Factors affecting the emergence, development and uptake of aviation biofuels

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Factors affecting the emergence, development and uptake of aviation biofuel

by

Per Kristoffer Gegg

A Doctoral Thesis
Submitted in partial fulfilment of the requirements for the award of
Doctor of Philosophy of Loughborough University
2014
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Abstract

Aviation biofuel is technically viable and nearing the commercial stage. In the last 5 years aviation biofuel has moved from relative obscurity to become fully certified for commercial use in up to 50% blends with standard jet fuel. There have since been 15 successful commercial flight tests using aviation biofuels including Lufthansa’s six month trial operating on a passenger revenue generating route in 2011. Airlines and biofuel companies such as British Airways and Solena are furthermore beginning to form partnerships to finance specialised aviation biofuel production facilities. However, aviation biofuels have yet to become widely commercialised. In fact, there are a series of issues preventing the emergence, development and uptake of aviation biofuels. The main issues are perceived as high costs of manufacture, limited availability of feedstocks, controversy surrounding the effect on food prices and the emissions output from land use change. Furthermore, there is a significant lack of academic peer reviewed literature which investigates these issues or offers solutions to support the development of the technology.

This thesis aims to investigate the factors that affect the emergence, development and uptake of aviation biofuels by drawing upon in-depth stakeholder interviews and survey data. Strategic niche management (SNM) theory is used and extended to analyse the contemporary issues and develop recommendations to support the continued emergence, development and uptake of aviation biofuels.

It is concluded that the emergence, development and uptake is being driven mainly by rising jet fuel prices, growing concern regarding aviation emissions legislation and fuel (in)security. Airlines, biofuel producers and specialised supply chain companies are driving emergence, development and uptake due to commercial opportunities. Despite these drivers, the emergence, development and uptake is being constrained by a combination of ineffective policy provision, high costs of production, limited feedstocks and uncertainty surrounding sustainability. Ineffective and unsuitable policy is exacerbating the issues of high production costs, limited feedstocks and sustainability. In particular, competition between aviation and road biofuels is limiting aviation biofuel expansion. Recommendations are to develop nurtured niche markets for aviation biofuels using principles from SNM. Within these markets, aviation biofuels are afforded commercial viability in order to learn about supply chain development, longer term infrastructural requirements and technological development. Information should be shared between the niche markets in order to maximise learning by doing and speed up efficiency gains. Once niche markets are established, the incentives
and protection should be gradually reduced to allow a competitive aviation biofuel industry to develop.

KEYWORDS: aviation, biofuel, emergence, development and uptake, strategic niche management.
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Special thanks to my family for their support and Charlotte for her constant encouragement.

Publications

Chapter 1

Introduction

1.1. Research context: The aviation biofuel phenomenon

In recent years the need to develop commercially viable alternatives to traditional fossil-based fuels has intensified (Worldwatch Institute, 2008). Increasingly volatile crude oil prices, stricter environmental policies and the negative externalities associated with the burning of fossil fuels have collectively contributed to an emergence of research into sustainable fuel alternatives (Searchinger et al., 2008; Hill et al., 2006; Aden et al., 2002; von Blottnitz and Curran, 2006). Liquid biofuels are at the forefront of these developments owing to their ability to integrate easily into existing infrastructures. Liquid biofuels can provide significant economic and environmental benefits compared to fossil-fuels, particularly for oil importing countries and those with a framework of strict environmental legislation (Worldwatch Institute, 2006). In the last 20 years the supply of biofuels has grown significantly due to the use of mandates, tax breaks, subsidies and funding arrangements between producers and governments (OECD, 2011). This growth has resulted in the establishment of commercial markets for liquid biofuels in Europe, North America, South America, Asia, Asia Pacific and Africa (Worldwatch Institute, 2006).

Liquid biofuels, the most common of which are ethanol and biodiesel, are predominantly used in the road transportation sector as substitutes for petrol and diesel (Worldwatch Institute, 2008). However, new transport sectors are also beginning to show interest in using the fuels. The rail industry, for example, has investigated using biodiesel as a way to reduce emissions from diesel locomotives. However, the developments have been slow and the adoption somewhat limited (RSSB, 2010). Shipping has also considered biofuels but the developments have been similarly limited (Florentinus et al., 2012). Perhaps the most prominent new sector to consider biofuels as an alternative fuel source has been commercial aviation, a sector which is undergoing continuous expansion but inherently reliant on non-renewable fuels.

1.2. Aviation biofuel

The aviation industry is pursuing biofuels as a means through which the sector can reduce its dependency on oil, lower greenhouse gas emissions and improve its environmental performance without recourse to new and expensive airframe and engine technologies. The air industry is particularly vulnerable to rising oil prices. This was evident in 2008 when oil prices rose to
unprecedented levels of $147 a barrel (Mazraati, 2010) resulting in a number of airlines filing for bankruptcy and numerous others being forced to merge with larger carriers (Hileman et al., 2009). The industry is also under increasing pressure from governments and the general public to address its environmental impacts amid growing concern that aircraft emissions are negatively effecting the environment (IPCC, 1999; Omega, 2009). As a result, the commercial aviation industry is making a concerted effort to reduce emissions by setting industry targets to achieve carbon neutral growth by 2020 (EC, 2011).

However, despite significant incremental improvements in fuel efficiency over the past 30 years, the aviation industry is reaching a point of diminishing returns as incremental efficiency gains are overtaken by increasing numbers of flights (Lee et al., 2009; Dray et al. 2009). There are few technological options that can drastically reduce emissions and avoid oil price rises while maintaining growth and profitability (Blakey, 2011; CCC, 2009; Marsh, 2008). Examples of technologies which are not viable include hydrogen fuel and electric propulsion; which are either cost prohibitive or technically not possible with current technology owing to poor power to weight ratios (Dray et al., 2009). Other efficiency saving technologies including fleet renewal and enhanced air traffic management procedures (such as continuous descent approaches) are useful measures to adopt but, they will not by themselves deliver the reduction in emissions which are required. One of the best ways to address this issue is to operate existing engines and aircraft with lower carbon fuel such as aviation biofuel.

In the last ten years aviation biofuels have moved from relative obscurity to being a viable sustainable alternative to standard jet A/A1\(^1\) fuel. The potential for aviation biofuels has been demonstrated through a multitude of engine and flight tests which culminated in ASTM\(^2\) certification status for commercial use in 2011 (ASTM Press release, 2011). ASTM certification now allows biomass to liquid biofuels (BtL) and hydrotreated renewable jet biofuels (HEFA) to be used in up to 50% blends on commercial flights. However, despite optimism about their future, the emergence, development and uptake of aviation biofuel has not been straightforward and numerous challenges remain.

1.2.1. Aviation biofuel development

Commercial aviation began to show a noticeable interest in biofuels around ten years ago (Kinder, 2009). The lack of prior interest in the fuels was due to the fact that the so called conventional liquid

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\(^1\) Jet A denotes the commercial jet fuel specification for UK and Europe. Jet A1 denotes the U.S. specification.

\(^2\) ASTM is the international fuels certification body which regulates the quality and performance of petroleum products. It sets and certifies the international standard for jet fuel.
biofuels (such as ethanol and biodiesel) were unsuitable for jet aircraft because of the presence of Fatty Acid Methyl Ester (FAME) (commonly called biodiesel), metal particles and water, as well as the fact that they would freeze at the low ambient temperatures experienced at high altitude. Biofuel developers were thus required to develop a more refined type of biofuel so as to make it suitable for commercial jet aircraft. Technology used to do this predominantly involved either ‘hydrotreating’ vegetable oils or gasification of biomass feedstocks and the use of the Fischer-Tropsch process (CCC, 2009). The Fischer-Tropsch process is a technique for creating hydrocarbon fuels by combining carbon monoxide and hydrogen gas through a series of chemical reactions (CCC, 2009). Notwithstanding the fact that these two technologies were available well before aviation showed interest in biofuels, certification was perceived as being a significantly large barrier to overcome (Kinder et al., 2009). However, growing concern for rising jet fuel prices, rising energy insecurity and increasingly strict emissions legislation (CCC, 2009) drove aviation biofuels into an intensive period of development and testing from 2002 to 2005.

Jet engine tests were carried out by the U.S military using Fischer-Tropsch derived fuels in various blend ratios to test the fuels’ performance and safety. After the military testing of the fuels had commenced, commercial companies such as Boeing, GE, Green Flight International and Virgin Atlantic became involved in testing biofuels around 2007 (Kinder, 2009). These initial trials stimulated a multitude of engine testing demonstrations by the commercial and military aviation sectors which eventually culminated in full ASTM certification for BtL and HEFA aviation biofuel in 2011 (Blakey et al., 2011). Following certification, major commercial airlines including Thomson Airways of the UK, Lufthansa, KLM, Finnair and Continental (now United) began to source biofuels and operate scheduled commercial flights using biofuel blends as part of further biofuel testing programmes (Enviro.aero, 2012). British Airways is co-funding the development of the UK’s first commercial scale aviation biofuel facility with Solena which will turn 500,000 tonnes of London’s domestic refuse into 50,000 tonnes of aviation biofuel a year (BA, 2011). There are also plans for other major airlines to engage in partnerships with biofuel companies including Virgin Atlantic and Lanza Tech (Enviro.aero, 2012). However, notwithstanding these developments, aviation biofuel production is not yet commercialised (CCC, 2009; SWAFEA, 2011). Indeed, there are major economic, social and political issues which are acting to prevent the widespread commercialisation of aviation biofuel.

1.3. The research problem

The principal issues associated with the emergence, development and uptake of aviation biofuels are high costs of manufacturing the fuel and the limited supply of feedstocks for the production
process (SWAFEA, 2011). This is restricting investment in the field and so limiting development. There is also growing controversy surrounding the ‘real’ sustainability benefits of biofuels with critics alleging they lead to food price rises, land use change emissions and occupy land that could otherwise be used for food production. Other issues include concerns surrounding the provision and sustainability of government policy regarding the carbon accountability of the fuel’s environmental sustainability. However, despite these issues, there is a lack of academic peer reviewed research that investigates the issues and proposes long term recommendations for the future of biofuel within the commercial aviation sector. Hence there is need for this thesis.

1.4. **Research aim and objectives**

As chapter 2 details, owing to the new and dynamic nature of the technology, peer reviewed academic studies of aviation biofuel are limited and many have not kept pace with the physical and legislative developments in the field. This is despite the fact that the aviation industry is relying on aviation biofuels to reduce its dependency on oil and lower emissions. The issues which are constraining the development of aviation biofuels therefore urgently need to be identified. In light of this, the aim of this thesis is:

**To investigate the factors which affect the emergence, development and uptake of aviation biofuel.**

To address the aim there are five research objectives:

1. Situate the emergence, development and uptake of aviation biofuel within existing theoretical literature on technological change.
2. Identify the political, economic, social, technological, legal and environmental factors affecting the emergence, development and uptake of aviation biofuel.
3. Investigate the relative importance of these factors for the continued emergence, development and uptake of aviation biofuel.
4. Analyse the support measures currently available for the development of aviation biofuel.
5. Make recommendations for strategies that will support the development and uptake of aviation biofuel.
1.5. Thesis Structure:

This thesis is arranged into nine chapters:

**Chapter 1 Introduction**

This chapter establishes the context and nature of the research problem.

**Chapter 2 Theoretical underpinning**

Strategic niche management concept (SNM) is introduced and applied as a theoretical framework to enable the thesis to analyse the emergence, development and uptake of aviation biofuel. SNM theory provides useful insights into the development of new sustainable technologies which often need support in their early stages.

**Chapter 3 Literature review**

A literature review of the extant biofuel literature will help identify the factors that have influenced the development of the biofuels industry to date. The chapter will explore the issues that have faced the conventional biofuel industry before reviewing the studies that relate to aviation biofuels specifically. The chapter will identify the factors that have aided the development of aviation biofuels as well as the factors that have acted to constrain the commercialisation and/or on-going emergence, development and uptake.

**Chapter 4 Research design and method**

This chapter will introduce the methods that are used to answer the research aim. The principal methods used are a literature review, scoping study based on in-depth telephone interviews, web-based survey and a case-study based on a combination of semi-structured interviews and documentation.

**Chapter 5 Scoping study**

The findings from the literature review are used to frame the questions posed in an in-depth scoping study that investigates the stakeholder factors associated with aviation biofuels. This will act to confirm the issues which were identified in the literature review. The combination of the literature review findings and the scoping study will provide a more robust research direction for the thesis.

**Chapter 6 Investigate the issues associated with the emergence, development and uptake of aviation biofuel**
This chapter presents the findings and analysis of the global internet based survey of aviation biofuel stakeholders. The aim of the chapter is to analyse the relative importance of the key issues obtained from the literature review and scoping study (Objective 3).

**Chapter 7 Analysing strategies to support the development and uptake of aviation biofuel**

This chapter presents the findings from the in-depth interviews and case-study. This chapter builds upon the data from the chapter 6 by investigating the support measures available for the development and uptake of aviation biofuel (Objective 4).

**Chapter 8 Discussion**

This chapter draws together the findings and analysis from the four stages of data collection by comparing and contrasting the principal issues with the extant literature and the Strategic Niche Management (SNM) theory in order to provide new insights.

**Chapter 9 Conclusions and recommendations**

This chapter combines all the research findings to discuss key conclusions in relation to the thesis aim, objectives and research questions. It also proposes recommendations that may assist in the continued development and uptake of aviation biofuel.
Chapter 2

Theoretical Underpinning: The strategic niche management of emerging sustainable technologies

2.1. Introduction

Aviation biofuel is an emerging technology which, while having many potential advantages, is not yet commercially viable. There are a number of issues which are acting to constrain commercialisation and widespread uptake. These issues include the high costs associated with production, a lack of policy support in relation to road-based biofuels, a lack of feedstocks and issues associated with infrastructure and investment. Possible solutions to these issues are not currently available in the literature so a new approach is required. One sensible route of enquiry is to consider theoretical frameworks within the innovation literature. This is because aviation biofuel can be considered an innovation when compared to existing aviation fuels.

Innovation literature explores factors and mechanisms that influence the creation, development and diffusion of innovations. There is a great deal of information surrounding the drivers, constraints and diffusion of new technologies, as well as recommendations for influencing the diffusion of new innovations from the business and management literature. Within this body of work, a specific area of innovation theory may offer particularly useful insights into the emergence, development and uptake of aviation biofuels. The theory is called Strategic Niche Management (SNM). SNM is a theoretical framework that was developed to understand the formation and diffusion of sustainable technologies such as electric vehicles, bioenergy and wind turbines. The theory suggests that sustainable technologies, such as aviation biofuel, should be protected and managed inside ‘niche markets’ until they are commercially viable and able to enter a mass market environment. Due to the relevance of SNM, the theory will be used to guide the research and analysis underpinning this thesis. The proceeding sections will provide a background to the theory.

