The application of bio jet fuels until 2050

Scenarios for future developments

Utrecht University, Faculty of Geosciences, Science and Innovation Management, Master Thesis, 45 ECTS

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Back in 2006 I decided to join the Science and Innovation Management program at the Utrecht University. This was the start for a five year and six months journey that would eventually lead to this master thesis. SIM seemed to be the program that was the closest to my broad interest I had at high school. This expectation became true and I followed a broad range of courses during these years. To me it was not always clear were the program eventually would lead to. As Steve Jobs once said in his address at a graduation ceremony at Stanford: *''You can't connect the dots looking forward; you can only connect them looking backwards. So you have to trust that the dots will somehow connect in your future.''* During the interviews I performed for this research and the writing of this report it all became clear to me and the dots finally connected. This thesis concludes a five year and six months journey in which I learned a lot.

I could not have executed this study without the participation of others. Gratitude goes to all stakeholders that participated in this study by allowing me to interview them. Without their inspiring visions and insights this study would not be very useful. Gratitude also goes to my supervisor Jacco Farla. The creation of this master thesis was not always a fluent process. As my thesis supervisor he always supported me with feedback and ideas to improve this product. Without his insights and advises I would not have had this result. Also thanks to my second reader Harro van Lente for putting his time in reviewing my proposal and final thesis. I also would like to thank The Netherlands institute for transport policy analysis and especially Joost Kolkman and Saeda Moorman for the chance they gave me to do an internship at The Department of Infrastructure and Environment. Their input and critical notes did increase the quality of this thesis a lot.

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Abstract

After the first flight was made in 1903 the growth of aviation has been enormous since then and is expected to go on the coming decades. In 2009 2.3 billion passengers and 38 million tons of freight have been handled by airlines. Over time it became clear that aviation has some large negative side effects. At the moment especially the effects on climate change get a lot of attention. Bio jet fuels are teen as the only option to reduce the climate impact of aviation in the coming decades. This study focuses on what possible transition routes are according to stakeholders involved. This is done by performing 20 interviews and using this data as input for four social technical scenarios. Four scenarios have been created which deviated on the rate of technological development and whether or not sustainability policies were applied. The scenario with a high technological development and a focus on energy security will have the highest application rate in 2050. Due to the use of third generation bio jet fuels based on algae in this scenario also makes significant improvements in sustainability. When the focus is immediately on sustainability the large amount of regulations and requirements will a constraining factor for a real market implementation. A focus that is first on energy security and later a shift towards sustainability would probably give the best results. During the interviews it also became clear that the visions as mentioned by stakeholders show some notable deviations from the literature. Especially the visions on the different possible feedstocks show some large differences. The creation of a transition arena in which stakeholders discuss these differences is recommendable.

Key words:

Bio jet fuels, Social Technical Scenarios, Sustainability, Energy security

Abbreviations

ATAG	Air Transport Action Group
ATM	Air Traffic Management
ASTM	American Society for Testing and Materials
DLUC	Direct Land Use Change
EC	European Commission
EU	European Union
EU ETS	European Union Emission Trading Scheme
FT	Fischer Tropsch
GHG’s	Green House Gases
HPO	Hydrogenated Pyrolysis Oils
HRJ	Hydrotreated Renewable Jet fuels
HVO	Hydrotreated Vegetable Oil
IATA	International Air Transport Association
ICAO	International Civil Aviation Organisation
ILUC	Indirect Land Use Change
MLP	Multi Level Perspective
NGO	Non Governmental Organisation
Pax	Passenger
RED	Renewable Energy Directive
RF	Radiative Forcing
RPK	Revenue Passenger Kilometre
RSB	Roundtable on Sustainable Biofuels
SNM	Strategic Niche Management
STS	Social Technical Scenarios
SWAFEA	Sustainable Way for Alternative Fuel and Energy in Aviation

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1. Introduction

1.1 Background

When the Wright brothers did fly for the first time in December 1903 they could not have imagined what the impact of their invention would be a century later (Romito, 2006). A steep increase in the demand for the transportation of passengers and freight has occurred since then. Since 1990 the aviation sector has a growth of on average 4.8% in revenue passenger kilometres (RPKs) (Franke, 2007). In 2009 24110 commercial aircraft were in use and airborne for 57 million hours. They were handling 2.3 billion passengers and 38 million tons of freight. An average growth in passenger traffic of 4.8% till 2036 is expected (ICAO Secretariat, 2010).

Over the last decades sustainability has become increasingly important, especially after the publication of the Brundtland report in 1987. In this report the first generally accepted definition for sustainability has been introduced: "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs (WCED, 1987)." In 1997, governments agreed on the Kyoto protocol, which set the objectives for CO_2 emission reduction until the year 2020. Because of the fact that no agreement could be reached on how to assign emissions from aviation and international shipping to single nations, they are excluded from this protocol (Grayling, 2003). Due to this, national policy measures can backfire on national airlines and it could also lead to a reduction of welfare because of a decreasing amount of visitors and flights compared to other countries without these measures (Mayor and Toll, 2010; Grayling, 2003).

The aviation sector is seen as an important sector for economic growth and employment. For the Dutch economy the contribution of the aviation sector is 290.000 jobs and a €26 billion (or 3.3%) share of the GDP (BCG and McKinsey, 2011). Due to the large growth of the aviation sector over the past decades environmental problems became more and more visible (Upham et al., 2003; DfT, 2011). Since 2007 the focus of policy makers in the EU has shifted from the local environmental problems towards climate change (Bows et al., 2009, p.46). Within this thesis the focus will also be on the impact of aviation on climate change. Aviation is responsible for 2% of the global CO_2 emissions and this is expected to increase to at least 3% by 2050. The two other main GHG's emitted by aviation are NO_x and H_2O (Lee, 2010). The overall contribution to GHG is estimated to be 3% and will grow to approximately 5% in 2050 (IPCC, 2007; IATA, 2009).

1.2 Problem definition

In order to reduce the impact of aviation on climate change a lot of organizations have set targets to reduce the GHG emitted. In general, the technologies and instruments that could be applied to decrease GHG emissions can be divided into four pillars (ICAO, 2010; IATA, 2009):

1. Aircraft technology improvements: this pillar covers all technological improvements that make airplanes more fuel efficient.
2. Operational opportunities: here the planning from airlines and the air traffic management (ATM) system are involved.
3. Alternative fuels: these are the technological opportunities for 'drop-in' fuels which can be used in existing airplanes without technological adjustments. But also more radical ideas like the use of hydrogen pertain to this pillar.
4. Economic measures: this one is not only a pillar by which GHG emissions can be reduced but also a way to stimulate the previous more technology based pillars.

In the earlier mentioned documents sustainability targets are set which for an important part should be met by the application of low carbon aviation fuels (EC, 2011; ICAO, 2010; IATA, 2010). But also airlines emphasize that biofuels are the main technology for a reduction in CO_2 emissions (Schoot, 2011). They also mention that due to the long product life cycle of an airplane drop-in biofuels are the only alternative fuels that can have a relative short term application. For these reasons the alternative fuels pillar are the subject of this study and more specific biofuels, although the different pillars cannot be seen as totally separate. They will interact and influence each other in their developments.

In order to reduce the impact of aviation on climate change a lot of organizations have set targets for future biofuel market shares. The latest target introduced is the white paper on transport published by the European Commission (2011a) that aims for 40% drop-in biofuels in 2050. The IATA (2010) has a more short term vision which aims for a 10% biofuels application in 2017 and 20% in 2025. The ICAO does not have an exact number but they talk about a large share of biofuels in 2050 (ICAO, 2010). A large Brazilian biofuel producer aims for 10% within ten years (Petrobras, 2009).

It is technologically possible to fly on biofuels which has been shown by multiple test flights. The first low carbon biofuels are certified but it is still not applied on a regular base (ICAO Secretariat, 2010b). To make this possible a system innovation is needed. A system innovation is a long term development in which a lot of stakeholders are involved. They also influence a lot of different areas and they focus on the production of products that do not have an existing market (Rotmans, 2003). These four characteristics are present in the case of bio jet fuels. This is maybe not the case on the level of application in aircraft but more in the supply chain of fuels in aviation.

As mentioned before a lot of stakeholders are involved in system innovation. To establish a joint action that can start the system innovation it is important that there is a coherent vision towards the future (Quist, 2007 p.20). The problem here is the fact that there are a lot of visions formulated by different stakeholders. They have very ambitious targets, but there is a lack of insight in the paths towards these visions. There are also very large differences between the visions which cannot be combined to one shared vision on the transition towards a large scale application of bio jet fuels.

The aim of this research will be to investigate the visions on and the related transition routes from stakeholders for the implementation of low carbon bio jet fuels till 2050. These visions are important because, they have the potential to guide joint action of stakeholders in the process of further developing the technology (Quist, 2007). By combining these visions to four storylines insight in possible transition routes can be created. The relevance of this is the fact that it shows the consequences from decisions and developments on the implementation from bio jet fuels. The scenarios can be used as input for discussions on putting in motion a transition path. These scenarios will be created by using the social technical scenario approach. This framework focuses on the linkages between different levels that may set in motion a transition path (Hofman and Elzen, 2010). Also recommendations for putting in motion the transition towards bio jet fuels will be provided.

By investigating the visions of the different stakeholders and the creation of scenarios based on this, contradictions between the views of different stakeholders can be identified. Also barriers that have to be tackled and the consequences of decisions or developments come to the surface. To make sure that a clear and complete overview of the visions is created, the three levels of the Multi-Level Perspective (MLP) (Geels, 2002) will be used during the interviews and while writing of the four scenarios. By using the MLP stakeholders will be stimulated to think about the co-evolution of technology and society, preventing that stakeholders will present a simple linear, deterministic vision. This is in line with the social technical scenario (STS) idea of transitions.

The geographical scope of this research will be on the European level. The European Commission (EC) is compared to other parts of the world very ambitious with regard to sustainable aviation. This is shown by implementing the aviation sector in the Emission Trading Scheme (ETS) in 2012. In the white paper on transport they have formalized their ambitious targets for biofuels (EC, 2011). This makes it interesting to study Europe as an example for the worldwide implementation. The relevance is the fact that it will give insights in the consequences of different decisions or developments. This study can be used as a starting point for a discussion on a coherent vision and strategy towards 2050. It is a reflexive tool for transition policy (Hofman and Elzen, 2010). The social relevance will be that it will contribute to the process of transforming aviation to be a more sustainable sector and therefore to the mitigation of climate change.

The previous leads to the following research question that will be addressed in this study:

What are the possible transition routes for the application of bio jet fuels according to the visions and perspectives of different stakeholders involved on the application of biofuels in the aviation sector towards 2050?

In the next chapter the different theoretical and analytical frameworks as introduced in this chapter will be explained. In chapter three the methodological steps are introduced. The focus will be on the interview method and how to process the data obtained in the interviews. After that an introduction on the aviation sector will be given. How did it develop till now and what is the state of the art knowledge on bio jet fuels. In chapter five the executed steps are displayed and the data is used to come to the starting point of the different scenarios which are written in chapter six. After that the scenarios will be compared with each other and the literature. This will eventually leads to answering the research question.

2. Theory

2.1 Technology Foresight

Technology foresight is a concept that is used to cover all methods that have the aim to inform on the future development of technologies. There are many different forms, which makes it difficult to come up with one comprehensive definition. The definition as used by the EC is 'Foresight is a systematic, participatory, future intelligence gathering and medium-to-long-term vision-building process aimed at present-day decisions and mobilising joint actions' (Miles, 2008). The main share of methods is about forecasting, which is about predicting the future of technological development. Forecasting stresses what will be likely futures but these may not be the desired futures. Most forecasting methods are based upon expectations about future developments. A possible pitfall of these methodologies is the fact that it may become self-fulfilling and so restrains developments in another direction (Hojer and Mattsson, 2000). So, especially for complex problems like sustainable development and in this study sustainable aviation with large ambitions specific foresight methods should be used to get the demanded results.

2.1.1 Foresight methodologies

A classification for foresight methodologies that is commonly used is qualitative, quantitative and semi-quantitative (Popper, 2008). The difference between the first two is just like it is in social sciences. The first is more focused on perceptions and creativity and the second focuses on statistical analysis. The new category semi-quantitative uses mathematical principles to quantify judgements and viewpoints of stakeholders. For all three classifications there are pros and cons. In this project qualitative methods seem to be the best option. There is at the moment almost no application of bio jet fuels in aviation. So, the extrapolation of current trends is impossible and the availability of data is very low. Most information has to come from stakeholders that are involved in the development of bio jet fuels. According to Popper (2008) there are 19 foresight methodologies that use qualitative data.

The main focus of this research project will be on the generation phase of the foresight cycle (Appendix A). The creation of new knowledge on the future of bio jet fuels in aviation is one of the main aims. So based on this the foresight method chosen should focus on the generation phase. Popper (2008) classifies all 19 quantitative methodologies as significant (11) or major (8) contributors in the generation phase. Due to practical matters only five of the major contributing methodologies could be applied: Scenario Writing, Scenarios, Science Fictioning, Surveys and SWOT Analysis.

Scenario writing and Scenarios seem to be the best option because these involve the input from stakeholders in the development of the different scenarios. Both methodologies focus on future developments and possible differences between developments. The difference is that the first one focuses on investigating the future effects of possible decisions. The later one focuses on development of scenarios based on an expert view or a set of stakeholders that is selected based on sector, region and organisation. But this could be used as input for scenario writing.

2.1.2 Scenario planning

When organisations look towards the future they do this to plan their strategies and future decisions. Based on this they may develop a scenario of a detailed future vision. This is incomplete due to the uncertainties that are present. Scenario planning is more useful for organisations because this incorporates these uncertainties (Popper, 2008; Saritas and Aylen, 2010). Porter (1985) gave in his book a clear definition of scenarios:

'scenarios are an internally consistent view of what the future might turn out to be — not a forecast, but one possible future outcome.' Scenarios in the form they are used right now are based on the work of Wack at the foresight department of Royal Dutch Shell. He defines scenarios as: 'A discipline for rediscovering the original entrepreneurial power of creative foresight in contexts of accelerated change, greater complexity and genuine uncertainty (Wack, 1984).'

Scenario planning simplifies the avalanche of data available into a limited number of possible routes. The scenarios tell a story of how various elements will interact under specific conditions (Schoemaker, 1995). Besides this there are multiple reasons for organisations to use foresight. Ringland (2010) describes six reasons why it is useful to perform scenario planning within an organisation:

1. Scenario planning will help an organisation to understand complex systems in which they are embedded. Intelligence is made more accessible for the organisation.
2. Scenarios do have an informing character, it will not prescribe the internal discussion within an organisation. Different scenarios can be used as input for the debate leading to the point of decision.
3. Scenarios can also be used to get a vision of the world outside or external to the organisation. This makes it possible have interaction with outsiders.
4. Scenarios may help senior staff to discuss strategic decisions and to overcome preoccupation.
5. Scenarios can support the release of group assumptions. In helps to get insights in whether or not assumptions are right.
6. The last reason is that it provides a set of possible futures against which plans can be benchmarked.

There is a wide range of typologies for the use of scenarios in foresight studies available. Borjeson et al. (2006) identified nine main typologies that exist in the literature on scenarios. These typologies are useful for communicating, understanding, comparing and the development of methods. When the different typologies are analysed they seem to use different variants of the probable, possible and preferable categorisation introduced by Dreborg (2004).

The classification used by Bojerson et al. (2006) is based on the tree main questions that are important in future studies. These questions are: 'What will happen?'; 'What can happen?'; and 'How can a specific target be reached?' These lead towards three main categories predictive, explorative and normative. Each category consists out of two scenario types (Figure 1). Besides these questions they did identify two other main characteristics the system structure and the distinction between internal and external factors. The first one is about the relations within the system and the boundaries of this. The second one distinguishes whether or not the development is within the scope of influence of a particular actor that composes the scenario.

