€/pkm: 0.011

Electric aircraft.

All based on Eviation (2020). Retrieved from https://www.eviation.co/aircraft/

Operating cost: $200/hr.
Speed: 407.44 km/hr.
Max range: 817 km.
Max operating cost: $400.
PAX: 9 seats.
Cost per seat: $44.45 = €36.89.

€/pkm: 0.054

Train.
Operational energy use: 68 Wh/pkm (Internal RSG research, 2019).
Price per kWh in the Netherlands: 0.094 (business prices)

€/pkm: 0.0064

Car (ICE):
Operational fuel use for 12 km: 1L.
Fuel price Netherlands: 1.74 €/L.

€/pkm: 0.145

Car (BEV).
Operational energy use: 180 Wh/pkm (Tesla, date).
Price per kWh in the Netherlands: 0.22 (consumer prices)

€/pkm: 0.040

APPENDIX E

CARBON EMISSION PER PKM.

Conventional aviation sub 800 km range.

Well to tank: 64.47 gCO$_2$/pkm.	(UC Berkley, date)
Tank to wheel: 148.6 gCO$_2$/pkm.	(Lufthansa, date)

Total Well to Wheel: 213 gCO$_2$/pkm

Conventional car (ICE).

LCA Drive: 217 gCO$_2$/pkm.	(Hoekstra, 2019)
LCA Manufacturing: 27 gCO$_2$/pkm.	(Hoekstra, 2019)

LCA total: 244 gCO$_2$/pkm.

Electric car (BEV).

LCA Drive: 55 gCO$_2$/pkm.	(Hoekstra, 2019)
LCA Manufacturing: 40 gCO$_2$/pkm.	(Hoekstra, 2019)
LCA Battery: 16 gCO$_2$/pkm.	(Hoekstra, 2019)
LCA total 111 gCO$_2$/pkm.	(Hoekstra, 2019)

Train

50 gCO$_2$/pkm.	(Internal RSG research, 2020) & (TNMT, date)

Total: 50 gCO$_2$/pkm.

Electric aircraft

WTT: 30 gCO$_2$/pkm.	(Internal RSG research, 2020) & (Adjacent bus market)
TTW: 58.7 gCO$_2$/pkm.	(Eviation, 2020)

Total WTW: 89 gCO$_2$/pkm.

APPENDIX F

LINE INTERSECTION CALCULATIONS.

By calculating the point in time at which both modalities intersect each other, taking into account that the train always has a starting time advantage, gives us the following formula:

(T-Ttrain) * (Average vtrain/60 minutes) = (T-Tplane) * (Average vplane / 60 minutes)

T = total minutes.
Ttrain = train time dependent on which intersection.
Average vtrain = average train speed.
Average vplane = average plane speed.

Input:
Ttrainlow = 65 minutes.
Ttrainhigh = 125 minutes.
Tplanelow = 175 minutes.
Tplanehigh = 315 minutes.
Average vtrain = 75 km/hour. (including standard traject stops)
Average vplane = 370 km/hour.

Intersection (low plane, high train).

(T-Ttrainlow) * (Average speed train/60 minutes) = (T-Tplanelow) * (Average speed plane / 60 minutes)

T = 188 minutes. Therefore R (range) is 78 km.

Intersection (low plane, low train).

(T-Ttrainlow) * (Average speed train/60 minutes) = (T-Tplanelow) * (Average speed plane / 60 minutes)

T = 203 minutes. Therefore R (range) is 173 km.

Intersection (high plane, high train).

(T-Ttrainlow) * (Average speed train/60 minutes) = (T-Tplanelow) * (Average speed plane / 60 minutes)

T = 363 minutes. Therefore R (range) is 298 km.

Intersection (high plane, low train).

(T-Ttrainlow) * (Average speed train/60 minutes) = (T-Tplanelow) * (Average speed plane / 60 minutes)

T = 379 minutes. Therefore R (range) is 392 km.