2.2. Theoretical background

SNM draws upon two main disciplines, evolutionary economics and constructionist technology assessment (CTA). Evolutionary economics attempts to explain why and how new technologies develop and become adopted by a market, whereas CTA looks at ways of managing the
development of a new technology. These theories were also considered as a theoretical framework for this thesis before being rejected in favour of SNM.

2.2.1. Evolutionary theories

Evolutionary economic theories suggest that innovations generally occur randomly and in an incremental manner. Evolutionary economics resulted from a combination of neo-classical economics and Darwinian concepts of biological evolution (Raven, 2005). The resultant theory describes the process of technological change in three stages: variation, selection and retention (Duysters, 1995). The first stage is variation. Variation is the physical process of innovation i.e. inventing new technologies or inventing variations of the existing technologies. Variations are assumed to occur randomly through a process of trial and error; this is likened to genetic mutation in Darwin’s theory of evolution. The next stage is selection. Selection is the process by which markets choose beneficial innovations and reject non-beneficial or detrimental innovations; this is similar to the Darwinian concept of ‘survival of the fittest’. The final stage is retention; retention is the mechanism by which successful innovations retain their market dominance despite the constant arrival of further random variations. Retention also helps to explain why some technologies dominate the market for long periods of time. The main mechanism of retention is caused by ‘routines’. These are described as established ways of doing things and established ways of using certain technologies. When these routines become established it is very difficult to break away from them. New innovations begin to cater for the established preferences of the dominant technology. The idea of retention led to Dosi’s (1982) concept of ‘technological trajectories’ which posited that established technologies strongly determine the trajectory of future innovations (Dosi, 1982).

Although evolutionary theories are useful when looking at the broad mechanisms of innovation, other scholars have subsequently described similar processes of retention and investigated the selection process more thoroughly. Instead of just looking at innovators and engineers, they analysed the entire selection environment. This added several additional dimensions to the process of innovation and diffusion including regulation, policy frameworks, laws, standards, infrastructure, scientific knowledge, skills, production technologies and institutional frameworks (Raven, 2005). This selection environment was then termed the ‘technological regime’ (Rip and Kemp, 1998). The technological regime further added to the evidence that radical innovations occur infrequently because they do not fit within the existing technology’s regime. Moreover, innovators are aware that radical innovations tend to fail, so tailor their innovations to fit within the regime. This translates into a general tendency for more incremental innovations in technologies rather than radical step changes (Levinthal, 1998). However, although the evolutionary theories describe the
process of innovation very well, they fail to explain the mechanisms for which radical innovations developed and diffused. This is despite the fact that it is essential that practitioners understand mechanisms so that they can design supporting measures to aid the commercialisation of an innovation. Subsequent attempts to explain the introduction and commercialisation of radical innovations changed the focus of research towards so called ‘niches’. Niche markets for new technologies were considered to be the bridge between research and development and the mass market uptake of the technology. These niches consequently formed the theoretical framework that eventually developed into SNM. Before SNM is described in detail however, the following section will explore the development of radical innovations within the context of evolutionary theories.

2.2.2. Radical innovations

Van den Belt and Rip (1987) attempted to explain the mechanism for the diffusion of radical innovations by using the concept of a ‘niche’. They described the niche as a protected environment in which the early stages of technological development can occur. The scholars advocated that such protection be given to certain technologies because of strong expectations that the technology will eventually be attractive to a market and, in time, potentially supersede the existing technology. Van de Belt and Rip used the example of the Stirling Engine which was largely developed by Philips in a protected R and D environment. The Stirling Engine was a much more efficient form of steam engine. At the time of its development there was no market demand for the more efficient Stirling Engine however, the expectation of wide-spread applicability in the future justified the support of its development. In other words, the addition of the ‘niche’ concept led to a better understanding of how some innovations are carefully planned and developed many years before a market exists for the application.

The other way a niche market could occur was theorised as being driven by changes in the actual technological regime or market for the innovation. It was suggested that small changes in market demands for particular products or materials or applications of technology could create market niches. These are described by Levinthal (1998) as unique application domains which cause innovators to create pockets of unique types of technologies that fulfil local market needs but not the wider technological regime. It is theorised that these unique application domains can expand and merge with one another, eventually becoming the dominant technology and superseding the existing technological regime. It will be shown later that SNM draws heavily on this concept.

Another body of literature combined concepts from evolutionary economics with insights from constructive science and technology studies to create a quasi-evolutionary perspective (Rip, 1995;
Schott, 1998). The quasi-evolutionary model of technical change described radical innovation as being partially controlled by ‘technology actors’ (see Levinthals, 1998). These actors create R and D programs and demonstration projects which involve the collaboration between producers, users, investors and policy makers. These projects were termed ‘technological niches’. Technological niches were described as innovations spaces that still need to be protected from the mass market. However, the R and D and demonstration stages are often as far as the technological niches develop because of failures in the way the niches are managed, or failure in transition from technological niche to mass market. SNM attempts to solve these issues by creating experimental spaces or ‘niches’ in which radical sustainable technologies can be nurtured before they develop into a mass market technology.

Although some core aspects of SNM have been introduced in previous sections, the management element of SNM was not developed from insights in evolutionary theories. The management aspect is drawn from lessons learnt in the constructive technology assessment (CTA) literature, as the next section will show.

2.2.3. Constructive Technology Assessment

Constructive technology assessment (CTA) was a development of the evolutionary theories already discussed (Raven, 2005). Rather than being a reflective analysis tool like evolutionary theories, CTA was developed to provide policy advice for managing the on-going and future development of innovations. CTA is just one element of a larger body of literature called Technology Assessment (TA). TA was mainly used to assess the potential impact of future technologies, particularly those that were controversial or deemed to be potentially harmful to society. Examples included nuclear power and DNA testing (Raven, 2005). TA was mainly used as an assessment for future impacts of technology whereas CTA was introduced to offer recommendations for guiding the innovation process itself (Raven, 2005). Although other methods for inducing innovation did exist, according to Rip, Misa and Schot (1995) they were not sufficiently specialised or comprehensive and therefore often unsuccessful. Common methods would include simulating R and D funding and using policy and regulatory measures such as environmental regulations. Raven (2005) calls these approaches ‘two-track approaches’. Two-track approaches do not capture the ‘social concerns’ about the environment in the management process. Raven (2005) explains that having only a two-track approach explains why some sustainable technologies such as GM crops are faced with environmental backlash from environmental groups despite the fact that the technology is heralded as offering benefits. The main reason for this is that not enough information about the benefits or
potential limitations of the technology is disseminated to wider public. These challenges led to the development of CTA.

CTA took a different approach. Unlike previous theoretical frameworks, it suggested that the support of technologies should be influenced by three issues: integration of actors, societal learning and reflexivity. Integration of actors involves the collaboration of four types of actor. These four are technology actors who invest in R and D programmes, societal actors that actually take up the technologies, regulating actors who design regulations and policy, and meta-actors who manage the interaction between the other three actors. Societal learning refers to a process of learning about how the technology fits within the existing technological regime and with all of the actors mentioned above i.e. what are the market demands for the technologies, how does regulation affect the technology, what level of social acceptance does the technology have and what are the public perceptions of the technology. Reflexivity is a somewhat ill-defined concept which refers to the ability of actor to consider the technological design and social design as one process (Schot and Rip, 1996).

The previous sections have shown that the theoretical roots of SNM can be traced to evolutionary economic theories and constructivist technology assessment. However, before discussing SNM in greater detail, it may be useful to discuss other complementary theories. During the identification of an appropriate theory for this thesis, two other theories were considered: namely technology readiness levels theory (TRL) and diffusion theory. These theories offer useful insights into the emergence, development and uptake of aviation biofuel, though they are limited by their inability to provide robust recommendations for supporting the emergence, development and uptake. Nonetheless, it is beneficial to offer limited discussion of TRLs and diffusion theory here.

2.2.4. Technology Readiness Levels

TRL is a measurement system for assessing the level of development of new technologies. It was developed by the National Aeronautics and Space Administration (NASA) as an approach to assess the development of space technologies often spanning several engineering departments (Mankins, 1995; 2002). Engineering projects were difficult to manage and communication surrounding the development of those projects was subsequently unclear. TRL incorporates nine levels of technological maturity which are described as ‘technology readiness levels’. The levels were originally drawn up to describe the development of a testing program i.e. the stages ranged from basic research (TRL1) to the proven flight testing of the technology (TRL9). These are summarised in figure 2.1
Figure 2.1. Technology Readiness Level definitions and explanations

<table>
<thead>
<tr>
<th>Readiness Level</th>
<th>Definition</th>
<th>Explanation</th>
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<tbody>
<tr>
<td><strong>TRL 1</strong></td>
<td>Basic principles observed and reported</td>
<td>Lowest level of technology readiness. Scientific research begins to be translated into applied research and development.</td>
</tr>
<tr>
<td><strong>TRL 2</strong></td>
<td>Technology concept and/or application formulated</td>
<td>Once basic principles are observed, practical applications can be invented and R&amp;D started. Applications are speculative and may be unproven.</td>
</tr>
<tr>
<td><strong>TRL 3</strong></td>
<td>Analytical and experimental critical function and/or characteristic proof-of-concept</td>
<td>Active research and development is initiated, including analytical / laboratory studies to validate predictions regarding the technology.</td>
</tr>
<tr>
<td><strong>TRL 4</strong></td>
<td>Component and/or breadboard validation in laboratory environment</td>
<td>Basic technological components are integrated to establish that they will work together.</td>
</tr>
<tr>
<td><strong>TRL 5</strong></td>
<td>Component and/or breadboard validation in relevant environment</td>
<td>The basic technological components are integrated with reasonably realistic supporting elements so it can be tested in a simulated environment.</td>
</tr>
<tr>
<td><strong>TRL 6</strong></td>
<td>System/subsystem model or prototype demonstration in a relevant environment (ground or space)</td>
<td>A representative model or prototype system is tested in a relevant environment.</td>
</tr>
<tr>
<td><strong>TRL 7</strong></td>
<td>System prototype demonstration in a space environment</td>
<td>A prototype system that is near, or at, the planned operational system.</td>
</tr>
<tr>
<td><strong>TRL 8</strong></td>
<td>Actual system completed and “flight qualified” through test and demonstration (ground or space)</td>
<td>In an actual system, the technology has been proven to work in its final form and under expected conditions.</td>
</tr>
<tr>
<td><strong>TRL 9</strong></td>
<td>Actual system “flight proven” through successful mission operations</td>
<td>The system incorporating the new technology in its final form has been used under actual mission conditions. (See Paragraph 4.2.10)</td>
</tr>
</tbody>
</table>

Source: TEC-SHS (2008)

The TRL levels were used as a systematic and consistent benchmark by which comparisons with other technologies could be made. However, although TRLs were very useful as an industry tool for assessing the progress of research projects, according to Dowling and Pardoe (2005), TRLs did not provide a detailed enough picture of the constraints or difficulties of integration into what they called an ‘operational system’. In other words, the TRL theory did not adequately assess the ability for the technology to successfully merge into a commercial market place. This is because TRLs are principally interested in the research and development stages of the technology and not necessarily the uptake and diffusion of the technology into a market. Cundiff (2003) also found that TRL does not provide any form of unique recommendations or strategies to support the development of the technology; rather it acts as a survey tool. Due to these deficiencies, scholars such as Sauser et al., (2006) offered a new perspective by looking at a system readiness level (SRL). The authors proposed
that a more complex set of interdependent issues affected a technology. The observations were identified from earlier work carried out by the U.S. Department of Defence (DoD) assessing the technological readiness of manufacturing industries. This new model incorporated issues specific to manufacturing such as ‘producibility’, depreciation and time. The new model was called manufacturing readiness levels (MRL) (Sauser et al., 2006). Other TRL developments included the addition of systems integration. This looked at the way the technology integrated into a system of other technologies. The integration of TRL was first used by the UK Ministry of Defence (MOD) (Sauser et al., 2006). TRLs were used to assess the on-going development of many new technologies (Sauser et al., 2006) however; it was known that the model was somewhat rudimentary. It did not, for example, fully understand how and why a technology would actually integrate and diffuse into a market. It also failed to understand how the technology interacted with other technologies within a market and how this would affect the development. Due to these limitations, Gove et al., (2007) proposed that TRL be combined with the newly developed integration readiness level measurement (IRL). This provided a metric to determine the ability for a technology to integrate into a system of complementary technologies, for instance in the development of computer components.

TRL is effective at assessing the research and development of technologies, as well as the integration of a technology with complementary technologies. However, TRL does not offer comprehensive insights into strategies and recommendations for supporting the emergence, development and uptake of innovations in a commercial market environment. Given these limitations, TRL may not be suitable as a main theoretical underpinning for this thesis, though certain aspects of the theory such as recommendations to streamline communication across several R&D departments will certainly be considered.

The other theoretical underpinning considered for this thesis was diffusion theory. Unlike TRL, diffusion theory focuses on how innovations are adopted, communicated and spread through social systems (i.e. markets) over time (Rogers, 1995). Diffusion theory differs from TRL in the respect that it is not chiefly focused on the research and development stages of the technology but rather its diffusion within an existing market. The next section will discuss diffusion theory in more detail. It will be shown that diffusion theory can in many ways be used to complement TRL theory because it focuses on the integration of the technology.
2.2.5. Diffusion theory

Diffusion theory is the study of how innovations are adopted, communicated and spread through social systems over time (Rogers, 1995). The social system is the space in which diffusion research is undertaken; it is defined as the space in which all of the potential adopters of the innovation reside. A social system could be a specific commercial market, a particular geographical location or perhaps a single industry (Rogers, 1995). Diffusion research is a tool which can be used to measure how fast and how likely innovations will be adopted and diffused in the future, based upon models of innovation uptake derived from empirical studies of past innovations. Diffusion theory may be of particular value where it is necessary to control the adoption of an innovation. Indeed, there are many situations where it is imperative to control or monitor the diffusion rate of an innovation. An example of this can be seen in developing regions of the world where vaccines and water sanitation are actively supported, though often fail to be adopted (Wellin, 1955). In addition, diffusion theory is relevant to situations where the adoption rate must be curtailed; for instance in the spread of recreational drugs and disease (Rogers, 1995).