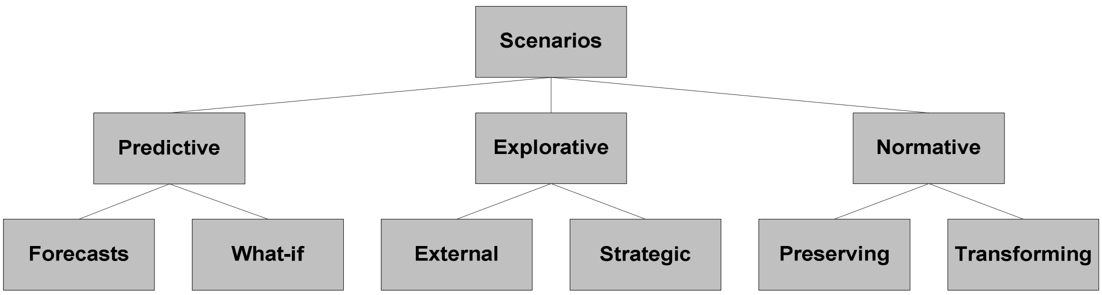

Figure 1: Scenario framework (Bojerson et al., 2006)

Predictive scenarios answer the question 'What will happen?' the focus is on predicting the future. The two types take different assumptions on the conditions into account. Forecasts answer the question 'What will happen, on the condition that the likely events unfold? ' The what-if scenarios answer the question 'What will happen, on the condition of some specified events?' Forecasts are best suited for short term predictions with relative small uncertainties. What-if can be used when there are some uncertainties. Different outcomes of these uncertainties can be defined and based on that different forecasts can be made.

Explorative scenarios answer the question 'What can happen?' In most cases explorative scenarios are used to explore developments that will possible happen. To span a wide scope of possible developments a set of scenarios is set out normally. The difference with what-if scenarios is that explorative scenarios have a long time horizon. Due to this larger developments can be taken into account. External scenarios focus on the factors that are out of control of the performing organisation. Strategic scenarios focus on both external and internal factors.

Normative scenarios have a clear target as starting point. The question they answer is 'How can a specific target be reached?' Here are also two types that can be distinguished by the way they handle the system structure. Preserving is about changing the current system and transforming is setting up a new system because the current system blocks the developments (Borjeson et al., 2006).

The focus in this research is on what can happen according to different stakeholders. Because of this explorative scenarios seem to be the best option within this study. The research question focuses on what could happen according to different stakeholders. The study will not be performed from the perspective from a single organisation. Strategic scenarios seem to be the best option because they take all issues into account. Since there is no difference between internal and external issues this seems to be the best option.

2.2 Social Technical Scenarios

The application of bio jet fuels seems to be an innovation with a possible large impact on the aviation sector and the fuel suppliers. The whole system from well to aircraft has to change and so a system innovation has to be created. There is a wide range of innovation taxonomies available. Freeman and Perez (1988) define system innovations as ''far-reaching changes in technology, affecting several branches of the economy, as well as giving rise to entirely new sectors''.

Quist (2007) gives an overview of innovation theories that are suitable for looking at system innovations. The Multi-Level perspective seems to be the best option for this topic because is describes how technological changes arise. The development from niche application till the large scale application of a technology is covered by the MLP. Problem here is that it is most often used to analyse changes that already took place.

Hofman and Elzen (2010) describe the concept of socio technical scenarios (STS) to use the MLP in foresight studies. In this concept are explorative scenario planning and the MLP combined to structure the scenarios developed. STS can be used to explore the drivers and characteristics from different transition pathways. They can be used to illustrate how various transition routes can be set in motion through a variety of patterns from the multi level perspective.

2.2.1 Multi-level perspective

The application of biofuels in aviation can be seen as a system innovation within a specific sector. With the MLP it is possible to investigate the development of a technology in a specific sector like the application of steam engines in the maritime sector or jet engines in aviation (Geels, 2002; Geels, 2006). The MLP is the conceptualisation of the assumption that new technologies develop and mature in niches and can result in the replacement of technological regimes (Quist, 2007)

Based on this concept Geels (2002) describes the MLP as an appreciative theory that tries to integrate concepts from different literature. Three levels are introduced. The micro or niche level, the meso level were the sociotechnical regime is situated in and the macro or landscape level. The multi-level perspective shows the interrelatedness of these three different levels (Geels, 2011).

Micro: Niches

When new radical technologies are invented they normally become 'hopeful monstrosities'. They have shown that they can fulfil a societal function but the performance characteristics are still low (Mokyr, 1990). Due to this new products have to be protected from the selection mechanisms of established market for further development. This has to be done in the period that the product performance of the invading product is below the established product (Utterback, 1994 p.159). This can be done by applying them in niches or incubation rooms (Schot, 1998). Strategic Niche Management (SNM) describes the social processes that take place within niches.

When a new technology enters a niche there are a lot of uncertainties about how it will develop. These are related to the five sub regimes of the sociotechnical regime. Questions that need to be answered are: How will the technology develop?; Who will use it?; How will the market develop?; and How will it be regulated? Learning about these questions is the main function of the niche. The tree main processes in niches are (Geels, 2002; Geels and Schot, 2007):

1. Formation and stabilisation of expectations and strategies
2. Learning processes
3. Formation and stabilisation of social networks

Meso: Sociotechnical regime

Nelson and Winter (1982) introduced the concept of technological regimes which are created when engineers and firms share the same routines. Kemp (1994) was one of the first to raise the problems that occurs with technological regime shifts. According to this article this is the main reason why new (sustainable) technologies struggle to become available on the market. Large firms are afraid for changes because it threatens their existing operations. Small firms struggle to get on the market because of the lack of resources and the absence of a market for their new technology (Kemp et al., 1998).

Geels (2002) introduced the concept of sociotechnical regimes. According to him not only the engineers but also users, policy makers, societal groups, suppliers, scientists and capital banks also influence the technological trajectory. Sociotechnical regimes refer to the semi-coherent rules carried by different social groups. In technological development ST-regimes account for dynamic stability. Innovation is possible but only incremental within the boundaries of the regime. So, it can be seen as some kind a selection and retention mechanism.

The ST-regime that is related to a technology consists out of five sub-regimes. These sub regimes are: Markets and user preferences, Culture, Technology, Policy and Science. These five sub-regimes form a dynamic stability. This means that incremental innovations can take place but for radical innovations there should be a new sociotechnical regime created. For radical innovation the existing regime should be replaced by a new one. Established technologies are stabilised by a set of concerted rules and elements of the system (Geels and Kemp, 2000).

Macro: Sociotechnical Landscape

The sociotechnical regime refers to rules that direct activities within a community. The macro level or sociotechnical landscape is about technology external factors. Just like regimes landscapes do change but very slowp, influencing them is in most cases very difficult or impossible (Geels, 2002). The landscape level refers to a broad set of factors that are putting pressure on the regimes and so technological development. Geels and Kemp (2000) developed a list of elements that are important at this level:

- Infrastructures
- Politic culture and coalitions
- Societal values
- Common sense
- Macro-economic developments
- Pervasive technologies
- Demographics
- Natural environment

Integration of the three levels

The key point of the multi level perspective is the interplay between the three previous introduced levels (Figure 2). When the system is stable only incremental innovations can take place. But sometimes the system will be replaced by a totally new technological regime a regime shift. Within this process four phases could be distinguished.

In the first phase a new technology emerges in a niche were it is tested and improved by actors that believe in the technology. This happens in the context of the already existing regime which in most cases is a mismatch with the new technology. In the next phase the technology is applied in a small market niche. More and more actors get involved and work on the improvement of the technology. In the third phase the break through of the new technology takes place. The technology will start to compete with the existing regime. In the fourth phase the new technology will replace the old regime with a new one to take away the mis-matches that were present (Geels, 2006).

Geels (2006) also identified two categories of drivers that lead to the breakthrough of the technology in the third phase. Internal drivers are within the niche and occur due to price and performance improvements of the technology. But also the push from actors within the niche that have vested interests is an internal driver. External drivers are situated in the landscape level. Due to changes in the landscape there will occur tensions in the existing regime. This results in destabilisation of the existing regime and a 'window of opportunity' for the new technology may occur. The existing technology cannot meet the requirements that external drivers impose. This may occur due to technological bottlenecks or reverse salients (Quist, 2007 pp. 55-58).

The MLP is in most cases used to study system innovations that took place already. In this research project it will be used in a different way. The scenarios that will be written have to by consistent story lines on the development of the technology. By using the four phases and three levels from the MLP a more realistic story can be written based on de findings from system innovations that already took place.

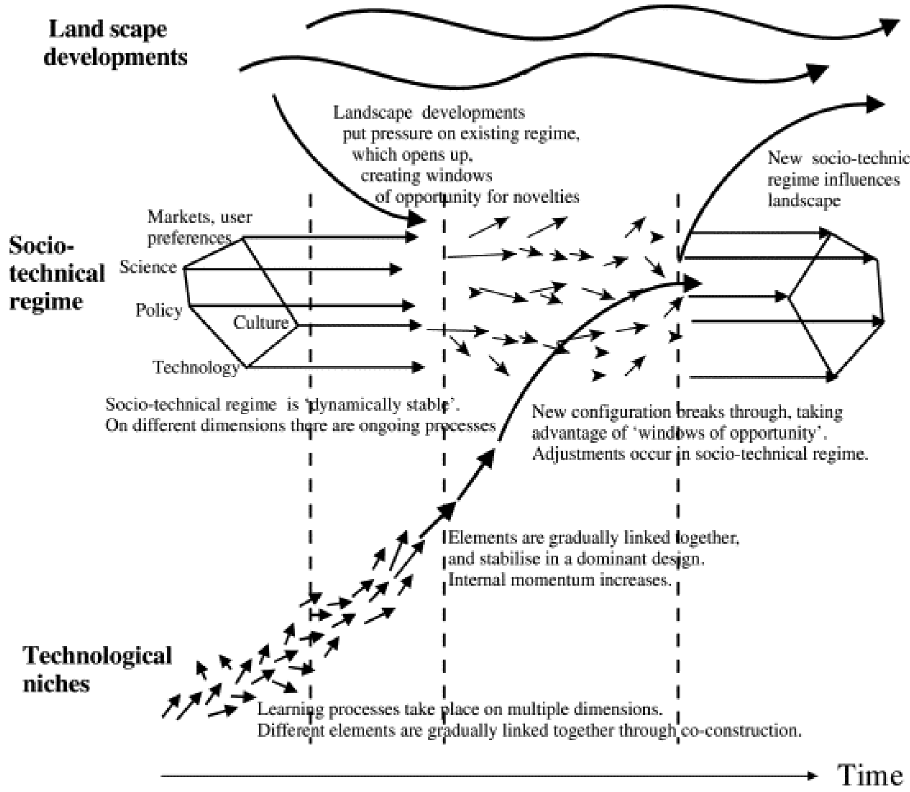

Figure 2: Multi-Level Perspective on system innovations (Geels, 2006)

2.3 Transitions scenarios

Based on the previous paragraph the main assumption that underlies the development of a STS is that it is not technological development that sets a transition path in motion. This is done by the behaviour of stakeholders and their reaction on technological development. STS are scenarios of how a transition could develop based on pre determined conditions. When scenarios are used to show the development of future transitions they should be based on properties from the literature on transitions. Scenarios should include the following four characteristics (Hofman and Elzen, 2010):

1. Transition scenarios should show socio technical development
2. Learning processes and niche dynamics
3. Incorporate further development and interaction between niches
4. Niche accumulation

Elzen et al. (2004) give in their book an overview of the patterns and mechanisms within transitions. These terms can be used in STS to show the dynamics that occur within the four steps in the transition scenarios. General patterns for transitions are substitution and transformation. In the case of substitution the regime is relatively stable and the new technology develops in a niche. When the new technology is able to outperform the existing technology it will break through and destroy the existing technology. In case of the transformation the regime is changing and due to changing preferences new technologies will occur. There will be a long uncertain period after which the regime will stabilise with a new technology that emerges to be the winner.

Geels and Schot (2007) give an overview of the knowledge on transition pathways. Based on their study, they define four main transition pathways:

1. The first one is the transformation path. Landscape pressure on the regime creates space for niches. System actors will adjust the development direction of these technological niches to make sure they will help to reduce this pressure.
2. In the technical substitution transition pathway there is also pressure from the landscape level on the regimes. In this case the technology already became mature in niches. They will break out of the niches and replace the existing regime.
3. In the reconfiguration pathway the symbiotic innovations are developed in niches. Novelties are introduced and lead to other developments. Over time more changes will be made and eventually a transition has taken place.
4. The last transition pathway they introduce is de-alignment and re-alignment. Due to large pressures the current system collapses and multiple new novelties are needed to stabilise the regime. This is when the re-alignment takes place.

Besides these general patterns Elzen et al. (2004) describes other patterns that can explain smaller parts of the transition process:

1. Niche accumulation and break through; This is a radical new technology that is tested in a protected area separate from the existing technology and will survive because it is positioned in a niche. Over time the amount of niches will increase and eventually the technology will take off (Raven, 2006).
2. Pressure on the regime to create space for niches; Due to large developments in the landscape level the existing socio technical regime is put under pressure. The regime has to start a search for alternative technologies because the situation will become untenable.
3. Niche proliferation; This is the spread of niches to other regimes and geographical areas. This is important for the support and to share the risks for the technology.
4. Synergy between niche processes; When niches start to cooperate they can create advantages and so increase the development rate (Elzen et al., 2004).

In their book they also describe a set of mechanisms that may take place in the development of the technology (Elzen et al., 2004):

1. Sailing ship effects; The existing regime will start to protect itself against the new technology. This is done by using all possibilities to improve the existing technology.
2. add-on and hybridisation;
3. Co evolution of technology and behaviour; When a new technology is introduced this may lead to adjustments in behaviour from users of the technology. These changes may in their turn influence the development of the technology. Eventually they have to find an equilibrium.
4. Co evolution of technology and society; New technologies may influence the functioning of society like internet did. But especially for technologies that are sustainability related it is important to adjust to the developing societal norms and values. This to make sure the public opinion is positive about the technology.

3. Method

In this chapter the different steps of this research project are described. First the data collection process will be explained. After this the methodology from data to the scenarios will be introduced. For this part of the research the method as introduced by Schwartz will be used which consists out of 8 steps (Schwartz, 1996):

1. Identifying focal issue/ decision/ topic
2. Identifying issues and trends
3. Driving forces
4. Rank by importance and uncertainty
5. Selecting scenario logics
6. Scenario writing
7. Implication
8. Consideration of scenarios

Schoemaker (1995) developed a framework that has 10 steps instead of these eight steps. But most issues addressed are more or less the same. So, input from this framework will also be used. Hofman and Elzen (2010) describe in their article seven steps for the development of socio technical regimes these steps are almost the same as the steps 8 steps of Schwartz (1996). Despite the fact that in this research STS will be used the 8 steps of Schwartz will be taken as starting point for the methodology. This will be supplemented with the additional elements from the Hofman and Elzen (2010) methodology. This is done because the methodology of Schwartz gives more points of engagement for the use of interviews as data source for the creation of the scenarios. The last step 'consideration of the scenarios' will not be executed because it is out of the scope of this research.

3.1 Scenario development

3.1.1 Step 1: Identifying focal issue/ decision/ topic

In this first step the delineation of the research has been done. Main decision made here is what is the actual topic and scope of the scenario research. The timeframe is important and may depend on a lot of factors. Important it is to choose a time frame that makes sense to the topic researched (Schoemaker, 1995). Also geographical scope is very important to clarify here.

Another important issue is the identification of the main stakeholders. Schoemaker (1995) created some questions that will help to identify them; Who will have interest in these issues?; Who will be affected by them?; and Who could influence them? In this research these stakeholders are important because they will be interviewed as input for this study. The scenario planning is based upon the visions of stakeholders in the bio jet fuel innovation system. In Table 1 an overview of the interviewees is given.