Innovations are adopted by individuals and groups within a social system based on three things; (1) the characteristics of the innovation (2) the nature of the social system and (3) the characteristics of the person that is making the decision to adopt the technology. The fact that the social system has a major influence on the diffusion process illustrates that diffusion is a highly social phenomenon, involving communication between members of the social system on many levels. It is also a reason why the diffusion of innovations is an unpredictable and complex process. Empirical studies from many fields of research have been brought together in an attempt to model the generalised behaviour of society towards innovations. The theory suggests that innovations tend to be adopted over time following an s-shaped curve (Figure 2.2).
The model theorises that the adopters can be grouped according to the speed of adoption. Innovators and early adopters are those which are the ‘key innovators’ and those which champion the technology – these are also referred to as change agents because they often encourage the spread of the technology (Rogers, 1995). The next stage of adoption is called the early majority adopters. At this stage the innovation has spread to around 50% of market share. When 50% market share is reached the so called ‘late majority’ and ‘laggards’ adopt the product. The final stage is saturation of the market.

Diffusion theory also examines the issues affecting diffusion. Diffusion theory tends to focuses on social norms, communication and other social phenomenon in much of its work. The theory has however developed into a number of perspectives, each following their own models of social behaviour. These include the work by Everett Rogers on the ‘Diffusion of Innovations’ (Rogers, 1969); ‘technological change’ theories in economic history (Rosenberg, 1972), the ‘Bass forecasting model’ in marketing (Bass, 1969) and the ‘mathematical theory of communication’ in communication studies (Shannon and Weaver, 1949). Each of these theories attempt to model the processes of how innovations and new ideas are diffused through societies and cultures, they each draw heavily on core principles of diffusion. However, the work on the ‘diffusion of innovations’ by Rogers (1969; 1995) is considered the seminal work in the field. Indeed, his theoretical framework underpins much of the modern work on diffusion research (Perera et al., 2003; Cheng et al., 2007; Hubbard, 2007).
Despite the apparent benefits of diffusion theory, the model is somewhat limited in its ability to offer comprehensive policy recommendations and/or strategies to support the emergence, development and uptake of future innovations. Indeed, this is mentioned as a limitation by Rogers (1995). Due to the fact that this thesis requires robust recommendations to be made regarding the future of aviation biofuels within the commercial aviation industry; diffusion theory may not be perfectly suited as a theoretical underpinning for this thesis. However, core concepts from diffusion theory, such as the S-shaped diffusion curve and the role of changes agents for the diffusion of a technology, are clearly relevant.

Thus far the theoretical roots of SNM have been laid out, and TRL and diffusion theory have been discussed. It was shown that although diffusion theory and TRL offer useful insights, their limitations suggest that SNM may offer more specialised recommendations with respect to the emergence, development and uptake of aviation biofuels. The remaining sections of this chapter will now discuss SNM in detail. It will explain the core SNM concepts and offer a step-by-step review of the process of forming an experimental project. It will be shown that the development and nurturing of an experiment has been the main focus of the SNM literature. The final section will show that although many useful insights will be taken from the SNM literature, limitations to its use still exist.

2.3. Strategic Niche Management

Strategic Niche Management (SNM) is a theory that aims to support the development and diffusion of sustainable technologies through the use of nurtured demonstration spaces (Hommels et al., 2007). Emerging sustainable technologies may fail to develop due to barriers such as high cost, lack of investment, lack of demand, and policy failure (Weber et al., 1999). SNM attempts to support such technologies by creating protected experimental spaces where these barriers are temporarily removed. It is believed that within these spaces producers, users and policy makers will gain valuable experience with the new technology; leading to cost reductions, efficiency gains and eventually the development of a self-supported market. More specifically, SNM involves the creation, development and controlled removal (i.e. gradually removing financial incentives) of experimental projects that foster the ‘co-evolution of technology, user practices and regularity structures’ (Schot and Geels, 2008 p. 537).

SNM is a relatively new framework which was developed as a result of research conducted in the Universities of Eindhoven, Twente and Maastricht in the 1990’s (Hommels et al., 2008). It was first introduced as a measure to analyse, support and make recommendations about the development and uptake of sustainable technologies. The theory posits that sustainable technologies encounter a
unique set of barriers during their development because they are often radically different from the incumbent technologies. SNM theory was formulated as previous innovation literature had failed to adequately understand the barriers and processes involved in the development and diffusion of radical sustainable technologies. To date, SMN theory has been used to analyse technologies including: biomass (Raven, 2005), biofuels (Raven, 2005), wind turbines (Kempt et al., 2001) and electric vehicles (Truffer, 2002). It can be used either as an reflective conceptual framework for case-study analysis (Raven, 2005; Hoogma, 2000) or as a forward looking management tool for on-going or future innovations (Weber et al., 1999; Kemp et al., 1998; Hoogma et al., 2002). The critical aim of SNM is to assist in the transition towards sustainable development through the support of new technologies (Weber et al., 1999).

Owing to its reverence to the current topic, SNM will be used as a theoretical framework for this thesis. As the terminology and concepts used within SNM is complex, it is essential that the developmental background of SNM is reviewed first before its implications for the conduct of the present research are discussed.

As described, SNM seeks to support the development of sustainable technologies through the creation and management of experiential spaces or ‘niches’. Within these experimental niches stakeholders co-operate and learn about the production and use of the technology and help to reduce costs, increase efficiency and facilitate commercialisation (i.e. similar to the concepts which were introduced by evolutionary theories, parallels can also be drawn between SNM and diffusion theory in the respect that both regard communication as crucial). However, SNM aims to encourage the formation of these experimental projects and manage the stakeholder interactions to maximise the amount of learning that takes place within them (Raven, 2005; Weber et al., 1999).

SNM can be used in two ways; either retrospectively for analysing past innovations or as a policy tool for influencing the development of new innovations. Both require different approaches. Retrospective uses of SNM have mainly involved analysis of case studies such as exploring the development process of sustainable technologies including biomass (Raven, 2005), electric vehicles (Hoogma, 2002) and wind turbines (Kemp et al., 2001). SNM as a policy and management tool uses knowledge of past innovations to make recommendations (Hoogma, 1998; Weber et al., 1999; Hoogma et al., 2002). Central to both however is the formation and development of experimental projects which eventually expand into a ‘technological niche’. According to Raven (2005) experiments are an important factor in the formation of a technological niche because the experiments encourage the interaction of stakeholders and policymakers within the existing technological regime.
Considering the research topic of this thesis a technology which has yet to progress past the experimental and demonstration phases, the following sections of this chapter will describe the recommendations from SNM for managing the development and expansion of experimental projects. This information can be used to analyse the on-going progress of aviation biofuel developments as well as to make recommendations for future emergence, development and uptake.

2.3.1. **SNM as a policy and management tool**

SNM can be used as a policy and management tool to foster the development of a sustainable technology. The process involves creating an experiment which forms into a technological niche and then into a self-supported market. However, central to the idea of managing the development of a technology is the formation of experimental spaces that involve producers, users and governments. These experiments are the first step towards supporting a technology using SNM. According to SNM theory, the evolution of an experiment can be controlled by applying certain measures to each stage of formation.

2.3.2. **Experiment formation, organisation and management**

Within the SNM framework, experiments undergo five stages of formation. The five stages are:

- Identifying a new technology or concept
- Designing an experiment
- Implementing the experiment
- Expanding an experiment into a niche
- Reviewing the protection of the niche

(Weber et al., 1999).

The stages are technically sequential, though the management of the experiment will be enhanced if all the stages of the experiment are taken into account from the outset. SNM theory makes recommendations about each of these stages. The first stage is identifying a new technology.

2.3.3. **Identifying a new technology**

According to SNM scholars, identifying a new technology is the starting point of any experiment (Weber et al., 1999; Raven, 2005; Kemp et al., 1998). The process starts with identifying problems that need to be solved within the existing technological regime, an example might be local air pollution. When a problem has been identified, a series of objectives for solving the problem must be investigated and analysed (Weber et al., 1999). An important recommendation at this point is to
set ‘realistic’ objectives for overcoming the problem that are not too challenging. Overly challenging objectives might unduly hinder the developmental stage of the experiment. Furthermore, most emerging sustainable technologies tend to be relatively crude because they have not had the advantage of experience. If the objectives are too challenging certain promising technologies may be overlooked (Weber et al., 1999).

After an objective has been decided upon, a series of technologies can then be assessed. The technologies must be assessed in terms of their ability to meet the objective as well as their compatibility with the existing technological regime. According to Weber et al. (1999) the ideal technology should fit closely within the existing technological regime but offer the future potential to lead to further (more radical) innovations. The technology should be assessed in terms of its compatibility with existing infrastructure, social norms and policy frameworks. Drivers and constraints associated with using a particular technology can be assessed and objectives can be altered to fit within the new regime. However, the technology should not be too close to the existing regime, instead, a balance must be made between evolution and revolution (Weber et al., 1999).

One of the main issues in selecting a technology is whether to choose a single technology or a variety of technologies. Picking a single technology allows for complete focus to be given to the development of the experiment and the management of the stakeholders that are involved. However, it can also lead to what SNM scholars call a ‘lock-in’ to a particular ‘path dependency’. Picking a single technology may make it harder to adjust to changing regimes and changing market conditions in the future, ultimately leading to failures in the experiments and unsuccessful development of the technology (Weber et al., 1999). A more robust option which is recommended in the SNM literature is to support a range of technologies. Although this creates more management issues, the issues can be resolved by phasing the launch of different demonstration projects (Weber et al., 1999).

A further issue to consider is that certain pioneering individuals may attempt to create their own experimental projects regardless of the selection factors mentioned above. These pioneers are called ‘change agents’ (Kemp et al., 1998) or ‘technological actors’ (Weber et al., 1999). Pioneering individuals may see the potential benefits of a technology before anyone else does, or indeed before a problem exists. Change agents and technological actors have thus been shown to be important for the formation of several experiments such as the development of the Stirling Engine, biomass co-firing (Raven, 2005), and even the innovation of policy (Ieromonachou et al., 2004).
When the technology is selected, either by the SNM manager or a change agent, the next stage is to design of the experimental projects.

2.3.4. Experimental design

When a ‘promising’ technology has been chosen, the project can begin to be designed. This stage is important for the future development of the niche because it involves finding a network of interested/supportive stakeholders, allocating roles amongst the stakeholders, identifying the various supportive measures for the project and establishing a long-term vision for the development of the technological niche.

In terms of finding stakeholders, SNM scholars such as Weber et al., (1999) acknowledge that it is important to build a large network of stakeholders in order to have a wide range of expertise, though having a network that is too large may hinder decision making because the network size becomes unmanageable. Weber et al., (1999) states that networks must contain all relevant stakeholders including producers, users and policy makers; but the total number of stakeholders should be limited to a manageable number in each specific project. A project with a small number of committed stakeholders will be more effective than a large array of stakeholders. This was observed by Ieromonachou et al., (2004) in UK traffic schemes in which the small size and scope of a project made it easy to introduce. According to Popper (2002), the project should ideally be as simple as possible and follow the principles of Keep it Simple Stupid (KISS). Conversely, however, if the experiment is too small and dominated by one of two stakeholders this can actually hinder the project (Weber et al., 1999). In Sweden, an experiment using truck-to-rail transport modes failed because a single large company managed the project and did not communicate efficiently with the rest of the stakeholders. They also failed to learn about the technology from a previous project (Weber et al., 1999).

It is also very important to build a relationship between the user and producer at an early stage. Creating the initial signals of demand for a technology from the user is a significant push for development of the experiment (Kemp et al., 2001; Weber et al., 1999). SNM literature is limited in the respect that there is little guidance for selecting stakeholders for the project. The literature offers some (albeit ill-defined) examples of selecting stakeholders based on past knowledge of a technology but no comprehensive selection criteria.

The next section describes the role of protection measures in the development of an experiment. Government support and policy measures are very important for the formation and success of a niche within SNM.
2.3.5. Protection measures

Experimental projects are protected from the commercial market in order to prevent market forces hindering learning and experience processes. The overall aim of the protection is to allow few financial transactions to be made to the open market (Weber et al., 1999). This usually means creating financial measures to support the experiment such as grant funding. Funding can come from private firms or governments, or a mixture of the two. The initial experiment is normally protected from the mass market using other measures as well, such as regulation. The measures will however be different according to the technology, the location, the type of users, the existing market and the exiting policy frameworks and regulations. These factors must be considered when designing the protection measure for the technology. A further level of protection is also provided in the form of gaining shared visions about the technology and marketing the benefits and feasibility of the technology to a wider audience. This creates artificial protection in the form of confidence, demand and interest in the technology.

A recommendation from SNM theory is to strike a balance between supporting the technology and exposing it to normal market interactions. If protection is too high the technology may fail to get out of the demonstration stage because it cannot support itself. However, if the protection is too low then the technology will not develop and the niche will never be formed. Weber et al., (1999) suggests that the minimum level of protection possible should be used. A way to do this is to first understand the market in which the technology will be entering and discover how aspects of the existing market could be slowly introduced to the demonstration project in order to help it learn about market pressures.

The next aspect of the design phase is ‘user involvement’. This refers to gaining involvement from different types of stakeholders at different stages of the project. It will be shown that certain stakeholders are more useful to engage at the start of the experiment, while other types of stakeholder are more useful to engage as the project develops.

2.3.6. User involvement

Involving different stakeholders in the experiment at different stages is very important according to the SNM scholars. Certain stakeholders should be introduced in a staggered fashion, while other types of stakeholders should be discouraged from entering the experiment. The core stakeholders should obviously be the producers, users and policy makers (Raven, 2005; Weber et al., 1999; Kemp et al., 1998). However, having clear communication channels between different stakeholders at different stages of the experiment is vital. In the early stages of the niche, it is useful to have
‘pioneer’ stakeholders in the projects including so called ‘change agents or ‘technological actors’. These actors are very good at communicating a technology’s benefits in the early stages of the experiment and these should be encouraged to be part of experiments. Pioneer stakeholders are also much more willing to accept negative issues associated with the technology and they are more proactive in supporting the technologies in the early stages. After this, the wider community of potential customers should be included into the experiment. These types of stakeholder will eventually take-up the technology. Potential customers for the technology can offer advice about customer requirements of the future mass market. Finally, issues can occur if experiments are dominated by so called ‘insiders’. An experiment that is dominated by a single firm can fail. Insiders are firms that have an active interest in the existing dominant technological regime; thus they may attempt to slow down the experiments or stop them altogether to protect their core business (Hoogma et al., 2002).