Quist (2007, p.29) defines five groups of stakeholders: Companies, Research Bodies, Government, NGO's and the general public. The last group has not been interviewed because it is not expected that they have relevant knowledge on the topic. In the selection of the stakeholders that will be interviewed a balanced group has to be created based on the four groups used. There is a relative high amount of stakeholders in the category 'companies'. This can be explained by the fact that within this category a lot of sub-categories can be identified like airlines, airports and bio fuel producers. To make sure these were all included the share of this category has been increased.

As mentioned earlier the scope of this study is on the application biofuels within Europe. Because most stakeholders were interviewed in The Netherlands there is a possible bias present. It is very important that the intended and achieved domain are the same (Ragin, 1987). To achieve this, a European orientation is a criterion for the choice of the interviewees. An example of this is that when a KLM employee is interviewed about the future vision he does not only represent a Dutch vision. Their developments are also used for the other airlines within their group, like Air France and CityJet which are French and English airlines (KLM, 2010). Were possible interviews with stakeholders outside The Netherlands were executed.

In this phase a literature study is executed to create an overview of the developments in the aviation sector. This literature study consists out of two main parts. In the first part the developments within the aviation sector till now are introduced. The second part focuses on the literature that is bio jet fuel related. This will be used for a chapter in which an overview of the available literature will be given. It is also useful to gather information as preparation for the interviews. This literature study is included in the study to introduce the topic, show some background information and to clarify terms used in the scenarios. This literature scan is shown in chapter four of this report.

3.1.2 Step 2 and 3: Key driving forces

As the main source for data twenty interviews have been conducted. During the first part of the interviews stakeholders were asked to formulate their vision on the sector in 2050. Special attention has been paid to the role of biofuels, which technologies are used, sustainability issues and the use of raw materials. This is done to create an overview of the expected situation in 2050. It turned out that it was for most stakeholders very difficult to formulate this. In that case the EU target of 40% bio jet fuels in 2050 was taken as starting point for the next step.

The objective in the second step is to connect the future vision introduced in the previous step with the present situation in the aviation sector. The focus here is on the technological, economic, environmental, social and cultural plausibility (Weaver et al., 2000 pp.97-108). This is in line with the sub regimes as used in the MLP (Geels, 2006). Stakeholders will be asked how to reach the proposed future vision. They will formulate their strategy and expectations on reaching this. But also barriers and opportunities were identified during the interviews.

To do this an open interview methodology is used to make sure that the stakeholders are not sent into a particular direction (Baarda and De Goede, 2007). It is also important that the methodology ensures the usage of all relevant aspects of the MLP. Special attention has to be paid to the interaction of the three levels. But also the interactions within the different levels had to be taken into account. To create a complete overview of the system innovation that has to take place these two issues are very important. This is in line with requirements for the development of a socio technical scenario as mentioned by Hofman and Elzen (2010). They mention that it has to show the socio-technical development, niche development, technological combinations and the break-out of the niches.

For the macro or landscape level this can be done by asking what the important developments in the past were and how these possibly will develop in the future. It is important to make a clear link with the future development of aviation especially in the socio-technical regime. For the micro and meso or regime level the methodology used by Van Merkerk (2007) for the construction of socio-technological scenarios is used. To do this a scenario map (Figure 3) is used in which technological, economic, socio-cultural and political issues have to be addressed (Merkerk, 2007), almost in line with the sub-regimes of the MLP. The approach Merkerk proposes, forces the interviewees to think about the whole socio-technical regime and the identification of relations between the different parts of the system. In the scenario map as used by Merkerk the technological and scientific sub regime ere taken together. For this research this is no problem because the difference between the two will not be clear for all stakeholders so they will be taken together.

The identification of the interrelatedness of the different aspects mentioned by the interviewee is the strong point of this methodology (Van Merkerk, 2007). This can be very useful in the creation of a coherent future strategy by the stakeholder. The last step that has to be made is to ask the interviewee about how the technology should get out of the micro or niche level into the socio-technical regime. The strategy they think is the best to get out the niche phase is important but also how this relates to the developments at the meso-level. So, what will create the opportunity for biofuels to break out of the niche level?

After an interview was executed an interview report has been written. In this document the information obtained from the scheme (figure 3) together with the other notes were summarized into a document (2-3 pages). This resulted in a set of 20 documents that were analyzed with the use of NVivo. The data has been classified with the use of 22 labels which were the main topics that appeared during the interviews. The text that came out of this process has been used as the main input for the development of the different scenarios.

A list of issues and trends has been created based on the previous conducted document. This list is longer than the 22 labels because one label in a lot of cases exists out of multiple issues and trends. An example of this is the label algae. The issues and trends related to this label are: technological availability, feedstock availability and commercialisation of residues. The list of issues and trends that was created was too long to build coherent and clear scenarios. To make it possible to do a clear analysis the amount of variables identified had to be reduced. By rearranging the issues and trends, dropping out the less relevant or predetermined ones it was reduced. The target was to create a list of around the twenty key driving forces that all would have the property to raise an interesting development in the scenarios.

3.1.3 Step 4: Critical uncertainties

The key driving forces in the previous paragraph are the driving forces that seem to have the largest impact on the scenarios. Out of this set there will be two critical uncertainties chosen that together will form the scenario matrix. Based on the information obtained from the interviews the two most important and uncertain variables are chosen as critical uncertainties (Schwartz, 1996).

It should be variables that are classified as important by most stakeholders. They have an expected large impact on the development of bio jet fuels. It is also important that it is uncertain what the direction of development of this variable will be. They should also have a large impact on the development of other variables. Hofman and Elzen (2010) emphasize that it is one of the most important decisions in the creation of scenarios. Therefore a lot of affort has been put in this decision.

3.1.4 Step 5: Establishing scenario logics

By combining the two critical uncertainties the scenario matrix is created. In this part the main characteristics of the four scenarios are described. The critical uncertainties are the basis of the logics but they will be complemented with some other developments and information to create a clear outline for the four scenarios. Based on these logics the storylines for the scenarios will be written.

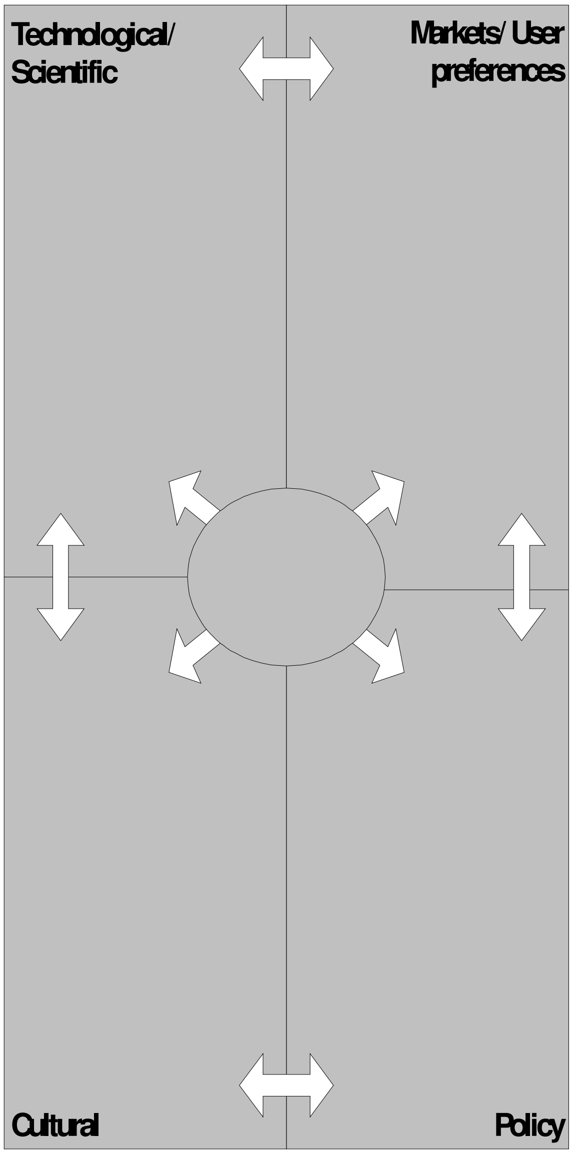

Figure 3: Scheme used during the interviews (Van Merkerk, 2007)

3.1.5 Step 6: Scenario writing

When the scenarios are written this will be done along the structure of the earlier introduced Multi Level Perspective. In every scenario the three levels (micro, meso and macro) will be treated. This to make sure the whole process of the system innovation will be described. The topics that were used in the interviews were also in line with this MLP so the data should have information on all levels in it. This will be combined with the earlier identified key driving forces. Important is to fulfil the four requirements for the development of STS as mentioned in the theoretical section. These are: Show socio technical development; Learning processes and niche dynamics; Incorporate further development and interaction between niches; Niche accumulation. All scenarios will be concluded with an overview table of the main characteristics.

3.1.6 Step 7: Implications

In this part the scenarios are compared with each other. Important is to look at the results of different decisions made within the scenarios. But also the differences in the outcomes of the different scenarios will be discussed. The main reasons for these differences will be shown. Additional to the methodology of Schwartz (1996) there will also be made a comparison with the literature. This is done because the scenarios are based on the visions of stakeholders. It turned out that the visions from stakeholders in some cases differs from the common view in the literature. The scenarios will also be evaluated against the background of the objectives of the study (Hofmann and Elzen, 2010). The aim of this research is to investigate the visions on and the related transition routes from stakeholders for the implementation of bio jet fuels till 2050. This to create a useful document for the discussion on the application of bio jet fuels. This step will be executed in the reflection chapter.

4. Developments in the aviation sector

4.1 Growth rates

Since 1960 the average annual growth rate of the global aviation sector is 9% in revenue passenger kilometers (RPKs) which is 2.4 times the average worldwide GDP growth rate in the same period (Penner et al., 1999). In the period from 1990 the growth in the aviation did slow down towards an average growth of on average 4.8% in RPKs (Franke, 2007; Bows and Anderson, 2007). For Europe the average growth over the past decade has been 5.3% which is higher than the average worldwide growth rates (Bows et al., 2009). So over the past decades the growth of the aviation sector did slow down. In 2009 there were over 18.000 commercial aircraft in use and airborne for 57 million hours (ICAO Secretariat, 2010). They are operated by approximately 1300 airlines and using 1200 airports (Airbus, 2007; Boeing, 2007).

There are a lot of predictions on the future growth rates of aviation. Airbus and ICAO both predict a 4.8% growth rate for the aviation sector until 2036, according to Boeing this could be 5% (Airbus, 2007; Boeing, 2007). An important development is the fact that the distribution of growth rates over the world will change. The main drivers for growth within the aviation sector were historically North-America and Europe. In the period 2010-2030 ICAO predicts they will have the lowest growth rates. The most important driver for growth will be Asia, growth rates here are exacted to double the western world growth rates in this period (ICAO secretariat, 2010).

There are not a lot of predictions specific on the growth European aviation for the period until 2050. The EC is the only organization that has made predictions of the growth in aviation over this period. DG Mobility predicts an increase in air traffic movements from 9.4 million to 25 million which is a 166% increase in air traffic movements (EC, 2011). The latest report in which both departments (Mobility and Environment) worked together an annual air traffic increase of 3% is predicted. The related increase in fuel consumption will be 2% (Maniatis et al., 2011).

The growth in fuel consumption is lower due to improvements in the operations and aircraft efficiency. A UK based organization thinks this 1.5% annual improvement will decrease over time to 0.5% in 2050 (Sustainable Aviation, 2008). So, 1% seems to be a well tough prediction. At the moment these efficiency gains are for a large part met by the replacement of older airplanes. The average fuel use of the current flees is 5 liter per pax/100km new planes will use approximately 3 liter per pax/100km (ICAO secretariat, 2010b). Based on the previous figures the aviation sector will triple till 2050. The increase in fuel consumption will be 116%. The current jet fuel consumption is 53 million tones (Maniatis et al., 2011) and based on these figures in 2050 this will be 114.5 million tones jet fuels. This increase will make it even more difficult to meet possible future targets for bio jet fuels in the future. CO_2 emissions will grow at the same rate to 360.6 million tones per year (KLM, 2010).

During the interviews all stakeholders were asked for vision on the growth of the aviation sector. Notable was the wide range (0%-700%) between the answers from different stakeholders. Based on the visions from stakeholders that are directly working in the aviation sector a sector that doubles or triples seems to be more probable. This is in line with the latest EU predictions for 2050.

4.2 Environmental issues

Due to the large growth of the aviation sector over the past decades environmental problems became more and more visible (Upham et al., 2003; DfT, 2011). There are three types of environmental problems related to aviation that can be distinguished. Based on this the 190 member states of ICAO established the following environmental goals related to the three types of problems (ICAO, 2007):

1. To limit or reduce the number of people affected by significant aircraft noise
2. To limit or reduce the adverse impact of aviation emissions on local air quality
3. To limit or reduce the impact of aviation greenhouse gas emissions on the global climate

The emission of CO2 due to the use of fossil fuels is the main GHG emitted within the aviation sector. Aviation is responsible for 2% of the global CO_2 emissions and this is expected to increase to at least 3% by 2050. The two other main GHG's emitted by aviation are NOx and H_2O (Lee, 2010). The overall contribution to GHG is 3% and will grow to approximately 5% in 2050 (IPCC, 2007; IATA, 2009).

There are a lot of scientific uncertainties about the impact of H_2O and to a lesser extent NOx on climate change or radiative forcing (RF) (Upham et al, 2003, pp. 80-81). RF is a way to standardize the effects of different emitted substances to make their impact comparable. Scientists agree that the impact of emissions created by aviation is higher because of the altitude it is emitted. But there is still a debate about the factor that is related to this (Penner et al., 1999; Lee et al., 2010). Lee et al. (2010) also mention that aviation causes negative RF (cooling) by the emission of sulphur and the destruction of methane. But these effects have a lower impact than the positive RF (warming) that occurs due to the other emissions.

Since 2007 the main focus of policy makers within the EU has shifted from the local environmental problems towards climate change (Bows et al., 2009, p.46). In the environmental report published by ICAO in 2007 all three types of environmental issues have been addressed. But in 2010 only the global environmental problems were addressed. This happened because climate change is the main issue for the United Nations (UN) and so for ICAO in the upcoming century (Hupe, 2010). Therefore the focus of this research is on environmental problems.

4.3 Biofuels

Biofuels are a very promising technology to decrease the environmental impact of aviation. Within this study the focus is on drop-in biofuels, this means no technological adjustments have to be made within airframes or engines. The drop-in biofuels can be used on the current fleet. The fuelling infrastructure does not have to make large changes because the biofuels are compatible with the current system (Kivits et al., 2010). The large difference that makes it a system innovation is in the supply chain that has to be developed. The process from feedstock to end product is totally different compared to conventional kerosene (Figure 4).

4.3.1 Certification

New technologies or components can only be used within the aviation sector when they are certified. ASTM international is the organization that has to standardize the new technologies. The aviation sector has to initiate this process. They have to fallow four main research steps that together form the ASTM research report. This report has to be reviewed by all relevant stakeholders in the sector before it is send to the relevant ASTM subcommittee (IATA, 2010). The four steps in the certification process are: Specification of the Properties; Fit-For-Purpose Properties; Component testing; Engine testing.

When this research is executed and aditional testing is done and indicates that the technology is ready for standardization the balloting process will be started. The by the sector approved ASTM research report will be send to the relevant subcommittee of the ASTM. When they approve the main committee on Petroleum Products and Lubricants has to review and approve it. After that the document will be made public for a one month public review period. When no objections are filed or they are unfounded the new standard will be certified (ASTM, 2011). The last step is the approval by the different civil aviation authorities (IATA, 2010).

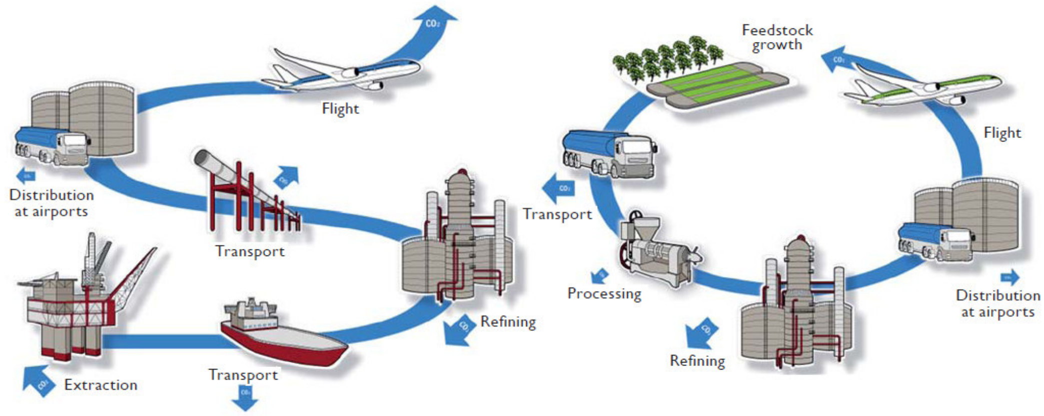

Figure 4: Fuel supply chains (ATAG, 2010)

ASTM International published in July, the fourth revision of the D7566 specification. This specification covers the production of aviation turbine fuels that consists of conventional and synthetic blending components. It is also called the alternative jet fuel specification. Drop-in fuels listed in this specification can be seamlessly integrated in the infrastructure without the separate tracking of it (IATA, 2010). To use bio jet fuels as a drop in fuel they also have to comply with the standard Jet-A1 or kerosene standard D1655 Specification for Aviation Turbine Fuels. Especially freezing point, flash point, energy content, and density were important issues in this standard (GreenAir, 2011).

4.3.2 Current and future developments

Over the past decade biofuels have developed from an unknown technology within aviation towards the most promising technology to decrease environmental impact of aviation. In 2008 the first test flight has been operated by Vergin Atlantic with a Boeing 747-400 with one engine on a 20% palm oil mixture. In November 2009 KLM was the first European airline to perform a test flight. This flight was a Boeing 747-400 with one engine on a 50% second generation biofuel mixture (Graham et al., 2011).

After that a lot of test flights have been performed by multiple airlines on 29 June 2011 KLM was the first airline that operated a commercial flight on a 50% biofuels blend. This was one week before the certification by the ASTM was approved. This was followed by a scheduled route on bio jet fuels to Paris in cooperation with SkyNRG (Warwick, 2011). Over the past months SkyNRG announced to start routes together with Fin Air, Thomson and Alaska airlines. All airlines use a bio jet fuel that is based on used cooking oil (SkyNRG, 2011).

In line with this development more and more organizations are publishing their future application targets. Boeing has the target to reach the 1% in the next five years. Based on the developments in this period they will develop their long term targets (Warwick, 2011). The EC, Airbus, leading European airlines and biofuel producers have published a 4% target for 2020. To reach this an investment of 2.7 billion Euro has to be made (Maniatis, 2011). The EC also published the white paper on transport (2011) with a long term vision for 40% bio jet fuels in 2050. The IATA is aiming for 6% bio jet fuels in 2020 which is 50% more than the EC aims for (IATA, 2009).

4.3.3 Sustainability

Since biofuels became an important option to make aviation and other modalities more sustainable concerns about the sustainability were raised. Especially NGOs and scientists did raise their concerns about the sustainability improvements that could be made with bio fuels (McBride et al., 2011). To decide whether or not biofuels are improving sustainability a set of criteria has to be used. There are several different sets with criteria the most common used one in aviation is introduced by the Roundtable on Sustainable Biofuels (RSB) (RSB, 2010). Their goal is to provide and promote the global standard for socially, environmentally and economically sustainable production and conversion of biomass. In Appendix C a table with an overview of the sustainability principles introduced by RBS is shown.

In the ICAO environmental report (2010) sustainability is divided into three categories i.e. economic viability, environmental respect and social commitment. In the literature this concept is also used but then it is called `the triple bottom line' consisting out of the concepts people, planet and profit. The concepts mentioned by the RSB seem to include the first two but the last one is left out. Especially for the commercial application of bio jet fuels this is a very important issue.

4.3.4 Classification

Biofuels is a collective noun for a broad set of combustibles used in different sectors. To make them conveniently arranged a clear classification is very helpful. There are already multiple existing classifications. The First one is that of primary and secondary biofuels. Primary biofuels are used in an unprocessed form. Secondary biofuels is biomass processed into for instance ethanol or bio jet fuels (Singh et al., 2011). At the moment there are three generations within the secondary biofuels.

The first generation is produced from sugars, grains or seeds they are processed in a simple process. Ethanol is the first generation biofuel that is mostly used. At the moment fuels from this generation have the largest share in the biofuels production (UNCTAD, 2008). The main problem with this category is the high production costs due to the competition with food which increases the price. This is in favour of the second and third generation biofuels (Nigam and Singh, 2011).

Second generation biofuels are produced from non edible residues or non edible crops. This makes sure the direct food versus fuel competition is limited. They are produced along two different approaches i.e. biological or thermo-chemical production. The equipment to process these biofuels has to be more sophisticated and is more expensive than for the first generation (Stevens et al., 2004). The feedstock used for these biofuels has the potential to become less expensive than the first generation feedstock because there is no food competition that increases the price. The main problem is the land use change that may occur due to this type of biofuels. This creates an indirect competition with food production (Nigam and Singh, 2011).

The third generation biofuels is only applied on small scale test projects at the moment. This type can be divided into two main parts i.e. microbes and algae. Microbes like yeast or chlorella can store a large amount of fatty acids in their biomass which can be used as feedstock for biofuels (Xiong et al., 2008). This can be seen as a promising option for the long term. Algae can produce large amounts of lipids, proteins and carbohydrates in a short period. There is a large verity of species which can live under a wide range of environmental conditions. Genetically modification may increase their oil-storing capabilities which make them more efficient. When this is achieved algae can be the feedstock that makes us free from our addiction to petroleum (Grant, 2011).

4.3.5 Production

There are many production processes for the production of liquid fuels. In a report from the SWAFEA (2011) study ten main families or pathways of production processes are introduced. At the moment three of them are certified; Traditional crude oil refining; XtL through the Fischer Tropsch (FT) process; and Hydrotreated Renewable Jet (HRJ). The last two are introduced by the IATA as the main drop-in petroleum replacement technologies. According to the EC (Maniatis, 2011) together with multiple stakeholders there are two more relevant technologies Hydrogenated Pyrolysis Oils (HPO) and Algae based biofuels.

Fischer Tropsch

The FT process can be divided into three main parts (SWAFEA, 2011; IATA, 2010). The first part is the production of syngas by a gasification process. As input for this process all carbonaceous materials can be used like coal, natural gas and in this case biomass. In the second step is the FT Synthesis which transforms the syngas into straight chain hydrocarbons. Out of the CO and H_2 in the syngas a wide range of C_xH_y products created. Based on the temperature and pressure this range of products can be adjusted (Demirbas, 2009). The last step is the post processing to create the fuel needed with the proper specifications. The FT fuel specifications can be tailored to meet or exceed the ASTM specifications by using hydrocracking. At the moment only 50% blending with crude oil based fuels is allowed in aviation. This is the case because of the absence of aromatics that are needed for the lubricity of seals in engines (SWAFEA, 2011).

Hydroprocessed Renewable Jet Fuel

The second certified bio jet fuel is Hydroprocessed Renewable Jet (HRJ) Fuel also referred to as Bio-derived synthetic paraffinic kerosene (bio-SPK) or Hydrotreated Vegetable Oil (HVO) (SWAFEA, 2011). As input for this process cleaned bio-derived oil is used. Then the oxygen is removed by hydro treating. This is nothing more than the injection of hydrogen to react with oxygen. The next step in the HRJ process is the same as the third step in the FT production process. The outcomes are cracked to reduce the carbon number to meet the jet fuel specifications (IATA, 2010). The main advantage from HRJ over FT is that the feedstock can be processed with mature technologies used for the treatment of crude oil. The down sight is that it is more expensive compared to FT (SWAFEA, 2011).

Hydrogenated Pyrolysis Oils

In the pyrolysis process solid biomass is converted into crude bio oil. This oil can be used as input for already existing crude oil refining facilities. Solid biomass is headed without the presence of oxygen during this heating (Demirbas, 2009). This transforms the solid biomass into a liquid that is comparable with crude oil which can be used in refining facilities. For this process all carbon based products can be used as feedstock. Sustainability depends mainly on the feedstock chosen (IATA, 2010). The main advantage of this process is the fact that existing crude oil infrastructures can be used for further processing (EC, 2011).

4.3.6 Feedstock

To make bio jet fuels a real alternative for conventional kerosene it is important that enough feedstock is available. A lot of organizations did publish about different options for feedstock supply in aviation. No publication suggests that first generation or edible feedstock should be used. Second generation feedstock like Camelina and Jatropha are mentioned quite a lot. Algae as a third generation feedstock are also in most reports. Notable is the absence of waste materials as feedstock for bio jet fuels in most reports.

Camelina
According to Herreras et al. (2010) Camelina has four main advantages. It can be used as a rotational crop, it needs minimal input, it grows on marginal land and it is approved as animal feed. When crops like wheat are grown every three or four years the land has to restore itself. This is done to increase the moisture and nutrients and to decrease the risk of diseases. Normally this is done by leaving the land empty for a year. But research did demonstrate that Camelina can be grown in that year and the land will still restore itself. So, this is an opportunity for farmers to create revenues from land that cannot be used for wheat or other food crops (Shonnard et al., 2010).

Next to the use as a rotation crop Camelina can be used grown on marginal lands or salty soil (IATA, 2010). Based on this the potential in the USA is larger than that for Europe. There is a relative small amount of fertilizers needed to grow Camelina and to get a plant that contains 38-40% oil (Herreras et al., 2010). After the oil is used the remaining can be sold as animal feed this is important for the profitability of Camelina. Based on this there seem to be no risks for direct land use change problems (DLUC). There are still risks for indirect land use change (ILUC) problems based on Shonnard et al., (2010) these can be averred by raising restrictions. Then still 800 million gallons (or 3 billion litter) renewable fuel can be produced only within the US.

Jatropha
Herreras et al. (2010) also summarized the advantages of Jatropha. The plant has a perennial high oil yield, it is a non food feedstock and grows on marginal land. It has also strong social benefits due to the manual harvest requirement. It can also be grown by small scale farmers in remote areas. This is also a disadvantage due to the fact that this increases the price. Another problem is the fact that the meal has no economic value. No income cen be created from this because it is toxic. When it is cultivated on waste land there is still fertilizers and irrigation is required (IATA, 2010). It is also a very recently discovered crop so this makes the expectations uncertain.

Algae
Algae are seen as third generation feedstock for bio jet fuels. The main difference with previous generations is the fact that it does not need any soil or land and so do not have any negative effects on farming (Maniatis et al., 2011). They need water which could be in bad condition and sunlight to grow. They may even filter the water to make it usable for other applications (Marsh, 2009; IATA, 2010). The three main advantages of algae are according to Herreras et al. (2010): they have a high growth rate, high oil production yield and they can grow on barren land. The latest discovered types of algae can double their mass within a day and exist out of 50% natural oil.

This oil can be processed by the already certified HVO process. After the oil is taken out approximately 50% of the biomass remains. This can be used for multiple purposes to create revenue. It can be used for nutrition, animal feed or bio plastics (IATA, 2010). But this dry biomass could also be used for further energy production. This could be done in combined head and power applications or pyrolysis (Maniatis et al., 2011).

Waste
It is notable that there is almost no attention paid to the application of waste as a feedstock for bio jet fuels. The IATA and ICAO do not mention waste in their main bio jet fuel documents. The EC acknowledge the fact that waste is an important feedstock when a stable supply chain has to be created. They argue that nine plants that are able to process waste have to be build before 2020 (Maniatis et al., 2011). Another large research project initiated by the EC also underlines the importance of it (SWAFEA, 2011). Another study on the sustainability of biofuels underlines this vision. Especially waste from municipalities may have a large contribution (The Royal Society, 2008)

5. Scenario planning implementation

5.1 Step 1: Objectives and identification of stakeholders

As mentioned in the previous chapters the topic of this scenario research is the application of bio jet fuels. The geographical scope of this research is at European level. The third main delineation is the timeframe till 2050. Based on these three directives a list of 40 stakeholders has been created. After that the stakeholders were ranked based on relevance and category. The first 20 were approached for an interview, eighteen agreed and two interviewees from the stand-by list were used. The final list of interviewees is shown in Table 1.

Table 1: List of interviews

Nr.	Organisation	Stakeholder group	Name
1.	AlgaeLink[1]	Companies	Peter van den Dorpel
2.	KLM	Companies	Thijs Komen
3.	Schiphol	Companies	Jonas Stekelenburg
4.	SkyNRG	Companies	Maarten van Dijk
5.	Shell	Companies	Ewald Breunesse
6.	Thomson[1,2]	Companies	Deidre Kotze
7.	BTG Biomass Technology Group	Companies	Bert van de Beld
8.	Royal Dutch Air force	Companies / Government agent	Paul de Witte
9.	Institute for transport policy analysis	Government agent	Hugo Gordijn
10.	VROM Biofuels	Government agent	Hans de Waal
11.	Directorate for aviation	Government agent	Michel Lunter
12	Agentschap NL/ ACARE	Government agent	Henk van Leeuwen
13.	Platform for Sustainable Aviation	NGO	Erik Laroy
14.	World Wildlife Fund	NGO	Arjette Stevens
15.	Stichting Natuur en Milieu	NGO	Willem Wiskerke
16.	European Environmental Bureau[2]	NGO	Faustine Defozes
17.	CE Delft	Research bodies	Bettina Kampman
18.	Netherlands Environmental Assessment Agency	Research bodies	Jan Ros
19.	National Aerospace Laboratory	Research bodies	Toni Kanakis
20.	Twente University	Research bodies	Hans Heerkens

5.2 Step 2 and 3: Key driving forces

Based on the performed interviews issues and trends have been identified. A list of 67 issues and trends has been composed out of the interviews performed. This list has been reduced to twenty-four key driving forces. These are the most important driving forces within the scenarios. In appendix C the terms on this list are explained.

1 interview executed by telephone
2 interviewee was not in The Netherlands

A. Growth of investments
B. Scattered demand
C. Stability supply chain
D. Pull from lead users
E. Development of third generation bio jet fuels
F. Availability of technology and feedstock
G. Development of waste as feedstock
H. Development of Camelina and Jatropha as feedstock
I. Niche development
J. Future vision from the government
K. Competition between modalities
L. Aviation specific mandatory blending
M. Development of maximum ETS emissions
N. Food vs. feedstock
O. Energy security vs. sustainability
P. Aviation implemented in world wide climate policy
Q. Level Playing field
R. Use and commercialization of residual materials
S. Willingness to pay from passengers
T. Limitation of production growth
U. Development of technology price
V. Interrelatedness of oil and feedstock prices

5.3 Step 4: Critical uncertainties

From the list of twenty four key driving forces the critical uncertainties are identified based on their importance and uncertainty. The scenario logics will be based on these critical uncertainties.

5.3.1 Critical uncertainties

The two issues were the most discussion occurred and the uncertainty was high were the speed of technological development and the question whether or not the focus would be on sustainability. Due to the widely divergent answers of the interviewed stakeholders the decision has been made to use these as critical uncertainties. These variables also seem to have a large impact on the development of the other key driving forces. In the next paragraphs these two critical uncertainties are explained.

Technological development

As mentioned in the previous background section on the developments in the aviation sector the difference between the different generations has been made based on the feedstock used for the production. During the interviews it became clear that there is no common used definition for first and second generation biofuels among the stakeholders. Because they have a lot of overlap the first and second generation bio jet fuels are taken together within the scenarios. So the first and second generation biofuels are based on all feedstock that has to be cultivated or waste materials. Third generation fuels are based on microbes and algae. During the interviews eighteen stakeholders only talked about algae as third generation feedstock. So in the microbes will not be used.

Stakeholders disagree on the question whether or not third generation bio jet fuels will be available on a large scale before 2050. Even within the different categories of stakeholders there seems to be large disagreement. Waste and algae are mentioned the most during the interviews.