Another factor regarding user involvement is to make sure that the stakeholders are supplied with robust information about the project’s objectives. This is to ensure that stakeholder expectations are well aligned. Different stakeholders may have different interpretations of the technology or different opinions about the future potential of the technology. Disagreements between stakeholders can harm an experiment’s development. It is thus beneficial if the stakeholder network is very well connected and active in communication. This may involve regular data sharing between research projects of tests and regular communication of key developments where commercial realities permit.

Thus far, the planning and design of an experimental project has been discussed in relation to the SNM. There has been little discussion of how these theories can be put into practice i.e. the implementation phase of an experiment. The next section will discuss the implementation of an experimental project. The implementation phase arguably represents the most difficult stage because it involves the co-evolution of technology, producers, users and policies.

2.3.7. Implementation

The implementation of an experimental project is the stage when the experiment is initiated. It is where technical constraints are identified and where solutions are devised and enacted by individual stakeholders. Caniëls and Romijn, (2008) postulate that the implementation of an experiment is the learning process. Indeed, as expressed throughout this chapter, one of the main aims of an experimental project is to encourage learning surrounding the technology. According to SNM, there are seven core areas of learning that take place in an experiment (Table 2.1).
Table 2.1 Core areas of stakeholder learning

<table>
<thead>
<tr>
<th>Area of learning</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Design of experiment</td>
<td>Stakeholders learn about design faults and how they be overcome</td>
</tr>
<tr>
<td>2. Government policy</td>
<td>Stakeholders learn what sort of government policy and legislation is necessary to stimulate the development of the technology</td>
</tr>
<tr>
<td>3. Cultural and psychological meaning</td>
<td>Stakeholders learn about the ethics of the technology and how it fits within the environmental concerns of society</td>
</tr>
<tr>
<td>4. Market demands</td>
<td>Stakeholders learn about the potential customers for the technology and their requirements</td>
</tr>
<tr>
<td>5. Characteristics of the production network</td>
<td>Stakeholders learn about the production and supply chain involved in producing the technology</td>
</tr>
<tr>
<td>6. Characteristics of infrastructure and maintenance network</td>
<td>Stakeholders establish what level of infrastructure is required and how this will be developed if needed</td>
</tr>
<tr>
<td>7. Nature of societal and environmental effects</td>
<td>Stakeholders determine whether the technology has any unintended effects on society and the environment</td>
</tr>
</tbody>
</table>


Recommendations relating to each area of learning are offered by most SNM scholars. The principle recommendations are to encourage learning through the use of networks of stakeholders (Kemp et al., 2001). The objective here is to encourage high-quality learning in each of the seven areas listed in Table 2.1. In other words, a broad array of learning is required. There are cases in which experiments have focused too much on technical aspects of the technology resulting in learning of societal and market demand factors being neglected. This occurred in an electric vehicle initiative case study which failed (see Hoogma et al. 2002). The recommendation is that market demands and societal needs should not be neglected as they are important in the transitional phases from experiments to technical niche and to market niche.

Another specific recommendation is for the stakeholders to be aware of the other similar trials and technologies and learn about their own experiment as a result. If the experiment can offer recommendations to other technologies and experiments, even if their own experiment fails; this is considered to be a positive learning outcome according to SNM scholars. Truffer et al. (2002) stated that a good experiment will lead to a broad range of lessons that can be applied over a number of technologies. Lessons should also be transferred between experiments in different regions by setting up better networking media or groups for stakeholders to communicate. Raven (2005) found that concurrent experiments in different locations improved the chances of success for biomass electricity generation in Europe.
Thus far this chapter has introduced SNM theory, explained the formation of an experiment and described the implementation of an experiment. The next section will explain how experimental projects form into technological niches and then into a self-supported market niche.

2.4. Transition from experiment to a technological niche

The transition from an experimental project to a technological niche either involves the scaling up of a single project or the replication and amalgamation of several projects in different locations. This is done at the end of the first projects life-cycle i.e. when a project has successfully met its objectives. Niches in SNM theory are defined as specific domains in which technologies are produced, used, tested and improved upon by an alliance of stakeholders; thus very similar to an experiment (Weber et al., 1999). There are two main types of niche: ‘technological niches’ and ‘market niches’, the former is the first stage of niche formation. A ‘technological niche’ is a niche that is not economically viable and thus still requires protection from the commercial market. A ‘market niche’ is slightly more developed and does not require government support, though the technology is not widely taken up by the market yet. As mentioned, the transition between experiment and a technological niche can occur in two ways. The first route to be reviewed is scaling up of a single project.

2.4.1. Scaling up

According to Weber et al., (1999), one way to scale up a single experiment is through good communication of the project’s successes and achievements. This will help to expand interest in the network; find new stakeholders; identify new users of the technology and new producers of similar technologies. During this time however changes to the network of stakeholders may occur. This is because the experiment may have become a more professional venture and more orientated towards profit and real world business working. The addition of a larger or experienced stakeholder may encourage the expansion of a single experiment (Weber et al., 1999). This occurred in a Swiss car-sharing initiative; where a previously bottom-up government led initiative evolved into a professionally run network because of the entrance of a few large firms. Another example illustrated that the entrance of large private firms can create an ‘impulse’ of extra momentum for the project which is very positive. A classic example of this is the development of the Smart Car. The Smart Car was originally introduced by Volkswagen as an experimental project, with minor success. It was not until Daimler-Benz became involved in the project that the Smart Car gained enough momentum to progress into a niche market. The Smart Car eventually turned into a successful commercial venture (Weber et al., 1999).
The other way to expand an experimental project into a niche is to replicate the first project in different locations and then amalgamate the schemes together.

2.4.2. Replication

Replicating experiments in other locations is a possible way of expanding experiments into a technological niche. However, the objective is not simply to replicate the first project. Instead, the main goal is to take lessons learnt from the original project and apply them to successive projects. The emphasis moreover is on retaining the experience from the original project and to transfer these to other experiments, building on the experience every time (Raven, 2005; Weber et al., 1999). Failure to do this can lead to time wasting because each project has to solve the same problems. There have been examples of where this has happened, ultimately leading to an unsuccessful development of an experiment. In Sweden, an initiative to use a road to rail ‘Rolling Highway’ failed because of a lack of information transfer between similar experiments that had already occurred in another part of Sweden (Weber et al., 1999).

Raven (2005) found that the successful formation of a niche was more likely if experiments were replicated in parallel to one another i.e. at the same time rather than sequentially. Raven stated that this was positive for the development of a market niche due to three reasons. First, parallel experiments increase the overall market share of the technology in the mass market. Secondly, parallel experiments, as mentioned above enable faster learning because problems with one experiment can be communicated instantly to others. Third, experiments will usually differ slightly from case to case; this offers more flexibility to changes in market demands or policy frameworks. Raven (2005) showed this in the case of using biomass co-firing in power stations. Co-firing was an older niche which was reinvented when the technological regime changed to favour the older technology.

Raven (2005) also showed that successful transition from experiments to market niche was characterised by continuity. Raven showed that the success of biomass niche development was increased if the development of experiments occurred smoothly and continuously, as opposed to disjointedly with long gaps between experiments. Raven states that the smooth development of experiments is needed to ensure that experience and knowledge with using the technology is not lost.

When the transition to a niche is actually made, the management changes from what was used for the experimental project. The support policies and protection measures need to be changed in order to facilitate more connection with the existing technological regime and the market (Kemp et al.,
The experiments will not form into a self-supporting niche market unless the specific protection measures are removed or changed in some way. The niche must also align more closely with local economic, political and social contexts. One option to do this is to use economic incentives such as tax breaks and subsidies, or a change to the legal system associated with the technology in order to favour the use of the technology (Weber et al., 1999). Raven (2005) showed that the transition from experiment to market niche was aided in large part by policy changes however, the changes in policy were unpredictable and in some cases the experimental stages moved from unsupported market niches back to supported niches. However, Raven (2005) also found that the transition from experiment to market niche was not always a linear process.

Other options to encourage the niche formation are to discourage the use of the existing technologies through education and information sharing about the benefits of the new technology. The overall objective however is to slowly discourage the use of the existing technologies and to shift attention towards the new technology. The German Bikeabout initiative project, for example, was accomplished by using a set of complementary polices that encouraged citizens to use bicycles and discouraged the use of the car (Weber et al., 1999).

Other mechanisms that help the transition of the niche include the scaling up of policy makers from local to national and international level. National and international policy makers have the advantage of being able to communicate with a wider audience and facilitate the connection of geographically disparate demonstration projects. A careful consideration during the transition from experimental project into the wider market is that of ‘overoptimistic estimations’ about the technology. It has been shown that when a technology is in a demonstration phase, the stakeholders in the field can be too optimistic about the strength of the technology. The application in a real market might be very different.

A final conceptualisation was offered by Geels and Raven (2006) in which experiments and niches at a local level can combine to form global niches. It is theorised that this sort of niche requires a multi-level analysis incorporating outside factors such as the technological regime. The multilevel concept essentially shows that the shift of an entire technological regime is not always created by a linear process starting with an experiment. Niches develop into the dominant technology by co-evolving and adapting to the existing regime (Shove and Walker, 2007). The addition of the multi-level perspective allowed scholars to explain that emerging technologies are not necessarily alternatives to the incumbent; they can literally influence the technological regime from within.
Assuming that the experiment is developing successfully and it has made the transition towards a technological niche, or even a market niche. The final step is to review the protection measure offered to the technology. However, finding the right balance between removing all the protection measures and over protecting, as mentioned earlier, is difficult. The next section will review this final stage of the experimental process.

2.5. Reviewing the protection measures

As previously described, experiments may be protected by a variety of measures in their early stages because of barriers such as high cost, lack of investment and policy failure. When the experiments develop and merge with other experiments, costs may reduce which make the technologies economically viable or comparative with the existing technologies. If this happens, the protection measures must be reviewed and changed in order to facilitate the successful transition from experiment to self-supported market niche. The same can be said for experiments that are not showing promising results. If the experiment shows little potential the protection measures should be removed altogether (Weber et al. 1999).

Weber et al. (1999) suggest external evaluation by ‘outside experts’ to determine success of the experiment. This will provide an unbiased view of the project. Weber et al., recommends a ‘phase out’ approach to removing incentives i.e. a gradual removal of measures in order to help the stakeholders within the experiment adapt.

2.6. Relevance of SNM for aviation biofuels

SNM is a useful theory through which to analyse the emergence, development and uptake of aviation biofuels. Indeed, with the context of aviation biofuels, experimental projects such as those mentioned in the SNM literature are already being established. Aviation biofuel trials have been undertaken in several continents with close collaboration between otherwise disparate stakeholders (i.e. biofuel producers, farmers and airlines). There is also some evidence that the trials are being nurtured to some degree. Airlines are willing to support the experiments by paying a premium for the fuels in order to learn about the characteristics of aviation biofuel and the challenges associated with supply chain development. Furthermore, there are aviation biofuel initiatives which have been set up including CAAFI and SAFUG which seek to encourage stakeholder co-operation and the continued trialling of aviation biofuels. These examples are remarkably similar to the principles observed within the SNM theory. However, there are still major hurdles which need to be overcome. For example, with the exception of Lufthansa, there have been no long-term trials of aviation
biofuels which have attempted to establish supply chain improvement and there has been very little in the way of emergence, development and uptake of aviation biofuels. Due to these deficiencies, this thesis will employ concepts from SNM to analyse the current developments in the aviation biofuels field and make recommendations for the efficient transition from experimental projects into technological niches and eventually a self-supported market niche.

2.7. Summary

This chapter has described the theoretical background of SNM and reviewed the stages involved in the formation of an experimental project and niche. SNM offers a useful way to analyse the development of radical sustainable innovations (in this case aviation biofuels) both retrospectively and as a policy tool for the future. A considerable number of recommendations are made in the literature regarding the development of future technologies. Central to these recommendations are the formation of experimental projects that are protected from the mass market. This creates an environment that is conducive for the engagement and interaction of relevant stakeholders and more importantly, the learning processes. The learning process is heralded as the catalyst for the development process of a technology according to SNM. Although the theory offers many benefits for technology studies, limitations can be observed. Some recommendations are somewhat vague and unquantifiable. An example is measuring the closeness of a technology to the technological regime. There does not appear to be any clear quantifiable measures for closeness to the technological regime; or indeed agreement as to which measures constitute closeness to the existing infrastructure, social norms and policy frameworks. This is an area where SNM could be improved. Other limitations are seen in the way that stakeholders are classified and selected for an experiment. There are no robust criteria for choosing and classifying stakeholders for a project. However, despite these limitations, the theory offers several useful insights that can be used in this thesis. The next chapter will explore the literature related to biofuels. The chapter will start by establishing the factors affecting the emergence, development and uptake of conventional biofuels, before then identifying the factors affecting aviation biofuel. The final section of the literature review will attempt to outline the theoretical model used to make recommendations for the emergence, development and uptake of aviation biofuels. The model will draw upon SNM theory discussed in chapter 2, as well as the factors affecting the emergence, development and uptake of aviation biofuels.
Chapter 3

Literature review: factors affecting the emergence, development and uptake of aviation biofuels.

3.1. Introduction

Developments within the field of aviation biofuel have occurred very quickly. Within the space of 10 years, the fuels have developed from basic testing to full certification for commercial use. As a consequence, issues associated with the emergence, development and uptake of aviation biofuels are unclear. Furthermore, there are very few peer reviewed academic studies dealing with aviation biofuel and this is potentially hampering knowledge within the sector. In order to appreciate the scope of the existing work surrounding aviation biofuel a detailed review of the literature will be carried out. The aim of this chapter is to establish the factors that affect the emergence, development and uptake of aviation biofuels and to identify the research gap which will be central to this thesis.

The chapter will begin by introducing the different types of biofuels that are currently available; including conventional biofuels, traditional bioenergy and more recent fuels. This is followed by an examination of the factors that have influenced the emergence, development and uptake of biofuels for the road transport sector. The factors are analysed following the Political, Economic, Social, Technological, Legal and Environmental (PESTLE) framework. After this, a detailed review of the extant literature on aviation biofuels will be conducted. Both peer-reviewed academic sources and official ‘grey’ (i.e. non peer-reviewed) literature will be consulted.