For the short term all stakeholders agree on the fact that there will be almost only second generation bio jet fuels. Waste products like used cooking oil are mentioned as the best short term feedstock. Later more and more types of waste will be added to increase the production capacity. Diversification of waste and other second generation feedstock will be important for the increase in production. Interesting is the fact that waste gets a lot of attention from companies and NGO's but research bodies and governmental organisations are less enthusiastic about it. They argue that waste streams are in most cases used by other sectors like electricity production.

Algae were as main third generation feedstock a controversial topic during the interviews. Most research bodies and NGO's expect a large increase between 2025 and 2050. Companies were more skeptical about the use algae before 2050. They argue that the algae that will become available on the market will be used by sectors were the willingness to pay is much higher. Only when these markets are saturated algae will become available for the production of bio jet fuels (Figure 5).

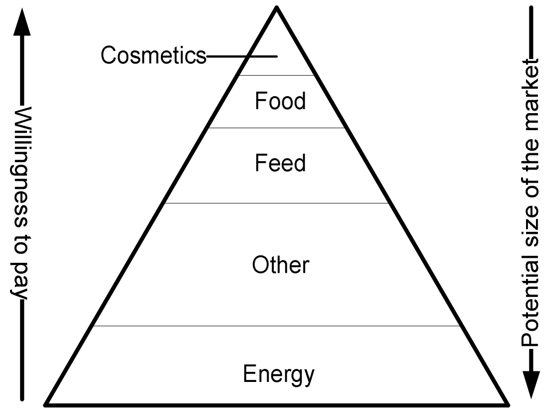

Figure 5: Economics of algae[2]

Stakeholders who are more enthusiastic about the use of algae as feedstock think a 'peel method' will be the best option for algae. This means that sectors which have a high willingness to pay take out the parts they need and the residues will be used by sectors lower in the pyramid. At the moment the technologies needed are developed but very uncertain. It is not clear how much will remain for the production of bio jet fuels.

The costs of algae production are also a point of attention of all the stakeholders. The stakeholders that are positive about algae argue that these can be reduced by the application of waste from different industries. Especially head, phosphate and carbon dioxide can be used for this reduction. Sustainability issues are for third generation bio jet fuels very small compared to the second generation.

Another technological development is whether or not the problem of aromatic hydrocarbons can be solved. The lack of these will cause safety issues when they are blended at a rate higher than 50%. At the moment it is impossible to make artificial aromatic hydrocarbons. This should be possible to enable higher certifications. Another possibility is to make an adjustment in the construction of airplanes but due to the long product life cycles in the aviation sector this will not have a large impact within the scope of this research.

Focus on sustainability

Based on the interviews three main reasons for the application of bio jet fuels can be identified: Sustainability, energy security and competitive advantage. The difference

[2] Figure is based on the a drawing one of the interviewees made

between the first two and the later one is the fact that the later one can only be the case when one or both other reasons become important. This leads to an increased demand for bio jet fuels which increases the prices. At the moment bio jet fuels are seen as a sustainable replacement for conventional jet fuel. Some interviewees wonder whether or not this is the best option when a market needs to be created.

These stakeholders also mention that energy security is at least equally important as sustainability. The volatility and price of oil did increase over the past decades. This trend is likely to continue in the future due to political instability and the reduction of oil reserves. The possibility of an oil crisis in the upcoming decades is a reasonable opportunity. This makes it more attractive for investors to invest in technological development and the creation of a bio jet fuel supply chain. Government policy could position bio jet fuels as a strategic important development. Due to this it could lead to competitive advantage. For the airline industry bio jet fuels can be a way of reducing the risks related to the fuel prices. They also point at the relative low carbon reductions that are present at the moment.

Stakeholders that think the energy security driver is the best way to create a market argue that sustainability will follow automatically in a later stadium. There will be fewer restrictions on feedstock and production technologies the takeoff will be due to this easier and faster. The stakeholders that support the focus on sustainability policy stress that there is a large risk for lock-in on unsustainable feedstock. Just like the current lock-in of the transportation sector on crude oil. In that case the environmental impact from aviation is not expected to decrease due to the high sunk costs of production facilities.

5.4 Step 5: Scenario logics

As mentioned before there are two critical uncertainties. The first one is on the application of the different generations of bio jet fuels. Second there is the distinction between two reasons for the application of bio jet fuels. The critical uncertainties are combined in Figure 6 and form the base of the four scenarios used in this research.

In scenario 1 and 2 there will not be a focus on sustainability policy. As mentioned before the other main reason to start applying and supporting bio jet fuels is to increase the energy security. Due to instability in the world the volatility and average price of oil are both increasing. On top of that the security of supply will decrease in the future. A strong and clear vision from the government will be developed. The EU decides to put in place policy focused on energy security and the reduction of oil dependency in the short term. This will put large pressure on the existing socio technical regime. Also airlines see this as an important thread for their operations and will be helpful in the development of bio jet fuels.

To guarantee the long term energy security biofuels will play an important role. The aviation sector has to contribute to this by applying bio jet fuels. Policy will be focused on stimulating and even enforcing this. Energy security becomes an important issue for strategic decision making within a lot of nations. The EU will start collaborations with other nations. Energy security is an important issue in most countries with a large aviation sector like the EU, VS and China. Nations like these have a large dependency on unstable oil supplying countries and start working together to reduce their power. Because this becomes a world wide initiative the sector will start to collaborate in this process. They will formulate an own vision on this. Maintaining the level playing field and avoiding threads are the main issues in this vision.

Scenarios 3 and 4 there will have a strong focus on sustainability. Due to the scientific evidence that climate change and CO_2 emission are related the European Commission decides to implement ambitious sustainability policy. They formulate a clear future vision for sustainable aviation and policy has to comply with this. Despite a large international lobby from the European Union other countries will not join the measures the EU would like to implement. They cannot be forced because aviation is not implemented in climate agreements. Implementing regulations for aviation will affect the level playing field.

Despite this thread the aviation sector will be included in this sustainability policy within a few years. The current EU ETS system will be maintained to enforce a CO_2 emission reduction. This will be done to decrease the environmental impact of aviation. Additional sustainability regulations would increase the ticket prices which lowers the demand for flights. Because only Europe is doing this a major degradation of the world wide level playing field of the aviation sector. European airlines will suffer more from this. Almost all their flights will be affected by this.

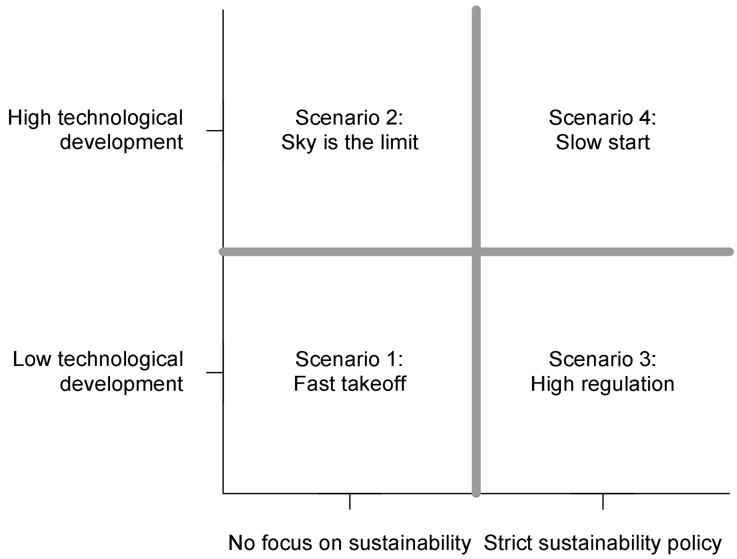

Figure 6: Scenario logics

Then there is the difference in technological development within the different scenarios. In the scenarios 1 and 3 this development will remain at a relative low level. Feedstocks used will be mostly like the ones used at the moment. The main feedstocks will be waste, Camelina and Jatropha.

In the scenarios 2 and 4 second generation bio jet fuels will be used in the first place. This will grow at a low rate because of sustainability issues that may occur when chains are added to the supply chain. When these really start to take off third generation bio jet fuels will enter the second generation of technological development. This means they will be applied in some niche markets. By using residuals from other industries like head and phosphor the production price from algae will be reduced. Eventually the third generation technology becomes mature and will also enter the third phase of technological development. This will take place after 2030. The development of the second generation feedstocks like waste will slow down at that moment.

Due to these increased requirements third generation feedstock will become increasingly interesting. Algae will be by far the most important feedstock in this category. More investments in this technology will be made. They will be used in small amounts due to price issues. To reduce the price of them a so called peel method will be used to make them more profitable. Other sectors with a higher willingness to pay like the cosmetics industry will use the substances from algae they need. What remains will be used to produce bio jet fuels. This will not happen before 2030 but from that moment the developments are expected to go very fast. After that the development of previous generations bio jet fuels will slow down. The improvements that still may be reached in this will be relative small.

Another important technological development that will take place in the scenarios 2 and 4 is the problem with the lack aromatic hydrocarbons in bio jet fuels. Where this slows down the certification process in the other scenarios this will be solved in the scenarios 2 and 4. It will be possible to add aromatic hydrocarbons to protect engine seals from bursting. There will be a technological breakthrough to solve this.

6. Scenarios

In this part the four scenarios as created in the previous chapter are written. These consistent stories will be based upon the insights obtained during the interviews performed. The structure of the multi level perspective will be used to structure the scenarios. The starting point of the scenarios is the current situation. In the literature study the current situation has already been introduced. The first period are the years 2011-2015, the second period 2016-2025 and the third period is between 2025-2050. After the scenarios an overview table with all important characteristics is given (Table 2).

6.1 Scenario 1: Fast takeoff

Due to the instability of oil prices the regime level will be put under pressure to develop space for new emerging technologies within niches. Airlines have started bio jet fuel related activities. More and more test flights will be performed all over the world. The strong future visions from the governments are supporting these activities. The main sources of feedstock in the beginning are different sources of waste complemented with feedstock produced by farmers.

6.1.1 First period (2011-2015)

There is a broad set of airlines that starts to test the technology in niches. First this will be test flights to test how their planes will react and to show the technology is ready. Scattered demand occurs which leads to low market power and unnecessary high prices. This will be solved by the creation of new bio jet fuel companies that bundle this scattered demand and by doing so they create buying power. The set up of these companies will be done by different actors within the fuel and aviation sector like airlines, fuel producers and consultancy organizations. These collaborations are a way to share the risks and to benefit from each others knowledge. By sharing knowledge with each other synergy between niches can be created which stimulates development.

This new type of companies can have multiple benefits as mentioned during one of the interviews: *'By combining the demand from multiple airlines larger batches can be ordered. This helps to convince suppliers to modify their production line for the production of bio jet fuels.'* The buying power these collaborations will lead to the increase of market power and decreasing prices for bio jet fuels. More and more stakeholders will be triggered to start testing this technology. This increase in the amount and cooperation between niches is called niche accumulation and the technology gains momentum. The creation of a market and a stable supply chain will be the main objective of these companies. At that moment bio jet fuels are still not competitive compared to convectional kerosene so additional measures have to be taken.

Due to the strategic importance of bio jet fuels the military starts to make investments in bio jet fuels. These programs are set up along side the niche application from civil aviation. As a result of this the speed of technology development will increase and civil aviation will eventually benefit from this. Multiple stakeholders mentioned the fact that the current used jet engines are an example of a technology that is introduced in civil aviation due to the developments made in military application. So, it is plausible that the technology pull for bio jet fuels created by the military will in the future support the application in civil aviation. Due to the developments in other parts in the world niche proliferation occurred. More and more companies start using this type of fuels to execute regular flights with passengers this are market niches. This indicates that the technology has entered the second phase of technological development, application on niche markets. One stakeholder said about this: *'In the demonstration phase it is important to blend at a high level to demonstrate the technology is ready for application in* *aviation. This will create trust in the technology.'* This is what will happen in this phase. A small amount of flights will fly with a high blending rate to show the possibilities.

6.1.2 Second period (2016-2025)

Because of the targets that are put in place to increase the energy security by decreasing the dependence on unstable countries the EC will start to implement policy. In the period from 2016 till 2025 an aviation specific mandatory blending will be implemented. This will force the bio jet fuel technology to go into the third phase of technological development, the takeoff phase. Important for the European aviation sector is that this will happen in collaboration with other countries with large aviation sectors like the US. By doing this the level-playing field will be guaranteed as much as possible. This appears to be very important for stakeholders as shown in the following quote: *'Measures taken by governments should not negatively affect the level playing field. This to make sure welfare and employment are not negatively affected.'*

Due to this mandatory blending all airlines will start using bio jet fuels which leads to higher operating costs for all airlines that operate in participating countries. This mandatory blending starts to increase the demand for bio jet fuels and related feedstocks. The main feedstock used at that moment will be waste. To fulfill the increasing demand more types of waste are used to produce bio jet fuels. Besides that other second generation feedstocks like Camelina and Jatropha will be used. Camelina will mostly be used as rotation crop in years were the land has to restore its fertility. Jatropha will be used mostly in areas surrounding airports because it helps to keep away birds. Another application is to protect sensitive crops from pests.

When the mandatory blending is announced a few years in advance risks for investors and other actors on the market decrease. Investments in feedstock production and processing facilities will increase because of this. So, a technology pull will be created on regime level. Technologies that will develop in niches start to come out of the micro level. The transition will start to follow a transformation route. Over time the requirements will be increased by the government. This will be announced in advance and the market will react on this by creating a renewed technology pull.

The demand for bio jet fuels will be increased due to this development. Scarcity occurs and leads to higher prices for bio jet fuels. The sector starts to search for more bio jet fuel supplies. More feedstocks and related processing technologies have to be applied to fulfill the demand. More types of waste will be added to the supply chain and processed by advanced technologies. One stakeholder mentioned *'In the next five to ten years it will be possible to convert all types of organic waste into bio jet fuels.'* A stakeholder that was working on the development of Pyrolysis technology supported this vision.

A problem that will occur is the mandatory blending for other modalities that start to compete with aviation for the available feedstock. This makes it even scarcer and the prices will further increase. In the niche phase there will be synergy between the niches and regimes of different sectors. At this moment in time problems will start to occur between them. This will be solved by not increasing the mandatory blending for road vehicles and the stimulation of other technologies like batteries.

6.1.3 Third period (2026-2050)

It will be important that between 2026 and 2050 the mandatory application rate is ambitious but realistic. This has to be determined by incorporating two important variables. The amount of feedstock that is available and technological development of bio jet fuels. To set these requirements the government has to work closely with research bodies to make sure the right decisions will be made. Eventually the increase in the requirements will be limited due to the lack of feedstock available. Waste flows will be used and other second-generation feedstock cannot be increased due to the fact that no more farmland is available.

The social sub regime will be important here because the public will not accept increasing food prices because of fuel production. The governmental and market sub regimes have to incorporate this requirement from the social sub regime. To incorporate this at governmental level will be a major task: *'Within the EC there are countries with a large agricultural lobby which benefit from high prices.'* These lobby groups will try to keep the prices high. The market will do everything to make sure they will not be associated with a competition between food and fuel production. This will happen in the period 2026-2050 and the growth of the application will grow slowly after that due to the lack of feedstock.

Eventually the socio technological regime for bio jet fuels is stabilizing. The sub regimes are interacting with each other and that created a stable situation. Bio jet fuels are used together with conventional jet fuel at a relative stable ratio. There will come a moment that the lack of feedstock for the production of bio jet fuels will hamper the development. Further development will only take place when a new technological breakthrough occurs, but this will not happen before 2050.

6.2 Scenario 2: Sky is the limit

Just like in the previous scenario oil prices are very volatile because of instability in the world. Due to this instability of oil prices the regime level is forced to adjust to this and has to find a way to decrease these uncertainties. At that time there was a lot of discussion between stakeholders whether or not bio jet fuels could contribute to the stability. This is the case because of the interrelatedness of feedstock and oil prices.

6.2.1 First period (2011-2015)

Airlines will more and more start bio jet fuel related activities. The amount of test flights performed with bio jet fuels will increase. The strong vision from the government on energy security will support this development. The main source of feedstock will be waste complemented with feedstock from farmlands. The fact that more and more companies will start using this type of fuels to execute regular flights with passengers indicates that the technology enters the second phase of technological development. In this phase the technology is really applied on real niche markets. On selected destinations airlines will start to operate flights on bio jet fuels to test them in real operations. This is done to make the general public familiar with the new bio jet fuel technology.

At the same time third generation bio jet fuels got a lot of attention due to uncertainties about the potential of previous generations bio jet fuels. Especially the military will start to invest in this third generation for strategic reasons. In first place they become less dependent of oil supplying countries. Second is the absence of aromatic hydrocarbons in bio jet fuels. These components are for a large share responsible for cirrus clouds. A higher bio jet fuel ratio means less aromatic hydrocarbons and less cirrus clouds. This made the planes used by the air force less visible for enemies. To achieve this, large investments in the technology will be made. A stakeholder said about this: *'The investments made by civil aviation in the development of third generation bio jet fuels are only a tip compared to the military investments.'* So the military will become a lead user from third generation bio jet fuels and make large investments in this technology.

While more companies started applying bio jet fuels in niches scattered demand starts to occur. This leads to low market power and unnecessary high prices. This will be solved by the creation of new bio jet fuel companies that bundle this scattered demand and by doing this created aggregate demand. This is done to increase the buying power and lowers prices. This can be seen as a form of niche accumulation and the technology gains momentum. Eventually this will lead to the take off from bio jet fuels. The creation of a market and a stable supply chain will be the main activities of these companies. They also stimulate the learning within niches and the interaction between the niches that are created. Due to the higher prices for bio jet fuels additional measures will be taken to create a real take off for the technology. The risks for investments in first and second generation bio jet fuels are higher because of the expected break true of algae. This will slow don their development.

6.2.2 Second period (2016-2025)

For the aviation sector bio jet fuels will remain expensive but the government wants a fast take off for strategic reasons. A mandatory blending policy will be introduced. This forces the technology to go into the third phase of technological development the take off phase. Important for the European aviation sector is the fact that countries outside the EU also join this regulation. The more countries join the better the level playing field will be guaranteed. This will also to the proliferation of niches all over the world. Due to this mandatory blending all airlines will have to use bio jet fuels the governmental sub regime forces the market regime to apply the technology. This development leads to higher operating costs for all airlines from participating countries. This mandatory blending will increase the demand for bio jet fuels and related feedstock but also the increases the speed of technologic development.

The main feedstock in the beginning will be waste. To fulfill the increasing demand more types of waste will be used to produce bio jet fuels. Besides that other second generation feedstocks will be used like Camelina and Jatropha. Because of the scarcity of these types of feedstock and the relative high prices this created the sector started to pull harder for third generation bio jet fuels. As mentioned in the interviews: *'Algae will profit from the whole system that is build surrounding the previous generations bio jet fuels. This will make testing and small scale applications on the market much easier.'* This is especially true for the infrastructure and certification needed for bio jet fuels. At this stage algae were applied in niches and small scale test applications alongside technologies from previous generations. The developments made by the military will support the first applications in civil aviation.

When mandatory blending will be announced and introduced risks for investors and other actors within the market regime will be decreased. Investments in feedstock production and processing facilities will increase. Over time the participating countries increase their requirements. This will be announced in advance and lead to a renewed market pull. These developments create pressure on the regime level to create niches for new technologies. More feedstocks and related processing technologies have to be applied. More types of waste will be added to the supply chain and processed by more advanced technologies.

6.2.3 Third period (2026-2050)

Due to these increased requirements third generation feedstock will become increasingly competitive. Algae will be the most important feedstock in this timeframe. More investments in this technology will be made. They are still used in small amounts due to price issues. To reduce the price of third generation feedstock a so called peel method has to be developed. This is done to make them more profitable. As mentioned by a stakeholder: *'To make algae a real option a peel option should be developed. Otherwise no producer would sell the algae to sectors with a low willingness to pay'* Other sectors with a higher willingness to pay like the cosmetics industry will use the substances from algae they need. What remains will be used to produce bio jet fuels as a way to make money out of residuals from high end production processes. This will not happen before 2030. After that the development of previous generations of bio jet fuels will slow down. The improvements that are made with this were relative small.

Due to the application of third generation bio jet fuels along the previous generations bio jet fuels a relative fast increase in the application rate will occur. This will happen because a lot has been learned from the application of previous generations. Eventually this will be slowed down due to the strict certification regime in the aviation sector. Bio jet fuels do not have aromatic hydrocarbons in it. This will cause problems with fuel seals in the engines and fuel systems of planes. Due to this a mid air engine shut down may be needed which will cause security issues. *'Due to the long product life cycles within the aviation sector there will be no engines and planes on the market that can fly on non drop-in bio jet fuels before 2050.'* So the limits due to the lack of aromatic hydrocarbons have to be taken into account.

The sector is responsible for the certification of new technologies. Therefore it is very important for the sector to start the procedures for higher ratios than 50%. This to make sure blends with a ratio higher than 50% can be applied in time. According to an interviewed stakeholder: *'The sector should start to find technological solutions for the lack of aromatic hydrocarbons right now. This to make sure the certification for 100% bio jet fuels is completed in time.'* The production of synthetic aromatic hydrocarbons could be a solution for this.

When more and more third generation bio jet fuels are applied an important advantage becomes the fact that sustainability of the fuels starts to increase. For previous generations bio jet fuels there is a lot of doubt whether or not they were sustainable. This does not seem to be the case for fuels based on algae: *'In reports on sustainability of biofuels algae are always seen as the most sustainable feedstock.'* For the application of third generation bio jet fuels the public opinion will be much more supporting. The social regime will have a larger role and this supports the market and governmental sub regime to apply bio jet fuels. This leads to an even faster growth in application. This can be seen as a co evolution between the technology and society.

The socio technological regime will develop till 2050 and will be stabilized at that moment. The sub regimes are still reinforcing each other. Bio jet fuels are used together with conventional jet fuels but the ratio is still growing. Because of the late take off from algae this growth rate will be very high in 2050.

6.3 Scenario 3: High regulation

In this scenario the EC decided that real action on sustainability has to be taken. Policies to enforce this will be applied on all emitting sectors within the EU. No exceptions for the aviation sector will be made so flights that use the European airspace will be included. Airlines can chose for themselves how to fulfill the CO2 reduction targets. New technologies have to be developed and applied to do this. Bio jet fuels will play al large role in this. The developments will be limited due to a low technological development.

6.3.1 First period (2011-2015)

The European government decides to implement policy to reduce the emission of greenhouse gasses. This decision is applied on all polluting sectors so it also covers the aviation sector. Experiences in the automotive sector they have learned that mandatory blending is not the way to reduce emissions. It turned out that in some cases the emissions were even higher and the public opinion became very negative. *'The aviation sector and the government seem to have learned from the implementation of mandatory blending in the auto motive sector. They are aware of the problems with sustainability this may create.'* It is also a measure by which the government has to decide the technological direction which is something they rather not do.

Instead of the mandatory blending the European Union Emission Trading Scheme (EU ETS) is introduced. In this scheme he EU determines a ceiling for the amount of CO_2 emissions for the aviation sector. This maximum amount of emissions is shared over the airlines operating in the EU. When they exceed their maximum emissions they have to buy emission permits from other airlines or other sectors. By doing this the emission of CO_2 gets a price. This stimulates the airlines to reduce their emissions. Airlines are opposing to this kind of measures because of the degradation of the worldwide level playing field.

The EU ETS leaves open how airlines reduce their CO_2 emissions they can decide by themselves which technologies they use or measures they take. A government representative said about this: *'Airlines are free to choose how to meet the requirements from the EU ETS. By applying this type of measures the government does not control the technological development.'* In the first place this will lead to improvements in the existing technology which is called the sailing ship effect. Efficiency will be increased but eventually will become very difficult and the CO_2 price will increase due to a shortage in emission allowances. Flying within, from and towards Europe will become more expensive. At that moment bio jet fuels will become a real option because of their improved economics.

Despite this the application of biofuels will remain low over the next decade. Because of the strict regulations to guarantee the sustainability only a few types of feedstock can be used for the production of bio jet fuels. Because of the shortage that occurs they become very expensive. The technology will remain in the first phase of technological development for a long period. Never the less some lead users will start to operate some lines on bio jet fuels this to create first mover advantages. This will eventualy take the technology to the second phase of technological development.

To stimulate the application of biofuels they are exempt from the EU ETS. The emission from bio jet fuels is equated to zero with the condition that they comply with the requirements on sustainability imposed by the EU. In this period the EU ETS may stimulate small-scale market applications in niches. Some airlines will select a destination were they start the real market application.

What is missing at this stage is a lead user that has the ability to make large investments. The army does not seem to be willing to make large investments in sustainability. This is not a strategic important issue for them. Because the amount of feedstock is limited it cannot be used for energy security reasons. Large airlines suffer from very small margins on their ticket sales. This makes investments very difficult. To reduce the prices and to create more buying power scattered demand has to be combined to aggregate demand. Companies will emerge to fulfill this function. This will help to create synergy between niches by making use of each others knowledge. Airlines can help each other by participating in such companies.

6.3.2 Second period (2016-2025)

Over time the EU ETS emission ceiling will be lowered. Also the requirements for bio jet fuels to get a CO_2 exemption will become stricter. The sector will make sure there are no links between the production of bio jet fuels and food production. This would create social unrest. The government will even go further to ensure sustainability. Indirect land use change (ILUC) will be implemented in the calculations for the CO_2 emissions. This will be done under large pressure from NGO's: *'The only way to make bio jet fuels a real sustainable option is when in the whole production cycle is included in CO_2 calculations. ILUC is an important issue in this.'* This is co evolution between the technology and society takes place. Society wants new technologies to be really sustainable. Due to the EU ETS ceiling that is lowered airlines cannot only improve existing technologies they are also forced to apply more bio jet fuels that comply with the requirements for CO_2 exemption.

When this is done more and more niche markets will be added which is niche accumulation. In the first part of this period this will go slow but the decrease in production costs and more possible technologies will increase the momentum of the technology. Due to a fast accumulation the technology gains momentum. At this stage it will enter the third phase of technological development the take off. Development of new technologies and feedstock that can comply with the strict sustainability criteria will be a continuing process. This take off will be slowed down because of the sustainability requirements.

Especially for Camelina and Jatropha these requirements can be a constraining factor. Their application will be limited. They can be applied as rotation crops or to protect food crops against pests. In an interview an idea for Jatropha was mentioned: *'Jatropha could be used as a sustainable protection against pests because it is toxic.'* Another stakeholder suggested: *'Jatropha could be used as a sustainable way to keep away birds by cultivating it around airports. They will recognize this toxic feedstock and stay away'* This puts even more pressure on the regime level to create space for new niche applications.

The regulations as imposed by the EC will create a technology pull and force the market to invest in this. It will take some time before the results of these developments become available. Another development is the fact that the automotive sector will be stimulated to change to technologies based on electric drive-trains. The scare feedstock supply will be less influenced by the competition between automotive and aviation. *'Because of technological development the automotive sector will switch to electric propulsion if necessary with governmental support.'*

6.3.3 Third Period (2026-2050)

An important issue can be the development of the public opinion on sustainability. In the future this will become more important and force airlines to offer more sustainable flights. This will help to create a faster increase in the application rate. Society and the technology are strengthening each other in this development. The governmental and social sub regime will be influenced by the social sub regime and start to strengthen each other. Sustainability will become more important in the public opinion and aviation has to comply with this.

To stimulate the increase of the application of bio jet fuels the EU ETS emission limit will be lowered. But this cannot go to fast to protect the European aviation sector and do avoid the need for the application of polluting bio jet fuels. So the market, technological and governmental sub regimes will interact with each other to come to the optimal application rate. They all will be influenced by the social sub regime. When sustainability becomes the standard society will require aviation to comply with this. Sustainability becomes attractive for the sector at that moment. More and more people will take sustainability as something that is the standard and this change in behavior will support the bio jet fuel technology.

Over time more feedstock chains will be added to the supply chain. In most cases the amount of chains per feedstock will be limited due to sustainability issues. One chain can be sustainable but when ten chains are used along each other this may create shortage in products needed for the production of feedstock like fertilizers. An interviewee said about this: *'Important is to assess the effects of adding up different production chains. One can be sustainable but a combination may cause sustainability issues.'* Agricultural waste will be used a lot because the technologies to convert this into bio jet fuels become more and more advanced.

In this period the application rate will grow only very slow because of the lack of feedstock supplies. Eventually there will be a technological barrier that arises and no more feedstocks can be converted into biofuel in a sustainable way. At that moment the development will stagnate and a new technological breakthrough has to occur. This will not happen before 2050.

6.4 Scenario 4: Slow start

Just like the previous scenario the focus will be on sustainability and the government enforces this with policy measures. Just like in scenario 2 the technological development will be high and more feedstocks and technologies will come available. These will profit from previous developments.

6.4.1 First Period (2011-2015)

The government decides to implement the EU ETS on aviation. Other measures like mandatory blending are based on experience in the automotive sector not seem to fulfill their goal very well. When the emissions assigned by the ETS are exceeded more credits should be bought. The aviation sector will try to avoid this by implementing technologies and measures that reduce the emission of CO_2. In first instance this will lead to improvements in the exciting technology, the so called sailing ship effect.

Bio jet fuels are the best option to create large reductions in CO_2 emissions. Applying bio jet fuels has to be stimulated by additional policy. A stakeholder said about this: *'Airlines are established to move seats from one place to another in an as efficient as possible way. The voluntary application of expensive bio jet fuels does not comply with this, especially the government should take responsibility to overcome this.'* The main tool will be the exception of bio jet fuel related CO_2 emissions from the EU ETS. The emission of bio jet fuels will be equated to zero. This is only allowed when they meet the sustainability criteria as set by the EU. This increased focus on sustainability is a landscape development that forces airlines to try new technologies in niches.

Because of the prospect that third generation bio jet fuels will become very sustainable there will be more and more attention for them. Especially according to the scientific sub regime this seems to be a promising option. The market will be less enthusiastic about this technology. An important reason for this was given by an interviewee: *'There are airlines that have tried to perform test flights on algae but failed in achieving this'* This leads to a trough of disillusionment for third generation bio jet fuels.

What is missing at this stage is a lead user that has the ability and the willingness to make large investments. The army does not seem to make large investments in sustainability. Large airlines suffer from very small margins on their ticket sales. This makes investments very difficult. To reduce the prices and to create more market power scattered demand has to be combined to aggregate demand. Companies will emerge to do this. This creates synergy benefits between niches.

In this period the attention from the civil aviation sector in third generation bio jet fuels is very low. So waste, Camelina and Jatropha will be the main feedstocks used in this stage. The technology will be in the second phase of technological development real niche market applications. Airlines will operate series of flights on bio jet fuels to test the infrastructure and supply chains needed. Learning about the new dynamics that bio jet fuels add to the aviation sector is the most important issue here.

6.4.2 Second Period (2016-2025)

The requirements for sustainable bio jet fuels will be tightened by the EC. This is done by implementing ILUC. This makes it more difficult to increase the supplies. Meanwhile the Aviation sector will grow and the EU ETS emission ceiling will be lowered. The production bio jet fuels that are used already will be increased. This forces airlines to think of other technologies to reduce their CO_2 emissions. This is a co evolution between the technology and society.

Over time more feedstock chains will be added to the supply chain. In most cases the amount of chains per feedstock will be limited due to sustainability issues. Agricultural waste will be used a lot because the technologies to convert this into bio jet fuels become more and more advanced. One stakeholder pointed at a possible problem with this: *'When more and more agricultural waste is used this may cause problems with other sectors that use these materials as input.'* This problem will be avoided by integrating sustainability policies. Aviation does not have another option than then application of bio fuels. The energy sector could use more solar and wind energy and road vehicles could use electric propulsion.