3.2. Biofuels

The term biofuel refers to any form of renewable energy that is derived from biomass (i.e. biological material). There are two basic forms of biofuel; primary biofuel and secondary biofuel. Primary biofuels are the most basic form of bioenergy and require no additional processing; these fuels include fire wood, wood chippings and agricultural waste. Primary biofuels are mainly used for domestic heating applications and electricity production. Primary biofuels are the main energy source for many developing countries of the world and represent by far the largest share of bioenergy globally (Naik et al., 2010). It is calculated that primary biofuels account for 80% of the
total bioenergy mix and around 8% of global energy demands and that firewood represents the biggest share of the total (Figure 3.1).

**Figure 3.1.** Share of the biomass sources in the primary bioenergy mix

![Pie chart showing the share of the biomass sources in the primary bioenergy mix.](image)

Source: IEA, (2009)

In contrast, secondary biofuels are made from biomass that has undergone some form of processing to change the chemical composition of the original material. This includes fermentation of sugar crops to make ethanol, pressing oil rich crops to produce vegetable oil and superheating biomass to produce combustible gases. The processing can also include mixing different types of liquid or gaseous biofuels together.

The ability to process biomass creates an opportunity to manufacture more types of fuel for a wider range of applications. However, by far the largest use for secondary biofuels is within the transportation sector. For transportation purposes, liquid fuels such as ethanol and biodiesel can be used to replace petrol and diesel. These fuels represent around 3% of the total bioenergy mix and approximately 0.3% of global energy demands (IEA, 2009). Liquid biofuels are the fastest growing bioenergy sector due in part to the increased demand from the transportation sector. Indeed, liquid biofuel production is forecasted to grow between 6 - 8% per annum until 2030 (IEA, 2009).

Biofuels can be solid, liquid or gas and they can be produced from an array of specific energy feedstocks, wastes and production processes. As a consequence, the landscape of the bioenergy sector is particular complex and goes well beyond the scope of this literature review. For this reason, the remainder of the chapter will discuss the biofuels that are used for transportation purposes.
Biofuels used for transportation purposes are predominantly liquid biofuels because they have similar combustion qualities to petrol and diesel. The next section will review the various types of transportation biofuels which are currently commercially available and will reveal how the feedstock base and production process fundamentally affects the quality, cost and compatibility of the fuels with different road vehicles.

3.3. Biofuels for transport

The main two types of biofuel used in the transportation industry are liquid ethanol and biodiesel. These fuels are primarily made from energy crops such as sugar cane, beet, corn and rapeseed oil. The type of liquid biofuel which is produced is dependent on the biomass used (energy crops/animal fats/vegetation), the processing techniques applied to the biomass and any chemicals which are added. To better understand the issues involved with using biofuels for this purpose, more information is required about the different types of transportation biofuel which are available. The next sections will discuss the two main liquid biofuels; ethanol and biodiesel.

Ethanol is produced from the fermentation of carbohydrate rich crops such as sugar cane, sugar beet, corn and wheat (Escobar et al., 2008; Hill et al., 2006; Mortimer et al., 2002). The process is identical to that of producing alcohol for human consumption. The principal uses of ethanol within the transportation sector are as a blending agent and substitute for gasoline (petrol), though about a quarter of global ethanol production is used in alcoholic beverages, solvents and industrial chemicals (Worldwatch Institute, 2006). Ethanol has many advantages compared to petrol. Ethanol produces fewer emissions of carbon monoxide, carbon dioxide and aromatic compounds (Farrell et al., 2006). Ethanol also does not risk contaminating water resources (Sánchez and Cardona, 2008). Estimates of life cycle emissions and energy assessments indicate that first generation ethanol, which is the most established technology, can provide net energy gains of between 25% and 67% depending on the feedstock that is used (von Blottnitz and Curran, 2005; Hill et al., 2006). However, despite having combustion qualities similar to petrol, ethanol cannot be used as a 100% substitute for petrol in un-modified engines (Dermbias, 2009). Most car manufactures permit ethanol blends up to 10% without modification to the engine, though higher blends are easily attainable with minor modifications to vehicle injection systems or by using flexi-fuel vehicles.

Blend ratios of ethanol and petrol differ between nations depending on infrastructural support, government incentives and/or mandates. The most common blends are 5% ethanol (E5), 10% (E10), and 85% (E85). Brazil offers 100% ethanol (E100) in some of its filling stations. Some nations have
mandated the blending of ethanol with petrol, though the mandates vary between nations. In Sweden and Finland, petrol has been mandated to contain a minimum blend of 5% ethanol (Galbe and Zacchi, 2002; E10, 2011) and in Brazil all petrol contains at least 20% ethanol (Xavier, 2007). Vehicle modification is common and factory fitted cars are growing in numbers. There is also a rising number of flexi-fuel vehicles in Europe, the US and Brazil that have the capability to run on any combination of ethanol or petrol. Over 27 million flex-fuel ethanol vehicles were sold globally in 2011 (ANFAVEA, 2011). Currently, the flexi-fuel car market is dominated by Brazil with approximately 16 million vehicles sales in 2011. The United States and Canada are the second and third biggest markets.

In terms of the production process, ethanol accounts for around 86% of the global biofuel market. The majority of this production occurs in Brazil (41.7%) and the United States (47.9%) (IEA, 2006). Other nations in parts of Africa and South America are also now beginning to expand their ethanol production capability. As well as the conventional process, ethanol can also be produced using advanced processing techniques using a larger variety of feedstocks including forestry waste, straw, wheatgrass and other inedible crops. The main difference in this production method compared to basic fermentation is due to the fact that advanced biofuel processing can convert complex sugars and starches from woody material and waste agricultural feedstocks. Crucially, these feedstocks can be much more sustainable, may not encroach on global food supply or contribute to rainforest destruction. However, they are complex and more expensive to produce so advanced ethanol biofuels are not yet commercial viable. The other liquid biofuel which is commonly used in the transportation sector is biodiesel. Biodiesel has combustion qualities similar to that of conventional diesel and can act as a substitute or blend in diesel engines.

Biodiesel can be referred to as Fatty Acid Methyl Ester (FAME), renewable diesels or green diesels. Unlike ethanol, biodiesel is manufactured from oil rich vegetable feedstocks such as palm oil, coconut oil, jatropha oil and rapeseed (Dermibas, 2009). Animal lipids and cooking oils can also be used as feedstocks, although these make up only a fraction of the global biodiesel market. Biodiesel is chemically different from ethanol and so can be used in a variety of diesel engines as opposed to petrol powered vehicles (Kågeson, 2005). Modern high-pressure diesel engines can run on fossil-fuel and biodiesel blends up to 70% without any effect on performance (Tziourtzioumis et al., 2009). Older diesel engines can use 100% biodiesel and even 100% vegetable oil without a significant effect on performance or power. Global biodiesel production is dominated by Europe, which produces for around 85% of the global total (Figure 3.2). Within the EU, Germany is the largest producer with 53% of European production; France produces 16% and Italy 12%. Life-cycle assessments indicate that
Biodiesel can yield net energy gains of between 45% and 93% depending on the production methods (Searchinger et al., 2008; Hill et al., 2006).

**Figure 3.2. Global Biodiesel Production (2005)**

The most common production process for biodiesel is transesterification. This process involves extracting oil from a feedstock using a press followed by mixing and heating the resulting combination with an alcohol such as ethanol or methanol. The heating causes the lipids in the oil to become chemically bonded with the alcohol via a chemical process known as transesterification (Apostolakou et al., 2009). This manufacturing process can be done on a large scale in industrial facilities or by amateurs in very small scale batch production. In fact, although there is a large market for professionally produced biodiesel, there are also ‘back yard’ producers of biodiesel who use waste cooking oil to produce biodiesel for their personal use (Guardian, 2008).

The previous section has shown that there are two main types of biofuel used in the transportation sector. These fuels can be made using a variety of feedstocks and production processes. The production process and feedstock will influence the type of biofuel which is produced and how the fuel is categorised. Biofuels are frequently classified into either first, second or third generation in order to distinguish conventional from advanced biofuels. The categories have become a way for the biofuel industry to classify the sustainability of the fuels and the complexity of the production process. Due to the importance of the classification system within the literature, the next section will discuss road transport biofuels in terms of the three categories.
3.4. Biofuel categorisation

Liquid biofuels for transport are categorised into first, second or third generation depending on the feedstock bases that are used and the conversion process undertaken (Bram et al., 2008; Escobar et al., 2008). The categories are often used to compare and contrast different types of biofuels in terms of their sustainability, the sophistication of the conversion technology and the feedstock bases used. Industry and academics are however increasingly challenging the use of these classifications on the grounds that they are confusing and misleading. One of the reasons for the confusion is due to the fact that the developments in the biofuel field are occurring very quickly and the changes in the complexity of modern biofuel processing technologies and the accountability of sustainability makes it difficult to classify a fuel (Westminster Biofuels Conference, 2010; 2011). However, despite this controversy, the terms remain in widespread use.

First generation biofuels are liquid biofuels that undergo the simplest conversion process; usually from edible feedstocks such as vegetable oils or simple sugars and starches. First generation biofuels are also referred to as ‘conventional’ biofuels because they are the most established. First generation biofuels are used for transportation and owing to their relatively long history have the best track record in terms of commercial viability (Hill et al., 2006; Searchinger et al., 2008; Dermibas et al., 2009). First generation biofuels have however been the target of environmental groups and activists as their production can negatively impact on global food supply, increase food prices (Runge and Senauer, 2007) and cause environmental degradation (Searchinger et al., 2008). First generation biofuel feedstocks such as palm oil, for example, are frequently met with controversy from environmentalists (Searchinger et al., 2008). However, issues of sustainability are but one of the limitations of first generation biofuels. There are in fact several areas of concern expressed by academics, governments and non-governmental organisation (NGO) groups. The main limitations of first generation biofuels are the availability of land for the crops, issues of food versus fuel production, limitations surrounding net energy gains and the sustainability concerns associated with land use change (Dermibas et al., 2009). As result of these limitations, the biofuel industry has been actively developing technologies which can utilise more sustainable feedstock bases and more efficient biomass conversion technologies (OECD, 2008). These newer technologies are referred to as ‘second generation biofuels’ or advanced biofuels.

Second generation biofuels, or advanced biofuels, are produced from inedible raw materials left over from agricultural crops, woody biomass and other plant material that contains cellulose (Naik et al., 2009). There are a variety of production methods for converting inedible raw materials into liquid biofuels (See Figure 3.3). There are two basic sources of biofuel; edible feedstocks and inedible
feedstocks. These can be converted into biofuels using four principal conversion routes; pyrolysis, gasification, hydrolysis and transesterification. Second generation biofuels are particularly attractive to countries with climates that are unsuitable for growing first generation biofuel crops and/or those with abundant forest resources (Hahn-Hägerdal et al., 2006). The true cost and level of development of many of these technologies is however not clear due to the commercial sensitivity of the processes. Indeed, in a recent biofuel conference in London, a leading advanced biofuel producer and developer, Novozyme, announced that the second generation technology is now available; though the main issues are cost and scale (Westminster Biofuels Conference, 2010). The International Energy Agency has projected the potential market penetration of second generation biofuels to 2050 and reports that the most important factors affecting their uptake are feedstock prices, economies of scale and technological learning (IEA, 2008).

Second generation biofuels are heralded as a potential solution to issues associated with first generation biofuels, though they still come under scrutiny from environmental groups who allege the potential remains for them to raise food prices and have a negative effect on the environment (Sims et al., 2010). Second generation, or advanced biofuel, are furthermore still under development. Nevertheless, some studies posit that a third generation of biofuels are now in development.

**Figure 3.3. Second generation biofuel production from biomass**

![Second generation biofuel production from biomass](source: Naik et al., (2009) p. 583)

Third generation biofuels are somewhat ambiguous in their classification. Some experts refer to the process of converting biological waste gases into methanol as third generation while others use it to
refer to a ‘one-step’ conversion of lignocellulosic material into ethanol using microorganisms (Carere et al, 2008). However, some studies describe these processes as creating advanced third generation biofuels (IEA, 2010; Worldwatch Institute, 2010). Sometimes the use of algae-derived biofuels produced via transesterification is described as third generation though, in reality, this should be referred to as a second generation feedstock which undergoes a first generation production process (Worldwatch Institute, 2006). There are also a number of biofuel technologies which are still in the development stages. These new technologies are often heralded as offering solutions to the problems associated with existing biofuels; namely, possible inflationary effects on food prices, potential environmental degradation and feedstock supply constraints with regards to land and climate. Notable new fuels in the development stages include; micro or microalgae, ‘biohyrodgen’, ‘biomethanol’, ‘butanol’, ‘mixed alcohol’ and even ‘wood diesel’.

Experts believe that micro-algae feedstocks can yield far greater quantities of fuel than land based energy crops (Sheenan et al., 1998). The net energy gains that can be obtained are not yet known but the production processes have recently shown major advancements in efficiency (Aresta et al., 2005). There are a vast number of algae species which can produce different types of fuel, including biodiesel, when their oils are extracted and refined; ethanol using second generation methods; methanol from anabolic digestion and even bio-hydrogen (Sheenan et al., 1998). The main advantage of micro-algae comes from the fact that it has a cubic growth potential and therefore can be grown three dimensionally in water using photosynthetic lighting (see Chisti, 2007). Because the yield per acre is increased cubically this dramatically reduces competition with land based crops. Algae differ from most land based energy crops because of their higher oil content and much faster growth rates (Sheenan et al., 1997). Some species can double their volume in 24 hours, allowing for weekly or even daily harvests (Chisti, 2007). Specially designed growth ponds and circulating raceway channels which can utilise waste carbon dioxide emissions from power stations may be used to promote algal growth (see Chisti, 2007). In theory, these growth ponds confer several environmental and economic advantages; (1) they absorb carbon emissions from the power stations; (2) they speed up the micro-algae’s growth; (3) they increase the energy yield; (4) they may be subsidised by power station operators and (5) allow cubic growth of biomass (Sheenan et al., 1997).

Several methods for obtaining fuel from micro-algae have been discovered but none are commercially viable at present (Chisti, 2007; Aresta et al., 2005). The technical hurdles which need to be overcome include lowering the so-called liquefaction\(^3\) temperature which currently requires temperatures in the range of 350°C to 395°C (Yang et al., 2004; Aresta et al., 2005) and reducing the

\(^{3}\) Liquefaction is a process whereby algae are heated under high pressure to convert the biomass into oil.
per litre cost in line with other biofuels. The exact net energy yields attainable are not yet proven and problems with current photosynthetic technologies remain (Chisti, 2007; Sheenan et al., 1997).

Thus far the main production techniques and feedstocks have been reviewed. It has been revealed that there are a wide variety of liquid biofuels used for transportation purposes. The main types are ethanol and biodiesel. Biofuels are commonly classified into 1st, 2nd or 3rd generation depending on the sophistication of the production process and the feedstocks used. The research and design environment surrounding biofuels is large and evolving quickly. There are a number of 2nd and 3rd generation biofuel technologies that are currently under development which promise major sustainability and cost advantages over the conventional biofuels. This chapter has not yet discussed the issues that may influence the emergence, development and uptake of the biofuels. In the following sections the drivers and constraints associated with the emergence, development and uptake of biofuels in the road transportation sector will be identified.

3.5. Drivers

There are an abundance of studies which examine the emergence, development and uptake of biofuels. The majority of research relates to conventional biofuels that are produced using first generation production techniques because these types have a longer history and established commercial market. The focus of these studies are on the North American, European and Brazilian markets, though developing markets such as Africa (Hodes et al., 2004) and Asia are also examined by specialist studies (see Zhou and Thompson, 2009). There are also comprehensive reports investigating the economic, environmental and policy issues motivating the use of biofuels for transportation such as the ‘Worldwatch Institute’ in 2006 and the International Energy Agency (IEA) reports (2008; 2009; 2010). The main factors affecting the emergence, development and uptake of biofuels are expressed as the ‘drivers’ of the fuel or the ‘benefits’ of the fuels in comparison to fossil-carbon fuels. Other terminology that is used includes the ‘justifications’ and ‘motivations’ to support biofuels. Conventional biofuels can offer economic benefits such as improved fuel security, employment and enhanced rural development while also offering environmental benefits such as emissions reductions and improved air quality. In addition, policy factors play a significant role in the emergence, development and uptake of biofuels. This is because biofuels remain largely uncompetitive economically with fossil-carbon fuels. Indeed, policy factors are in fact one of the most significant drivers of development and growth.

Due to the complexity of the various driving factors affecting the emergence, development and uptake of biofuels, the issues will be analysed thematically following the PESTLE framework i.e.
political, economic, social, technological, legal and environmental factors. These will also be used to form the structure of the literature review sections. A summary of the driving factors can be seen in Table 3.1 below.

**Table 3.1. Driving factors**

<table>
<thead>
<tr>
<th>Political</th>
<th>Economic</th>
<th>Social</th>
<th>Technological</th>
<th>Legal</th>
<th>Environmental</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voluntary target</td>
<td>Rising oil prices</td>
<td>Job creation</td>
<td>Compatibility with existing combustion engines</td>
<td>Binding mandates</td>
<td>Renewable energy tariffs</td>
</tr>
<tr>
<td>Subsidies</td>
<td>Domestic Energy security</td>
<td>Corporate Social responsibility</td>
<td>Compatibility with existing infrastructure</td>
<td>Emissions reduction requirement</td>
<td>Emissions reduction requirements</td>
</tr>
<tr>
<td>Tax rebates</td>
<td>Agricultural development and employment</td>
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<tr>
<td>Grants</td>
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<tr>
<td>Tariffs</td>
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<td>Trade Policies</td>
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</table>

**3.5.1. Political factors**

A key driving force behind the development and uptake of biofuel is the influence of policy. Biofuels are heavily reliant on government support policies such as mandates, tax breaks and subsidies. In fact, policies have been instrumental in facilitating the emergence, development and uptake of biofuels in North America, South America, Europe, Asia, Africa and Australia (IEA, 2009; OECD, 2008). Policies are important because, with the exception of Brazil, conventional biofuels are unable to compete economically with standard transportation fuels such as petrol and diesel. In fact, there are no known examples of biofuel markets having been developed without some form of specific policy influencing the development and uptake of the fuels (Worldwatch Institute, 2006; IEA, 2009; OECD, 2008).

Biofuel policies primarily support the supply and demand side of the market; using financial incentives and/or obligations for the fuel and feedstocks. These tend to be the foundation of most policy frameworks within the European Union, North America, Latin America, Africa and Asia (IEA, 2009). Other common policies include; government backed bank loans, infrastructure development funding (Hunt et al., 2006), trading certificates, tariffs, tax waivers, support for research and development and targeting of new technology (GBEP, 2007, see Figure 3.4). Most polices are used to
lower production costs of the biofuel and thereby remove the price differentials between fossil fuels
and to fund development of new fuel biofuel technologies (IEA, 2009). Mandates and obligations are
known to be effective when used in combination with financial incentives; this induces maximum
demand for both the agricultural feedstocks and the final fuel (OECD, 2008; IEA, 2009). Finally, long-
term policy support is often directed towards the research design and commercialisation of new
fuels and production technologies (IEA, 2009).

Figure 3.4. Bioenergy policies adopted by region

<table>
<thead>
<tr>
<th>Country</th>
<th>Binding targets</th>
<th>Mandates</th>
<th>Voluntary targets</th>
<th>Direct incentives</th>
<th>Grants</th>
<th>Feed in tariffs</th>
<th>Compulsory grid consumption</th>
<th>Sustainability criteria</th>
<th>Tariffs</th>
</tr>
</thead>
<tbody>
<tr>
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<td>E,T</td>
<td>T</td>
<td>T</td>
<td>E,T</td>
<td>E,H</td>
<td>E,H</td>
<td>Eth</td>
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</tr>
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<td>T</td>
<td>E,T</td>
<td>E,H</td>
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<td>n/a</td>
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</tr>
<tr>
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<td>E,H,T</td>
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<td>n/a</td>
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</tr>
<tr>
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<td>(T)</td>
<td>(E)</td>
<td>(E)</td>
<td>Eth</td>
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</tr>
<tr>
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<td>(E),T</td>
<td>T</td>
<td>Eth</td>
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<td>n/a</td>
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</tr>
<tr>
<td>Canada</td>
<td>E,**</td>
<td>E,**</td>
<td>T</td>
<td>T</td>
<td>E,H,T</td>
<td>Eth</td>
<td>n/a</td>
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<td></td>
</tr>
<tr>
<td>France</td>
<td>E*,H*,T</td>
<td>E,H,T</td>
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<td>(E,H,T)</td>
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<td>n/a</td>
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</tr>
<tr>
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<td>E*,T</td>
<td>H</td>
<td>E</td>
<td>E</td>
<td>As EU below</td>
<td>n/a</td>
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<tr>
<td>Italy</td>
<td>E*</td>
<td>E,T</td>
<td>T</td>
<td>E,H</td>
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<td>As EU below</td>
<td>n/a</td>
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</tr>
<tr>
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<td>E,H,T</td>
<td>E</td>
<td>E</td>
<td>Eth</td>
<td>B-D</td>
<td>n/a</td>
<td>n/a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Russia</td>
<td>(E,H,T)</td>
<td>(T)</td>
<td>n/a</td>
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<td>UK</td>
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<td>E,H,T</td>
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<td>E</td>
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<td>Eth</td>
<td>B-D</td>
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<td>USA</td>
<td>T</td>
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<td>(T)</td>
<td>Eth</td>
<td>B-D</td>
<td></td>
</tr>
</tbody>
</table>

E: electricity, H: heat, T: transport, Eth: ethanol, B-D: biodiesel
*: target applies to all renewable energy sources, **: target is set at a sub-national level
(1) policy instrument still under development/awaiting approval
1: blending or market penetration
2: publicly financed incentives: tax reductions, subsidies, loan support, guarantees

Source: GBEP, (2007) p. 31

National biofuel strategies are often administered as biofuel policy mixes directed to specific stages
of the biofuel supply chain in order to support the entire production process (IEA, 2009). One of the
most common forms of policy adopted in OECD countries is a subsidy on either the feedstock or the
fuel (OECD, 2008). Subsidies have been effective at promoting biofuels in several countries, most
notably in France (Rozakis and Sorie, 2005), the UK and Germany (Bomb et al., 2007) as well as
major producing countries such as Brazil (Hunt et al, the EU (Pelkams 2007) and the US (Jank et al.,
2007). The largest known grant for biofuels is found in the US where subsidies reached $100 million
for ethanol and almost $50 million for biodiesel in 2005 (Worldwatch Institute, 2006). In the US, the money is mainly used to fund the expansion of production facilities and to remove price differentials between oil and biofuels. Subsidies can be applied to the prices of feedstocks on a fixed rate basis or in other forms where ‘cost-plus’ formulae are used to remove price differentials with petroleum fuels (Reuters, 2005). Subsidies influence the expansion of biofuel markets; for instance it is well cited that Brazil’s rapid expansion of ethanol production was from the 1970s onwards directly attributed to subsidies, as well as the addition of other financial incentives including bank loan guarantees, public loans and state-guaranteed private bank loans for producers (De Canto, 1985; Kojima and Johnson, 2005). Targeting technology and/or supporting innovation and demonstration plants is a further important feature of biofuels support policy (Worldwatch Institute, 2006; IEA, 2009). Early support for biofuels often involves financial backing and incentives directed to various stages of the fuels development.

Supporting the development of new biofuels technologies has been shown to be a key objective for several OECD countries (OECD, 2008). Brazil, Europe and North America are often cited as the pioneering regions of biofuel policy (Pelkams 2007; IEA, 2009; Worldwatch Institute, 2006). In fact, these regions still maintain the most comprehensive support packages for biofuels and bioenergy today (Neeft et al., 2007). Biofuel policies are most prevalent in Europe and North America where production costs and feedstocks tend to be highest, though Brazil has had the longest experience with biofuel policies worldwide; the first being adopted in the 1930’s (De Castro Santos, 1985).


In a number of investigations econometric modelling is used to examine the environmental and economic impacts of biofuel support policy. These are carried out on either national or international scales; include the use of the ‘Aglink-Cosmo’ model; used for OECD countries and the ‘Stylised Agri-environmental Policy Impact Model’ (SAPIM); which examines the relationships between agricultural policy and the environmental effects of expanding biofuel supply. Other notable studies include...
TRIAS; which is an update from earlier studies; POLES, Astra, Regio-Sustain and VAclav (ISI, 2008). These studies have been useful for policy makers in assessing the likely long-term effects of policy support for biofuels in several regions. However, there is evidence that policy support and targets for biofuel production are not always successful. With respect to the EU, a biofuel mandate was put in place to supply 10% of the transportation market with biofuels. This figure was realised to be far too optimistic, despite the fact that several EU level documents recommended the target. Recent studies however, such as the Lensink and Londo (2010); uses the least cost optimization model 'BioTrans' to assess the EU policy impact and forecast demand for advanced 2nd generation biofuels. Lensink and Londo used cost assessments of biofuels production in Europe which incorporated a cost reduction effect via the learning-by-doing process. The study indicates that there are significant lock-in effects (i.e. an ability to establish a technology and supporting infrastructure quickly) for the 1st generation fuels if crop prices remain low indicating that the 10% target within the E.U is unlikely to be reached. Furthermore, 2nd generation fuels are heavily dependent on cost reductions via the learning process (Lensink and Londo, 2010). Their model however suggests that the supporting policy measures in the EU will be effective for reducing production costs in the long-run.

A growing number of studies investigate current and future policy support in the developing regions such as Africa (Schut et al., 2010; Arndt et al., 2009). It is often the case that smaller investigations are initiated as part of larger government funded reports such as the PREMIA project, OECD reports (2006; 2007; 2008), International Energy Agency (IEA) annual reports or the World Bank. Indeed, these larger reports offer the most comprehensive tracking of the policy developments in EU, North America, Africa and Asia. Nevertheless, the smaller studies offer in depth analysis on the national scales. Notable examples on the national scale studies include (Rozakis and Sourie, 2005) in France; Henke et al., (2005) in Germany; (Hillring, 2002) in Sweden; (Hoekman, 2008) in the U.S and (Jank et al., 2009; Faaij, 2006); which covers the entire E.U region. There has clearly been a great deal of government policy effort to incentivise the initial development of biofuel markets, many of these incentives are still in place. However, given the large monetary costs involved, the policies need to be robustly justified by governments.

The justifications for introducing biofuel and bioenergy policy support have been investigated in several government reports (IEA, 2011; 2009; OECD, 2008; GBEP, 2007) and smaller academic studies (Sawin, 2004). It is frequently asserted that supporting policies are justified by governments because of the environmental and economic benefits attributed to the fuels. However, issues arise when assessing the relative benefits of the fuels. As detailed in the previous sections of this chapter,
valuations of the benefits can differ by country and between studies. Similarly, nations will be influenced by their specific geopolitical and economic needs (IEA, 2009). For this reason, the level of cross evaluation between these studies is limited. The terminology and scope for policy motivations is furthermore not always consistent; for instance some studies such as the OECD (2008) investigate ‘objectives’ of government support, while others such as the Worldwatch Institute, (2006) examine the ‘justifications’ for biofuel support. In reality the two types of study are investigating the same phenomenon simultaneously. When the International Energy Agency investigates the issues of bioenergy policy, they use the term ‘policy priorities’ to examine the roles of each nation in terms of bioenergy support (IEA, 2009). Almost all studies cite the environmental and economic benefits of biofuels as the main drivers of policy support, together with the promise of future cost reductions for new technology (IEA, 2009).

A recent study by the GBEP (Global Bioenergy Partnership) investigated the key motivations of bioenergy policy in a number of countries (summarized in Figure 3.5). The study indicated that ‘climate change’, the ‘environment’ and ‘energy security’ were the most prominent objectives for the countries investigated. The report also indicated that the bioenergy sector is optimised when a combination of both national and locally administered support policies are adopted (GBEP, 2007).

**Figure 3.5.** Key motivations for bioenergy support and key policy documents by country in 2007

<table>
<thead>
<tr>
<th>Country</th>
<th>Climate change</th>
<th>Environment</th>
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Source: GBEP (2007) p. 22
Other investigations which have adopted a similar scope to the GBEP report include the OECD and IEA, which investigated the objectives of policy support for biofuel and bioenergy for 17 OECD countries. The OECD research involved a survey sent to 17 countries using a set of pre-determined objectives by the OECD researchers; the priorities of each country were identified using the questionnaire results (OECD, 2008). OECD secretariat research between October 2007 and April 2008 indicated that policy choice does vary between countries (Figure 3.6), with nations ranking their objectives depending on their specific geopolitical and economic requirements.