The coming decades the application will increase at a slow rate because of the slow increase in sustainable feedstock production. This will in a later stadium be supplemented with the application of algae. From that moment the growth will increase because of the fact that there are almost no sustainability issues related to this feedstock. As a result of this the attention within the sector for the application of third generation bio jet fuels will increase. These become more profitable because of two reasons. The price of second generation feedstock will increase because of scarcity which makes algae more attractive. Algae will become available by using the peel method. Sectors which have a higher willingness to pay will use the algae first and the residuals will be used for bio jet fuels. The government is stimulating the third generation technology by creating a positive incentive. This is done by allowing third generation bio jet fuels to be counted double for the EU ETS.

At this stage third generation bio jet fuels are technologically under developed compared to the previous generations. A stakeholder said about this: *'At the moment it is very difficult and expensive to get the water out of the algae to make them ready for processing. Because of this it will take till 2025-2030 before real market application is possible.'* Due to this the application of third generation biofuels will remain very low in this period and only get a market application in niches. Due to the strict regulations only a few types of feedstock can be used for the production of bio jet fuels. This makes them very expensive. The technology will remain in the second phase of technological development for a long period. Never the less more and more users will start to operate some commercial lines on bio jet fuels so called market niches. Along this development the army will start a long term algae development program for strategic (energy security) reasons. It is expected that civil aviation will benefit from this.

When this is done more and more niches will be added. This will go very slow over the upcoming decades. Important is to work on new technologies and feedstock that can comply with the strict sustainability criteria. The regulations as imposed by the EC will create a technology pull by forcing the market to invest in this. It will take some time before the results of this become available.

6.4.3 Third Period (2026-2050)

An important issue will be the development of the public opinion on sustainability. More and more things become sustainable and this becomes normal according to the public opinion. Due to this flights have to become green for airlines. *'When all things become sustainable airlines cannot remain as polluting as they are right now. Then they become the pariah of the transport sector.'* Airlines have to do everything to avoid this development. This will help to get the third generation technology really in the take off phase. The governmental and social sub regime will start to strengthen each other and create a strong technology pull influenced by the social sub regime. The technology will be forced into the third phase of technological development and takes off.

To stimulate the increase of the application of bio jet fuels the EU ETS emission limit will annually be lowered. By doing this the pressure on the regime to decrease its emissions will be increased. But this cannot go to fast to protect the competitiveness of the European aviation sector and to avoid the application of polluting bio jet fuels that do not comply with the requirements imposed by the EU. So the market, technological and governmental sub regimes will interact with each other to come to the optimal application rate. They all will be influenced by the social sub regime. A co evolution between the technology and society takes place.

This is when the real take off from third generation bio jet fuels will take place. Large investments in the production and processing of algae will be made by the aviation sector and external investors. The price of algae will remain a problem. But this can be reduced by using the earlier peel method and the use of waste materials from other industries. Another way to reduce the costs is: *'Algae production can be located near other industries to use their waste like head, CO_2 and phosphate.'* After 2030 the take off can go very fast and it is important that the application certification is further developed at that moment. To do this a solution for the lack of aromatic hydrocarbons should be found.

Due to the late takeoff the development will continue until and after 2050. The development of the previous generations bio jet fuels will be very slow at that time. Third generation will be at a very high development rate.

Table 2: Overview of scenario characteristics

Scenario aspect	Scenario 1: Fast takeoff	Scenario 2: Sky is the limit	Scenario 3: High regulation	Scenario 4: Slow start
Key technologies	First and second generation bio jet fuel technologies	Mainly third generation bio jet fuels; Synthetic aromatic hydrocarbons	First and second generation technologies	Mainly third generation bio jet fuels; Synthetic aromatic hydrocarbons
Key concepts	Energy security; Mandatory blending; Collaboration with third countries (non EU); Waste as main feedstock; Food vs. Energy competition	Focus on energy security; Mandatory blending; Worldwide interests; Algae as main feedstock; Certification issues, Military application, Competition with road traffic	Disturbed level playing field; Sustainability; EU ETS; Waste as main feedstock; Fuel requirements to guarantee sustainability	Sustainability; EU ETS; Algae; Public opinion; Sustainability criteria; Powerful policy; Affected level playing field; Certification issues
Key actors and roles	EU takes the role to guarantee the future supply of energy by reducing the dependency on unstable countries; Third countries cooperate with the EU in creating energy security; Airlines have to incorporate bio jet fuels in their operations	EU as regulator; Third countries in corporation with the EU; Military as a lead user that makes large scale investments in third generation technologies; Airlines that are forced to apply bio jet fuels	EU for implementing regulations to enforce sustainability; Airlines as lead users; NGO's as critical stakeholder; Farmers as feedstock producers	Government implement sustainability regulations; Airlines make sure they comply with the obligations of the EU ETS; Investors enable the fast development of algae farms and related production facilities
Key multi-level patterns	Changing values at landscape level more instability in energy supply; Technology pull from the regime level; Niche accumulation; Technological substitution transition pathway	Changing values at landscape level more instability in energy supply; Technology pull from the regime level; Niche accumulation; Transformation transition pathway; Synergy between niche processes	Sailing ship effect; New trends at regime and landscape level; Creation of space for niches by putting the regime under pressure; Technological substitution transition pathway	Sailing ship effect; New trends at regime and landscape level; Creation of space for niches by putting the regime under pressure; Competition between technologies for recourses; Transformation transition pathway
Key learning processes	Learning to deal with a broad set of different feedstocks; The reaction of airplanes on the use of bio jet fuels; Cooperation on world wide level	Learning to deal with a broad set of different feedstocks and suppliers; Applying knowledge on the implementation of first and second generations to the third generation; Long term effects on airplanes	Effects of the use of a lot of feedstocks and suppliers; Long term effects on airplanes; Implementation of world wide policy; Effects on the development of crude oil and feedstock prices	Add-on of new third generation technologies; Interrelatedness of feedstock and oil prices; Long term effects on airplanes; Effects of NGO pressures

7. Reflection

In this section a comparison will be made between the four scenarios. The important differences and similarities between the four scenarios will be shown. After that some issues raised in the scenarios will be compared with the literature on that topic. This is done to identify mismatches between the literature and the opinions of stakeholders on these issues.

7.1 Comparison of the scenarios

Were in the beginning the scenarios start in the same way with a sector that is put under pressure because of the use of large amounts of fossil fuels they start to deviate over time. The four scenarios formulated show that, based on the insights of stakeholders, different transition routes are possible with different results in 2050. There are large differences in the expected application rates of biofuels in the four scenarios.

All stakeholders support the expected outcome that the scenarios with a high technological development do have a higher adoption rate than the scenarios with a low technological development. Another outcome is that the scenarios with a focus on sustainability have more regulations in place. This will slow down the implementation of the technology, which results in a slower adoption rate than when the focus is on energy security. The technology will remain longer at the micro or niche level. But scenario 2: 'Sky is the limit' also shows that a short term focus on energy security may lead to long term sustainability because this increases the speed of development of third generation bio jet fuels.

This makes it possible to order the scenarios from low to high in adoption rate in 2050: Scenario 3: 'Regulation overload', Scenario 1: 'Fast takeoff', Scenario 4: 'Slow start' and the highest adoption rate for scenario 2: 'Sky is the limit'. Despite the fact that scenario 2 is focused on energy security it is possible that large improvements in sustainability will be made. This is the result of the large application of third generation bio jet fuels. At the moment it is expected by most interviewed stakeholders that those will not have that much problems with meeting sustainability criteria. In Figure 7 the development of the application rate of the different scenarios is shown to illustrate this.

It is shown that according to the stakeholders different policy measures may support the implementation of bio jet fuels but the goals that can be reached with it are very different. When the focus is on sustainability there will be much more regulations needed to ensure this sustainability. Especially in the first phase this will be a constraining factor. The lesson learned from the application of bio fuels in road vehicles is that mandatory blending is an important policy measure to start the market and to enforce the application of a new technology. A negative effect is that it is a real threat for the sustainability of bio fuels. A possible lesson that could be drawn from this is that it may be interesting to start using the technology as a means to increase energy security and later the sustainability criteria could be tightened. EU ETS seems to be a better option to guarantee sustainability. The emission of bio jet fuels will be equated to zero to stimulate their development. This happens only when they comply with the production requirements imposed by the EU. These will be tightened over time. A combination of both, ETS and mandatory blending, is according to stakeholders related to the government not advisable. This would mean a large bureaucratic burden on the aviation sector.

The scenarios also show that there are large economical interests at stake. The level playing field is very important for almost all stakeholders interviewed. All measures taken are judged against this criterion. An interesting issue here is the fact that when stakeholders mention positive incentives to use bio jet fuels this is not seen as a disturbance of the level playing field. So it seems that they are using double standards to judge possible measures. In all four scenarios policy implied by the government is seen as the most important driver to pull the bio jet fuel over the valley of death. Although it in the case of energy security also a direct tread is for airlines. So they will protect their own interests by applying bio jet fuels. It is interesting that during the interviews with government agents they pointed at the importance of the sector to take initiative. So there seems to be a mismatch between the expectations they have from each other.

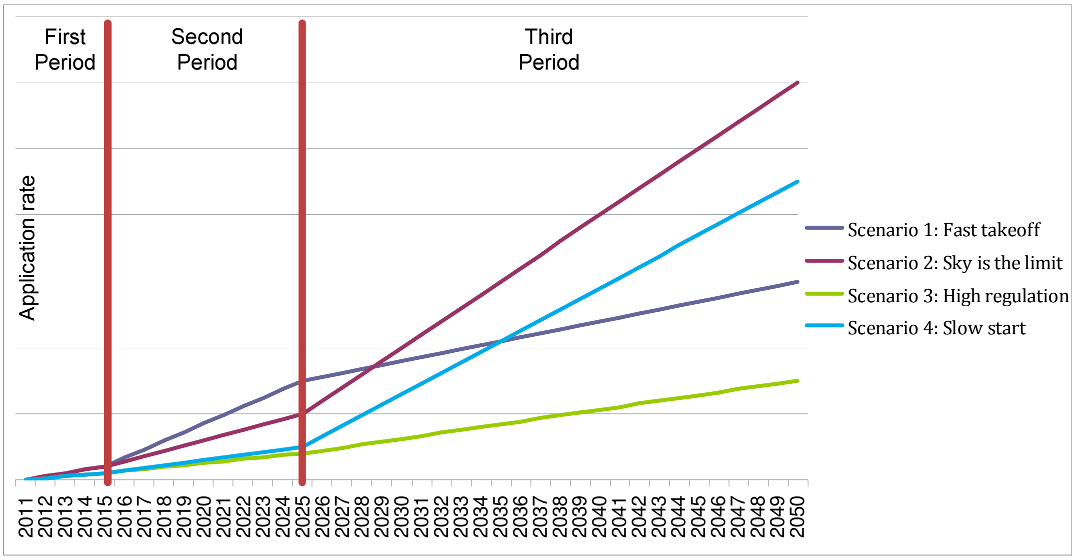

Figure 7: Overview of application rates in the different scenarios[3]

7.2 Comparison with the literature

The insights from the stakeholder interviews show some interesting deviations from the existing literature on bio (jet) fuels. In this section the insights from the literature review deviating from the interviews and scenarios are shown and when possible explanations for these deviations will be given. The sources can be scientific papers, reports from the sector and governmental documents.

During the interviews the visions on the application of third generation bio jet fuels based on algae were very divergent. The two extremes were the only option for the large scale application of bio jet fuels and it will not be used within a century. An interesting insight in this is the fact that especially airlines and stakeholders very closely related to these airlines are more negative on the possibilities of algae. Other stakeholders thought it would be possible within five years. So there is a wide range in the expectations. In the literature on bio jet fuels algae are mostly seen as an important option in two or three decades.

Especially in the literature and policy documents related to bio jet fuels there is a positive vision on the possibilities of algae. The main problem mentioned is the fact that algae have to be dried before they are processed. This is a technological barrier that is expected to be solved in time. In the scenarios the main issue regarding algae is the willingness to pay in other sectors. In the scenarios with low technological development

[3] Please note that this figure is not based on actual numbers. It gives an illustration of the expected development of the application rate of bio jet fuels in aviation within the different scenarios.

the main reason for the absence of algae is the fact that other sectors are able to pay more for the algae produced.

During the interviews some stakeholders pointed at the different interests that are at stake. Researchers are positive about algae to raise more money for their research. Other stakeholders may be negative because they are reluctant to do the investments that have to be made. Interesting is the fact that even in the IATA report on bio jet fuels algae are positively reviewed. This is not in line with the previous explanation because their members (airlines) eventually have to make these investments.

Within the scenarios there is not a large role for Camelina and Jatropha. Especially in the scenarios that focus on sustainability the role of both feedstocks is limited to small scale applications. There will always be ILUC problems related to the cultivation of these feedstocks. Also the fact that materials like fertilizer and water are needed in large amounts may lead to problems with the food supply. Therefore it will be only used on small scale. In the literature there is a slightly different vision on this. There Camelina and Jatropha are seen as feedstocks that can be grown in large amounts on poor soil. Interviewees do not have any confidence in this expectation. It can be used to supply small niches and later as a small source of supply.

The last feedstock is waste. In the literature there is not a lot of attention for the application of waste as a feedstock. In the Bio jet fuel reports from ICAO and IATA it is not mentioned at all. However, in the scenarios this is seen as an important short term option to produce bio jet fuels in the coming decades. The supply may increase the coming decades because more types of waste can be added when the technology develops. For some reason this is not acknowledged by the main international organizations in aviation.

In the literature on bio jet fuels the focus is always on sustainability; this is the main reason to implement bio jet fuels. Energy security is in some cases mentioned as an additional advantage. During the interviews some interviewees mentioned that a focus on energy security is the best way to create a take off of the technology. According to them sustainability will be an advantage that will be beneficial on the long term. The military is by multiple interviewees mentioned as an important lead user because they are able to make large investments and do not focus on sustainability. In the literature this option is never mentioned. There is always a focus on sustainability from the beginning energy security is mentioned as a side issue.

A topic that is not very widely discussed in the literature is the lack of aromatic hydrocarbons in bio jet fuels. This could cause safety issues due to mid air oil leakage that is related to dried seals. According to a group of interviewees this is an important barrier for the certification of blends higher than 50%. They see this as a real problem but in the most important bio jet fuel documents this cannot be found. The certification process that is related to this is also a topic which does not get a lot of attention in the reports. But during interviews stakeholders mentioned that blends higher than 75% will be a real problem.

In reports from multiple organizations that are related to the aviation sector military application of bio jet fuels is left out. This can be the fact because of the scope on civil aviation. But the role as a lead user to make large investments of which civil aviation could profit seems to be neglected. In history this has been a pattern that has taken place multiple times. At the moment the US navy is making large investments in bio jet fuels. So the argument that they are not interested in bio jet fuels cannot be used.

During the interviews stakeholders mentioned possible positive and negative effects of competition between modalities. In this case this competition will be between aviation and road vehicles. Road vehicles can help to set up production facilities and a supply chain. But due to this competition the price can be pushed up. This will hamper the implementation in aviation. In the literature on bio jet fuels this issue is not mentioned at all. Especially when sustainability becomes the standard in every sector all policies have to be aligned with each other.

So there seem to be some deviations between the vision in the literature and the visions that were found during the interviews. There are two possible explanations for this. First the stakeholders could be poorly informed. Another option is that the literature presents possibilities that are theoretically possible but in the real world cause more problems than foreseen. A third option is that researchers present their results more positive to raise more resources for their research projects.