Figure 3.6. Priority given to different objectives behind biofuel support policies

![Graph showing priority given to different objectives behind biofuel support policies]


However, most countries ranked the objectives identified by the OECD as high priority, with greenhouse gas emission reductions and rural development coming out as the top two ranked objectives (OECD, 2008). In general, the geopolitical and economic objectives were similar between nations, except for Brazil which gave relatively low priority to energy import reduction due to the fact that the country already produces a large proportion of its energy needs from hydroelectric sources. Most other countries, particularly within the EU, ranked domestic energy supply as a high priority (OECD, 2008). The OECD research also identified other reasons for supporting bioenergy, these were; (1) reduction of transport sectors energy intensity; (2) diversification of energy supply outside of transport; (3) the development and aid of small business start-ups; (4) improvement in economic sustainability; (5) the development of a recycling-based society and (6) the fostering of technological developments (OECD, 2008).

As aforementioned, national biofuel support is generally administered in the form of ‘policy mixes’ which may include a combination of mandates, subsidies, import tax exemptions, fuel tax exemptions, market regulations, and/or other financial and structural aids (IEA, 2009; Pelkams
Policies for biofuel development are managed on local, national and international scales, with financial incentives being commonly funded through national tax revenue. However, revenue can also be redistributed among consumers via a levy on fossil carbon fuels making the policy revenue neutral (Junginger, 2007).

In order to maintain support throughout the entire supply chain, policies are directed toward specific stages of the production process (i.e. agricultural tax exemptions and mandates will tend to support the supply-side of the market by influencing feedstock costs, whereas fuel-tax exemptions and fuel subsidies will be used to support the demand-side of the market by influencing the end user price of the fuel (GBEP, 2007)). Pelkams (2007) describe the structure within Europe as consisting of four basic stages; (1) ‘feedstocks’ are supported by regulatory measures such as crop subsidies and set aside land policies; (2) ‘biofuel production’ is supported through economic and fiscal measures such as research and development funding and producer tax incentives; (3) ‘distribution’ is influenced by fuel standards and obligations such as mandates; and finally (4) ‘the market’ is supported by networking and information diffusion with funding of demonstrations, procurement methods and end user incentives including free parking for biofuel users etc. (Figure 3.7).

**Figure 3.7.** The biofuel supply chain and support measures in Europe

Research design and development is supported by specific policies in a similar manner as stated above. In some nations, particularly OECD countries, support is provided throughout the developmental stages of the technologies. It is first directed to the initial research and design phases, then to the ‘early market and demonstration’ phases, then finally to the ‘mass market’ stages (Grubb, 2004). Early support for comparatively expensive biofuels is justified by governments
on the understanding that over time ‘learning-by-doing’ and economies of scale will yield cost improvements and more efficient biofuel technologies (IEA, 2009; OECD, 2008).

An additional component of policy support for biofuels may come from international climate policies under the Kyoto Protocol; such as the Clean Development Mechanism (CDM) and Joint Implementation (JI) projects. The clean development mechanism is an intuitive that allows developed regions to off-set their emissions by investing into emission reduction projects in developing regions (UNFCCC, 2012). The joint implementation initiative allows country’s under the Kyoto protocol to earn credits by reducing emissions for Annex B countries (UNFCCC, 2012). These larger-scale policy measures may indirectly support national objectives for pursuing biofuels that have the potential to yield environmental or developmental benefits. On the other hand, these mechanisms are most prevalent for developing regions and it is acknowledged that the verification of biofuel production methods are important to guarantee that the fuels are eligible as clean development mechanism projects (Schlamadinger and Jürgens, 2004). The next section will detail the policies that are used for supporting research and development. Innovation theory is briefly described in this section as well as in the theoretical underpinning chapter (Chapter 2) since it relates specifically to the policies that have been used to support biofuels for the road transport sector.

The ability to support each stage of the development using policy is crucial. Theories described in biofuel literature include diffusion theory (Rogers, 1995) and ‘the innovation chain’ (Grubb, 2004); as well as ‘learning by doing’ theories such as Méjean and Hope (2009). Other studies have used conceptual frameworks that have been developed to understand the dynamics of particular stages of technology developed such as Strategic Niche Management (SNM) (Raven, 2005). With respect to bioenergy and biofuels however, the ‘innovation chain’ and elements of diffusion theory are often used to conceptualise the development of new biofuels. These are cited in policy studies as an important feature for the development of new technologies (GBEP, 2007). Many studies use the idea of influencing innovation using policy as a measure to increase the speed of development of the biofuel industry as well as certain technologies. However, innovation and the so called ‘technological system’ are very complex phenomena, and using policy to influence innovation is challenging (Grubb, 2004). There is a body of literature which investigates the policy influence for bioenergy and renewable technologies at stages along the innovation chain. These follow the route as described; moving from ‘Research and Development’ to ‘Early Market’ and finally to ‘mass market’ (Figure 3.8).

**Figure 3.8.** Policy influence along the innovation chain
In the initial stages of research for a new technology, there are large barriers to overcome in terms of obtaining financial backing. Financial backing via Public-Private partnerships is often the first stage of research and development funding given to bioenergy (IEA, 2009). Other forms of direct funding can come from governments in the form of subsidies and so called ‘soft loans’ for pilot demonstration projects such as in Brazil (Goldemberg et al., 2004).

In the early market phase (i.e. after the demonstration plants have proven successful and scale up is considered to be viable) other polices are used as incentives to support the initial market creation (IEA, 2009). According to the IEA, a key objective of policy in these early market phases is the need to reduce cost differentials between fossil fuels and the bioenergy alternative, thus creating a competitive market (IEA, 2009). The technology should be introduced to the market quickly in order to capitalise on so called ‘learning by doing’ which will tend to bring the costs and efficiency of the technology down. Learning by doing refers to a well-known business model observed in new technologies, where unit costs decline as a result of experience with the production process (Arrow, 1962).

According to the IEA there are three main policy measures which are adopted in the early market stages for bioenergy. The first priority is to reduce production costs via feed-in-tariffs, feed-in
premiums, and tax exemptions. These are directed to specific stages of the production chain in much the same way as the other policies discussed. At this stage, it is important for financial incentives to be incrementally reduced over time; this will prevent dependency on subsidies and signal to firms that cost reduction is required. For bioenergy, there are some nationally administered quantity based instruments such as quota obligations and tendering. According to the IEA, normally an obligation scheme does not require additional government spending, since financial costs will be incurred by the consumers if the cost of production is passed on. In tendering schemes an obligation is auctioned to the highest bidder; which economically is the lowest subsidy level required to meet the obligation (IEA, 2009). However, obligations, particularly in renewable power generation, don’t differentiate between environmentally sustainable and non-sustainable technologies. For instance, if an obligation is set there may be a situation where by the cheapest and dirtiest fuels are used because they are the easiest and cheapest way of meeting the obligations. In the so called, tendering system - contracts with a set price and quantity are bid upon competitively by technology developers. According to the IEA this can lead to reductions in production costs. However, the tendering process is complex and difficult to administer.

Policies for the mass market are the most discussed aspects of biofuel policy. For existing biofuels these include; subsidies, tax exemptions, loans, trade tariffs, obligations, market regulation and other market support. However, asserted in several papers and reports is the draw back and difficulty in aligning the best policy mixes with the best technologies in terms of sustainability and effectiveness at meeting the objectives of each nation. For example, if the policy mix is too broad then fuels which are not environmentally beneficial may be adopted. Other policies used to support biofuels include trade policies.

Trade policies are policy factors despite the fact they are closely linked to the economics of energy security. Trade policies are an important component of biofuel policy and bioenergy policy (Zah and Ruddy, 2009; Worldwatch Institute, 2006; OECD, 2008; GBEP, 2007). The development and trade in biofuels, bioenergy and related renewable fuels are affected by the agricultural and trade policies adopted in different regions (Worldwatch Institute, 2006). In terms of biofuel, there are several trade policies in place; the largest trade routes influenced by policy are between the EU, US, Latin America and Australia. Each of these regions and countries has imposed import duties on foreign biofuel, namely ethanol, biodiesel and their raw feedstocks. However, some preferential unilateral tariff reductions are applied to certain developing countries (Zah and Ruddy, 2009; Worldwatch Institute, 2006). There are still some ambiguities in the classification of traded biofuels, for instance; in the EU in 2006, ethanol destined for petroleum was classified under the same coding as alcohol.
destined for human consumption (Worldwatch Institute, 2006). Tariffs also differ between regions; according to research carried out in 2006 the US ethanol tax was €0.15 per litre, in the EU it was either €0.19 per litre for denatured ethanol (with additives) or €0.10 per litre pure. Biodiesel is also taxed at rates specific to each nation, though according to the Worldwatch Institute research in 2006 oilseeds and soybeans are much less restricted by tariffs and trade policies.

Finally, the impact of trade policies has been reviewed by authors such as; Ericsson and Nilsson, (2004) in Europe. Ericsson and Nilsson (2004) indicate that trade policies have been shown to have been beneficial for development, as well as create undesirable effects as well. For example; evidence suggests that some trade policies which encourage export in developed regions are promoting unsustainable agricultural practices in some countries (Steenblik, 2007). Following the PESTLE framework, the next section will discuss the economic factors driving the emergence, development and uptake of aviation biofuels.

### 3.5.2. Economic factors

There are number of economic factors which influence the development of biofuels. Economic factors include rising oil prices, increasing need to bolster domestic energy security and job creation.

There are a number of biofuels studies which investigate the economic factors driving biofuels. The economic studies range in size and scope from local cost/benefit case study evaluations of individual producers (Clancy et al., 2008; Hammond et al., 2008) to national and international market analysis (IEA (2004; 2007; 2010), and OECD, (2008)) and emergence, development and uptake (Ericsson et al., 2004). These studies argue that biofuels should satisfy five main conditions before being considered for commercial use: (1) they must provide a net energy gain, (2) be price competitive with crude oil, or be expected to become price competitive within a defined time frame, (3) have an adequate feedstock resource base, (4) demonstrate positive environmental advantages and (5) engage in minimal competition with food crops (Searchinger et al., 2008; Hill et al., 2006; Aden et al., 2002; von Blottnitz & Curran, 2006). However, these conditions are seldom ever met in their entirety, especially with respect to price competitiveness with crude oil (Hill et al., 2006).

Furthermore, some of the factors, such as demonstrating positive environmental externalities, are difficult to quantify. Nonetheless, recent economic evaluation such as that by Ajanovic and Haas, (2010), does indicate that certain biofuels, particularly within the EU, will become price competitive within the next few years. However, the current economic cost of biofuels is generally not competitive with conventional fossil-fuels.

Almost all of the biofuel literature refers to the influence of rising or unstable oil prices (Hill et al., 2006; Fortenbery, 2005; OECD, 2007 and IEA, 2004). Rising oil prices cause the cost of petrol and
diesel to increase and thus make alternatives, such as biofuel, more attractive to both producers and consumers (IEA, 2008). Rising oil prices can also slow economic growth and cause trade imbalances for oil importers which divert scarce resources away from social welfare development in developing regions (Lee et al., 1995). Oil price forecasting is used to predict the market entry point for biofuels in a number of government funded initiatives such as Defra (UK) (2008); Bernard, (France) (2007) and IEA, (International) (2004; 2008). Other economic literature carries out present day cost evaluations based on current oil prices and current production costs (Ulmanen et al., 2009; Searchringer et al., 2008). Research from the Worldwatch Institute use the example of Brazil to express an overwhelming influence that oil price can have on incentivising biofuel production (Worldwatch Institute, 2006). In Brazil’s case it was apparent that the rapid expansion in ethanol production seen after the 1970s was driven directly by the 1970s oil crises (see Hunt et al., 2006). Europe and North America exhibited a similar influence from oil price rises, though their expansion was not as pronounced as that shown in Brazil (Hira & de Oliveira, 2009; Hammond, 2008). Finally, volatility of oil prices in recent years has influenced biofuels.

While the dynamics of oil prices are complex and go beyond the scope of this literature review, the expectation of rising future oil prices acts as a major driver for the development of alternative fuels, including biofuels (Stern, 2006; IEA, 2008). Rising global demand for oil coupled with increasing difficulty in extracting new reserves leads to a theoretical breaking point between supply and demand; referred to as ‘peak oil’ (Stern, 2006). Although the timing of ‘peak oil’ production is far from certain, the International Energy Agency projects global oil supply will peak in 2020 (IEA, 2004), after which oil prices will potentially escalate to unprecedented highs. The significant long term signal for governments and industries is to bolster domestic energy supply via the expansion of renewable alternatives, including solar energy, wind power and biofuel (Robèrt et al., 2007). The rising price of oil is a significant driver for the development and use of biofuels particularly for countries which are net importers of oil; not least because of the buffering effect they can have against exogenous supply shocks but also due to their ability to bolster domestic fuel security.

Bolstering domestic energy security and diversifying energy production is also cited as being significant drivers for the development of biofuels, particularly for net oil importing countries and developing regions with limited petrochemical infrastructure (Hodes et al., 2004). Some studies refer to the benefits as ‘strategic benefits’ (Goldemberg, 2004) while others use ‘supply security and risk abatement’ as a definition for domestic energy security (Slingerland & van Geuns, 2005). Nonetheless, reducing reliance on oil imports can provide significant cost savings to nations; Brazil saved USD$121.3 billion US dollars (including interest from avoided foreign debt) between 1975 and
2004 by producing biofuel. These cost savings are major incentives for national economies to pursue biofuels, though it should be noted that cost savings can vary considerably between nations (Worldwatch Institute, 2006). Additionally, diversification of energy sources away from fossil-fuels, particularly oil, poses as a major long term driver for biofuel uptake. Related to energy security, several sources acknowledge the renewable nature of biofuels as a significant justification for long term policy (Rajagopal & Zilberman, 2007), although this factor is closely linked with the threat of peak oil.

The next driver to be discussed may be described as being somewhat removed from the first two drivers because it is not related to averting oil production. However, for the feedstock producing countries, as well as the financiers, it is expressed as being of great importance for the long term development and support for biofuels worldwide. This benefit also acts as a major justification for support policy. Economic factors are clearly important for the emergence, development and uptake of biofuels. However, they are not the only issues which affect the development of biofuels. Indeed, the next section will discuss the social factors which affect the development and uptake of biofuels.

### 3.5.3. Social factors

Social factors play a role in creating a demand for biofuels. Social factors are closely linked to the economic and environmental benefits attributed to the fuels, including the greenhouse emission benefits of the fuel as well as the potential economic welfare gain attributed to the fuel. In the literature however, the main discussion concerning social drivers for biofuels surrounds agricultural development and job creation.