Table 3: The major differences between stakeholders and the literature

Issue	Stakeholders	Literature
Algae	Diverse visions from the only option for a large scale application to no possibility for application in the next century	Algae are the best option for feedstock supplies in two to three decades
Camelina and Jatropha	Almost no positive visions for an important contribution	Very important for the development of bio jet fuels on the short and medium term
Waste	Seen an important option for the scaling of bio jet fuels	Almost no attention for waste as feedstock
Aromatic hydrocarbons	Important barrier	No attention
Certification	In line with the previous issue they have some doubts on the feasibility if higher blends	Is mentioned as a administrative barrier that has to be taken
Sustainability	Is one of the possible goals with the application of bio jet fuels	Is the only important option
Role military	See this as an important lead user for the application of bio jet fuels.	Does not mention the possibility for an early uptake by the military at all.
Competition between modalities	Can be an important constraining factor	Not mentioned in reports on bio jet fuels

8. Conclusion and Recommendations

In the introduction of this study the aim and research question have been formulated. The aim of this research was to investigate the visions on and the transition routes related to this from stakeholders for the implementation of low carbon bio jet fuels until 2050. These visions are important because, they have the potential to guide joint action of stakeholders in the process of further developing the technology (Quist, 2007). By combining these visions to four storylines insight in possible transition routs have been created. The research question of this study was:

What are the possible transition routes for the application of bio jet fuels according to the visions and perspectives of different stakeholders involved on the application of biofuels in the aviation sector towards 2050?

Based on the interviews the scenarios have been composed. Interesting are the large differences between the visions of different stakeholders. These are captured in four scenarios on the application of bio jet fuels. The most important variables were used to define the axes along which the different scenarios are stretched. Within the scenarios the differences become clear that occurred due to the different logics that were introduced for the scenarios.

The two variables that will have the largest impact are the level of technological development and whether or not the focus will be on sustainability. Notable is the fact that a lot of stakeholders have doubts about the possible contribution of bio jet fuels on sustainability. This is a deviation from the common point of view in the literature were bio jet fuels are seen as the main and in a lot of cases only technology to make aviation significantly more sustainable before 2050.

The first deviation in transition routes was a focus on sustainability or on energy security. Stakeholders mention that for the short term sustainability would slow down the take off of the technology. In the case of sustainability the development will slow down because of the large amount of requirements. In the case of energy security the take off will be fast and in the long term this also may lead to improvements in sustainability.

Technological development and more specific third generation bio jet fuels is the other main difference. Were in the literature third generation bio jet fuels are seen as an important option the visions of stakeholders were more deviated. The visions deviated from algae as the only option to no application in the next 100 years. This difference also leads to two different transition pathways. These are the technological substitution transition pathway and the transformation pathway. When large developments with third generation bio jet fuels are made these will start to compete with previous generations. It will take some time to come to a stable situation which is in line with the transformation transition pathway. In the cases were the technological development is slow it is more a technological substitution pathway. The technology will remain at niche level until it is mature and then it will start to takeoff in line with the possible feedstock supplies.

This study showed that there is a lot of discussion between stakeholders on what the expected future will be for bio jet fuels. Not only on the development of the technology but also on which goals it will be used for. In the near future there will be a lot of discussion on these two main issues. But also the question who is responsible for the creation of the conditions needed for the real take off of bio jet fuels. Most stakeholders seem to point at the government to provide positive incentives. This to make sure they remain competitive. Governmental agencies point at the sector because there is at the moment no possibility to provide positive incentives. So when more policy has to be put in place to enforce the application the level playing field will be affected because it will have a negative effect on the competitiveness of the European airlines.

Based on the scenarios and the previous mentioned issues it can be recommended to focus in the short term on energy security. Even when sustainability is the main goal that has to be reached in the long term. In the short term the bio jet fuel technology can take off with a relative small amount of additional requirements. This keeps the price and administrative burden low. When eventually the algae derived bio jet fuels take off sustainability can be reached more easily. And third generation bio jet fuels can profit from the knowledge that has been created with the application of previous generations. It is important to make sure society remains positive about bio jet fuels. When there is a negative public opinion created on bio jet fuels this may hamper the implementation of this greener third generation. This leads to a faster uptake and for the long term the sustainability improvements may be larger. The short term energy security focus can be seen as an intermediate goal to enable a long term transition towards sustainability. Because this is a topic that is threatening the whole aviation sector and seen as a future problem all over the world collaboration with airlines, fuel producers and third countries will be much easier.

To enable joint action the visions of different stakeholders have to be aligned with each other. During the interviews it became clear that there are on a wide range of issues large differences between stakeholders. The government could take a mediating role in this by setting up a transition arena in which the differences are discussed and visions can be adjusted towards each other.

In the interviews it turned out that in some topics the stakeholders have different visions than what is likely based on the state of the art knowledge. It is important to trace were these differences come from. This mismatch may create problems with the implementation of the technology. A shared vision is very important to enable joint action. When researchers and international organisations have other visions than stakeholders that actually have to develop and implement bio jet fuels resources may be put on the wrong projects. It also shows a mismatch between the theoretical and practical vision on the topic.

This study also shows that there are a lot of doubts on the application of third bio jet fuels. Stakeholders that put trust in a future with third generation bio jet fuels can be recommended to start applying earlier generations to learn about the implementation of bio jet fuels in their operations. The stakeholders that do not see an algae based future can not neglect the possibility that it may break through. So they can focus on second generation but should also pay attention to developments with algae. This to make sure they do not miss the boat with third generation bio jet fuels.

9. Discussion

Scenario writing is a subjective process which is always to a certain extend influenced by the author. By using only statements that were made at least by two separate interviewees and by using a clear methodology it should be possible for other researchers to come to the same results based on the data.

The interviews executed for this study are mostly performed in The Netherlands. Only two interviews outside The Netherlands have been performed for this research. Despite the fact that a lot of stakeholders were working in an international organisation or network this may lead to a bias in the intended and achieved domain. By emphasizing that the aim of the research was to study bio jet fuels on a European level this bias was limited to a small level. An interesting topic for further research is the question whether or not there are differences between the visions of stakeholders all over Europe.

During the interviews most stakeholders would mention the issues that fit in their own perspective. A good example is the fact that in the categories companies and NGOs a lot of responsibilities were assigned to the government. It cannot be denied that the government is an important stakeholder but this seemed to be a bit exaggerated. This can be seen as a problem because issues may become exaggerated. But in the aim of this study this does not seem to be the case. It can be valuable information because differences in perceptions from stakeholders become clear due to this.

In the reflection section it became clear that on some topics there is a mismatch between the visions of interviewed stakeholders and the state of the art literature on bio jet fuels. Stakeholders could have mentioned these things because they do not know that knowledge on specific topics has changed or they simply do have the wrong knowledge. Another possibility could be that researchers and policy makers that publish about the topic do not have real experience with it. The stakeholders interviewed have more hands on experience what may lead them to other conclusions. For further research it could be interesting to make a more detailed comparison between visions of stakeholders and the literature on bio jet fuels. Especially an explanation of the differences between the two would give interesting insights between the theoretical and practical application of bio jet fuels.

In this study the focus was on bio jet fuels because in the literature they are seen as the main option for reducing the impact of aviation on climate change. During the interviews it turned out that energy security may be a better driver especially in the short and medium term. A reduction of the environmental impact seems to be more a long term benefit. So it would be interesting to perform a study on options for short term improvements like weight reduction and ATM improvements. It also may be interesting to include local environmental problems in further research. Multiple interviewed stakeholders mentioned the possibility that this would be improved by the application of bio jet fuels.

In the planning of this study an overview of the bio jet fuel related literature was foreseen as a way of introducing the topic. During the execution of the research it became clear that there were some interesting deviations between the visions of the stakeholders and this literature. Therefore the decision was made to pay extra attention to this in the reflection chapter. This shows not only the differences between a larger group of stakeholders but also a difference between the theory and practice of bio jet fuels. This was not directly needed to answer the research question but added some interesting insights in the disunity of the sector.

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Appendix A: Foresight Cycle

Miles (2002) introduced five phases in the foresight cycle which are displayed in Figure 8. Different foresight methodologies can be useful for one or more phases in the process. In the pre-foresight phase the objectives and delineation of the research are defined. This is a crucial phase because the outcomes of the research are highly depending on this. The methodological framework will be defined based upon these decisions. In the recruitment phase important stakeholders that can be useful for the foresight have to be identified. New knowledge is created in the generation phase. Here the new ideas are combined into a vision on the future. In the action phase this new knowledge is used for decision making and to decide on directions for innovation and change. The renewal phase is the foresight process is evaluated. New questions may arise which lead to a new cycle, in that case the pre-foresight phase will start over again (Popper, 2008; Miles, 2002).

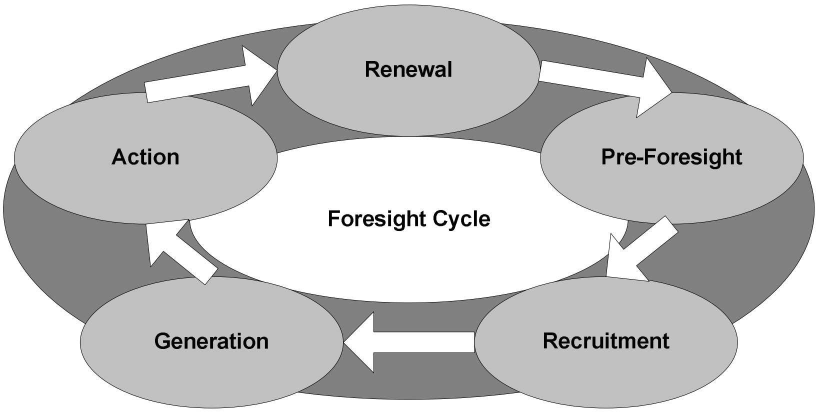

Figure 8: Five phases of the foresight cycle (Miles, 2002)

Appendix B: Sustainability principles

Table 4: Sustainability criteria (RSB, 2010)

Principle	Description
Legality	During the production process it is not allowed to violate laws and international agreements.
Planning, Monitoring and Continuous Improvement	All operations should be economic viable and subject to a open and transparent impact assessment .
Greenhouse Gas Emissions	Biofuels have to reduce the GHG emission by at least 50% in the complete Well-to-Wheel cycle.
Human and Labor Rights	During the production process no human or labor rights can be broken and the well-being of the workers has to be increased.
Rural and Social Development	Biofuel operations have to stimulate the social and rural development of the local community when this is under the regional standards.
Local Food Security	The production of feedstock shall not threaten the local and worldwide food supply or increase worldwide food prices by farmland competition.
Conservation	Ecosystems, biodiversity and nature have to be conserved, all operations have to make sure they do not threaten one of these.
Soil	Soil degradation has to be reversed to maintain the original physical, chemical, and biological conditions.
Water	The physical, chemical, and biological conditions have to be preserved. Especially ground water recourses have to be preserved and a water management plan has to be implemented at all operations.
Air	During the operations the air pollution has to be mineralized, local air quality shall not be affected.
Use of Technology, inputs, and Management of Waste	The use of technologies, inputs and management of waste should be focused on maximizing production and to minimize the risks involved in all operations. Technologies to reach this should be available for everyone.
Land Rights	Land rights and land use rights have to be taken into account.

Appendix C: Issues and trends

A. Growth of investments

The growth of investment is according to the stakeholders mainly influenced by the risk investors have to take. When the risks are lower the total amount of investments will increase. These investments are important to develop production facilities and for the advance the technology.

B. Scattered demand

When a lot of stakeholders in the aviation sector start to test bio jet fuels scattered demand occurs. Stakeholders will learn a lot but they do not share this and the development will be very slow. They also do not have a good bargaining position with feedstock suppliers and bio jet fuel producers. This will lead to relative high prices which is a high barrier for the aviation sector.

C. Stability supply chain

When bio jet fuels are applied the supplies should be guaranteed especially when they are applied obligatory. When airlines cannot rely on the fuel deliveries this is unacceptable for them because this threatens their operations.

D. Pull from lead users

In historical technological development the role of one or a small group of lead users has always been important. They will make the technology mature and set up the underlying infrastructure. Other users of the technology will profit from the developments made by the lead users.

E. Development of third generation bio jet fuels

Stakeholders did have a lot of different opinions on the role of third generation bio jet fuels. Some argue that second generation will be the most important for the coming century and others assume only third generation bio jet fuels will be the only option for a large scale application on the short term.

F. Availability of technology and feedstock

This issue is on which technologies come available and which feedstocks have to be used in it. The more technologies available the more types of feedstock could be used. This is very important for sustainability and growth of the application.

G. Development of waste as feedstock

The use of waste as a feedstock is by all stakeholders seen as a good option. Only the sustainability of this and the amount of bio jet fuels this would lead to is discussed a lot.

H. Development of Camelina and Jatropha as feedstock

Camelina and Jatropha are in the literature often mentioned as good sources of feedstock with relative small sustainability problems. Most stakeholders disagree with this and do not see them as a sustainable option.

I. Niche development

At the moment bio jet fuels are applied in niches. For the development of the technology it is important that the amount and size of niches grows to make sure the technology will eventually take off.

J. Future vision from the government

All stakeholders argue that a clear future vision from the government is very important. This will influence a lot of other development surrounding bio jet fuels. All other stakeholders can anticipate on the future developments will be enforced by the government.

K. Competition between modalities

Biofuels will not only be used in aviation, other modalities will also apply it and use the same production facilities and feedstock. Stakeholders stress that this may stimulate because for instance investments can be shared. But there may also start a competition on which sector gets the feedstock. This could be harmful for the application of bio jet fuels.

L. Aviation specific mandatory blending

At this moment there is a mandatory blending for road vehicles. This could be supplemented with an aviation specific mandatory blending. An intermediate regulation could be the acknowledgement of bio jet fuels for the road vehicles obligation. This could be done to reduce the competition between the two sectors.

M. Development of maximum ETS emissions

At the moment the aviation sector has its own Emission Trading Scheme. The development of the emission ceiling is very important for the development of bio jet fuels. This because bio jet fuels are assumed to have no emission by the ETS. The lower the ceiling the more bio jet fuels will be applied according to a share of stakeholders others argue that it only will increase the prices in aviation.

N. Food vs. feed

Within the sustainability discussion food vs. bio jet fuels is an important issue. When farmland is used for the production of bio jet fuel no food can be produced on it and so the food production will decrease. This will increase the prices of food. Stakeholders did not have a clear vision on whether or not the indirect consequences of this should be incorporated.

O. Energy security vs. sustainability

These are the two main reasons for the application of bio jet fuels. Both have large implications for the development and decision in the development of the technology. Stakeholders see this as one of the main decisions that have to be made and from there a transition path should be developed. Despite the fact that this will lead to different routes they will not be completely independent.

P. Aviation implemented in world wide climate policy

During climate negotiations and agreements like the Kyoto protocol the aviation sector is excluded because there is no agreement on how to account the emissions emitted by planes. This leads to the situation that there are not a lot of countries that are trying or willing to reduce emissions from the aviation sector.

Q. Level Playing field

Especially for airlines and local governments the level playing field (LPF) is very important. This because when policy is put in place local airlines will always be affected more than airlines outside the area were the policy is implemented. So, LPF is an important issue because the competitiveness of the local airlines.

R. Use and monetarisation of residual materials

When bio jet fuels are produced there are residual materials or waste products that may be interesting as feedstock for other sectors. By selling these products there is a better business case created. It can also be the way around that residuals or waste from other sectors is used as feedstock for bio jet fuels.

S. Willingness to pay from passengers

A lot of problems with the implementation of bio jet fuels occur because they are to expensive. When there passengers are willing to pay for this these problems can disappear. At the moment this is not the case but in time this may occur due to the increasing effects of climate change and help the development.

T. Limitation of production growth

For sustainability reasons governments could decide that the production of bio jet fuels would slow down. This to make sure sustainability targets can be reached and food prices will not rise. The production limit can be increased when more sustainable feedstocks become available.

U. Development of technology price

Over time it is expected that the price of the production technologies will decrease. The speed at which this happens is important for the implementation. It is also important for the question which technologies and feedstocks will be implemented. Stakeholders had very different opinions on this.

V. Interrelatedness of oil and feedstock prices

Were a lot of stakeholders state that higher oil prices are good for the competitiveness of bio jet fuels other stakeholders disagree with this. They mention the fact that crude oil and feedstock prices are strongly interrelated. When oil prices raise the price of feedstocks will also rise because they form a balance.