Supporting the development of rural economies is asserted as being an important driver for biofuel development. Biofuel development can support agricultural feedstock prices and benefit rural economies through job creation and increased agricultural feedstock demand (OECD, 2008). The OECD describes these benefits as creating ‘new market outlets’ and additional demand for agricultural products. The European Union’s biodiesel development program (that expanded biofuel production by over 20%) prioritised EU growers of oilseed crops in the policy design and the Brazilian Protácool programme has been heralded as the driver of sustained high sugar prices and rural employment (Smeets et al., 2006). Similarly, Asian nations including India (Gonsalves, 2006), Thailand, Malaysia and Indonesia (Sumathi et al., 2008) justify policy support from job creation and increased agricultural income. Research shows that rural job creation is especially attractive to developing regions and those with high unemployment (Urbanchuk, 2009). In relation to the petrochemical business the biofuels industry is considerably more labour intensive; some studies
even indicate it to be about 100 times greater (Worldwatch Institute, 2006). Brazil is the largest employer in the biofuel industry employing well over half a million people. In 2006 U.S. ethanol production employed as many as 200,000 (RFA, 2006) though more recent research indicates that the employment figure grows to 475,000 people if logistics and research employees are counted (Urbanchuk, 2009).

In addition to social drivers of biofuels, protecting the environment is currently a high priority for society and governments globally. Biofuels offer potential environmental benefits over fossil fuels thus making them attractive socially to governments, as well as economically to industries when governments impose ever- stricter environmental legislation.

The next section discusses the technological factors that have driven development of aviation biofuels.

3.5.4. Technological factors

Technological drivers are discussed in the literature however not explicitly related to drivers. Studies commonly describe a key benefit of biofuels as offering a contemporary solution to issues such as energy security and emissions. This is because unlike many of the other technologies such as electrification and hydrogen power, biofuels can be used by existing road transportation infrastructure and technology (Dermibas, 2008; Hill et al., 2006). In terms of road based biofuels, the main technologies used to manufacture the fuel have included transesterification and fermentation. These two processes are not new or cutting edge technologies. However, a strong driver for continued market development stems from research into newer technologies and feedstocks (IEA, 2010). These technologies offer the industry a means to expand and develop amid growing demand for the fuels. They also offer the industry a solution to the issues of food versus fuel and other sustainability issues which are attributed to biofuels.

The following section focuses on the legal factors driving the development of biofuels. These factors are closely linked to policy factors because they are ultimately delivered through governments and policy frameworks.

3.5.5. Legal factors

Legal factors are important for the development of biofuels. They are also significantly complex and vary considerably between countries and regions. Within the EU the legal issues have been explored
by several papers. An EC paper by Petillion (2005) outlines the legal issues of biofuels for transport within the EU. Biofuels are currently subject to two directives. In 2003, the 2003/30/EC directive was put in place to ensure promotion of biofuels and other renewable transport fuels across the (EU Directive, 2003). The directive gave general guidelines for each EC member state to target biofuels. The original target was to ensure that the European Union as a whole will replace 2% of all transport fuels with biofuels by 2005. This figure would rise to 5.75% in 2010. In a later directive of 2009/28, the overall binding target was changed to 10% of each Member States transport fuel. However, the 10% target would include other renewable fuels as well (EC, 2011). The 2009/28 directive also added sustainability criteria for sustainable biofuel. The main legal factors driving the development of biofuels are mandates and emissions reduction quotas. As mentioned, various policies have been used to support the development of biofuels by either encouraging the research and development of the technology or by supporting the financial viability of existing biofuel production through subsidies and tax breaks etc. Mandates are widely used as a method to induce production of biofuels by enforcing a minimum production level or by introducing a minimum blend in existing fuel supplies. Mandated volumes are not however universally accepted as a method for driving the development of biofuels. Mandates and obligations are known to be effective when used in combination with financial incentives; this induces maximum demand for both the agricultural feedstocks and the final fuel (OECD, 2008; IEA, 2009). EC research suggest that the existing policy framework is affective at growing the biofuels market however, net trade in feedstocks for biofuels included wheat and maize are expected to decline up to 2020 (EC, 2011). The final section will detail the environmental driving factors.

3.5.6. Environmental factors

The perceived environmental benefits of biofuel are major drivers for uptake and expansion (Dermibas, 2009; Hill et al., 2006; Gnansounou et al., 2009). The environment is experiencing rapid increases in greenhouse gases that are likely to be influenced by anthropogenic activity and the burning of fossil-carbon fuels (Houghton et al., 2001). It is anticipated that if these trends are allowed to continue unchecked the world faces a serious threat of major climate change and potentially irreversible ecological destruction (Houghton et al., 2001; Vitousek, 1994). The monetary clean-up costs to society are likely to be unprecedented and require action to be taken now (Stern, 2006). These threats have led to growing global efforts to reduce anthropogenic emissions to levels which may have less serious implications. Governments from 177 nations have now subscribed to the Kyoto Protocol and several of those nations have set challenging emissions targets for the future across several economic sectors. Transportation emissions are responsible for around a quarter of the global total and research shows that this sector is the fastest growing source (IPCC, 1999). The
largest share of transportation emissions are produced by road transport; which has seen relentless expansion in the last 100 years. Shipping and aviation are also significant contributors and will grow in share significantly in the next 50 years (Heitmann and Khalian, 2011). Biofuels offer one of the best near term solutions to these increases due to their drop-in nature and life-cycle emissions savings when compared with petrol or diesel.

In this context the most important environmental benefit of biofuels is the life cycle emissions saving; calculated using life cycle analysis (LCA). A biofuel crop will sequester atmospheric carbon dioxide (CO$_2$) via photosynthesis and this will be contained within the liquid biofuel. When the fuel is burnt the carbon content will be released as carbon monoxide (CO) and CO$_2$, but because this carbon was sequestered by the vegetation whilst growing, there is a theoretical zero net gain in emissions. In reality however, during the so called ‘life-cycle’ of the fuel it will undergo several procedures which require additional energy including cultivation, harvesting, processing and transportation to the market. These energy inputs are subtracted from the accounted net energy gain and life-cycle emissions of the fuel thus reducing the benefits of the fuel in terms of carbon (EPA, 1995). There are also indirect effects of biofuel production which further effect the life-cycle emissions of the fuel. These indirect land use effects have become a major concern and many attest that these factors were not adequately accounted for in some of the early LCA studies (Gallagher, 2008; Searchinger et al., 2008; Fargione et al., 2008).

LCA calculations have been carried out for an extensive number of biofuel types and processing techniques in a variety of world regions including North America and Europe (Hill et al., 2006), Brazil (Macedo et al., 2008) and India (Kadam, 2002). There are major variations on the accepted LCA methodology as well as a noticeable variability in the resulting emissions savings (Larson, 2006). In fact, the emission savings after combustion are often contradictory; for example Fortenbery (2005) reports a 79% savings in CO$_2$ whereas Hill et al., (2006) describe savings as low as 59%. A detailed study by Mortimer et al., (2002) indicates that most emission savings are contested because of the ambiguous forms of assessment and lack of a universally accepted methodology. Their evaluation suggests the true figures will vary by as much as 20% depending on the production method and accounting procedure applied.

Nonetheless, compared with the combustion of conventional fossil-carbon fuels, biofuels are reported to produce lower emissions of carbon dioxide (CO$_2$), carbon monoxide, sulphur dioxide and methane, but the exact savings vary depending on the feedstocks, production methods and regional solar irradiance (Escobar et al., 2008; Fortenbery, 2005; Hill et al., 2006). For rape methyl ester (biodiesel) life cycle emission savings can range from 16% to 63%, while ethanol savings can range
from 45% to 65% (EC, 2006). This is more optimistic than Delucchi (2005) who suggested that ethanol can provide anything from a 32% decrease in emissions to a 20% increase.

Irrespective of the purported environmental and economic benefits that biofuels can offer, biofuel production has been seldom ever price competitive with fossil-fuel. As a result, biofuels require additional support from policy makers in order for the markets to develop and function. Indeed most countries use supporting policies to remove the price differentials between fossil-fuel and biofuels and many guarantee production via mandating and tax relief (OECD, 2008).

3.6. Summary of drivers

It has been shown that there are three main factors driving the development and uptake of biofuels. These factors can be categorised as economic, environmental and political. Currently, the most important drivers are policy incentives such as subsidies because biofuels are seldom price competitive with their fossil-fuel counterparts. Expensive policy incentives are justified by governments because of the economic and environmental benefits that biofuels are expected to yield. Policy support usually comes in the form of price or production incentives applied on a national level. However, there are also mandated production figures which have been put in place in several regions of the world. With all things considered, policy is shown to be most effective when a combination of subsidies and mandates are applied in situ to specific stages of the biofuel supply chain. Justification for supporting biofuels is derived chiefly from the environmental and economic benefits attributed to biofuels, particularly rural development and reduction of GHG emissions. The administration of biofuel policies is not always consistent, even within economic regions such as the EU. This calls for better future alignment of polices. The choice of policy is also shown to be important for the development of new technologies; which subsequently is a key justification for early support of biofuels. Governments are keen to support new technologies which have the potential to produce cost reductions in the future and thus yield tangible returns, be it environmental or economic, to the original investments into the technologies. As mentioned, the justification for policy support is driven by the economic and environmental benefits that biofuels are perceived to yield.

The economic benefits of biofuel are rural development, job creation and fuel security. However, the dynamics of biofuel markets and the trajectory of the price reductions across the industry are dynamic and evolving. Clearly, economic analysis of policy support and the effect policy has on innovation is urgently required (Rajagopal et al., 2007).
With respect to the environmental benefits, biofuels can offer considerable Greenhouse Gas (GHG) savings in comparison to fossil-fuels. Environmental benefits are a significant driver for the biofuel industry and policy support, though the quantification of the benefits to the environment is contested. There is, for example, growing evidence to suggest that the GHG savings attributed to biofuels, when indirect land use emissions are considered, is much lower than first predicted (Gallagher, 2008). This has called the environmental sustainability of the first generation biofuel industry and its relatively well supported policy incentives into question. Indeed, although there is a plethora of factors that are supporting the development of biofuels, there are also a number of issues which are hindering their development. These issues can be expressed as constraints, or resistance towards biofuels (Table 3.2). The following sections will review these issues in detail.

3.7. Constraints to emergence, development and uptake

Table 3.2 Constraining factors

<table>
<thead>
<tr>
<th>Political</th>
<th>Economic</th>
<th>Social</th>
<th>Technological</th>
<th>Legal</th>
<th>Environmental</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incorrect use</td>
<td>Small producers</td>
<td>Environmental concern</td>
<td>High costs of 2nd and 3rd generation</td>
<td>Incorrect use of policy</td>
<td>1st generation biofuels – low LCA savings</td>
</tr>
<tr>
<td></td>
<td>High costs of 2nd and 3rd generation</td>
<td>Land availability</td>
<td></td>
<td></td>
<td>Competition with food</td>
</tr>
<tr>
<td></td>
<td>Agricultural development and employment</td>
<td></td>
<td></td>
<td></td>
<td>Degradation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Deforestation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Nutrient leaching</td>
</tr>
</tbody>
</table>

3.7.1. Policy factors

For conventional biofuels, policy is not considered a constraint for development. On the contrary, policy is by far the largest driver of biofuel emergence, development and uptake in almost every biofuel producing nation. However, as mentioned, there are a number of negative issues associated with biofuels. It is known that unsustainable practices are occurring in certain world regions due to underdeveloped policy frameworks and poor understandings of the environmental benefits of biofuels (Searchinger et al., 2008). It is also understood that biofuels can have negative effects on the environment in developed regions if the industry is not regulated properly (IEA, 2011). The basis for many of the arguments against biofuel stem from suggestions that biofuels can, in some cases,
contribute to environmental damage (Fargione et al., 2008), lower emissions savings (Searchinger et al., 2008), lower profitability (Ruan et al., 2008) and increase food prices (Mitchell, 2008).

3.7.2. **Economic factors**

Some biofuel producers are struggling to remain profitable because they are either not contracted to an oil-mill in close proximity or they are not positioned close to a major port or waterway (EU FAS posts cited in EU GAIN report, 2008). The less profitable producers are increasingly being taken over by larger companies (EU GAIN report, 2008) and this situation is thought to be suboptimal for the industry as a whole (Ruan et al., 2008). According to Ruan et al., (2008) the smaller producers benefit from lower capital costs, lower feedstock costs and simplified transportation. If the smaller producers are continually taken-over, the market has a possibility to develop into an oligopoly consisting of two or three large firms with significant market power. This can lead to restricted output and higher prices.

However, many of the negative issues associated with biofuels concern first generation biofuels which convert mainly food based crops such as corn and palm oil into ethanol and biodiesel. Nonetheless, despite promising technologies, for example 2nd and 3rd generation biofuels, the negative issues associated with biofuels are important contemporary issues which continue to have a significant impact on the development of the industry.

As a measure to address the environmental issues there have been a number of efforts to develop sustainability criteria for biofuels. These criteria aim to regulate the industry in terms of the production methods it can/should use and which types of feedstocks and areas of land are suitable. These regulations are seeking to provide reassurance to consumers and governments of the sustainability of biofuels. At the time of writing there are a number of initiatives that have been set up to support the sustainable development of biofuels. These are both international and regional in nature. The other debate concerns land requirements for biofuels, particularly in Europe.

3.7.3. **Technological factors**

There are numerous technological constraints associated with biofuels; however, most of these are related to the emerging second and third generation technologies such as algae biofuel. Conventional biofuel, which dominates the world-wide market, has fewer technological constraints associated with their emergence, development and uptake. One serious constraint of conventional biofuels relates to land restrictions. Conventional biofuels require intensive agricultural management on land which is fertile. This means that biofuel can very often take land that would
otherwise be used for food production. Furthermore, due to land restrictions from development, the availability of land is diminishing. For example, research suggests that biodiesel production is unlikely to meet the demands of the European market because of inadequate production (Hahn-Hägerdal et al., 2006; EU GAIN report, 2008). The EU is finding it increasingly difficult to devote areas of land to biodiesel crops without encroaching on food production or protected forests (Mitchell, 2008; Hahn-Hägerdahl, 2006). Under EU law most forestland is protected from clearing (Hahn-Hägerdahl, 2006) therefore nations with proportionally large coverings of forest such as Sweden, Norway and Germany may lack the potential for a domestic supply (Hahn-Hägerdahl, 2006).

3.7.4. Environmental factors

Environmental constraints related to biofuels are quite complex. There are numerous studies that discuss the undesirable sustainability issues associated with biofuels. Biofuel production has been linked to deforestation, increased emissions and reducing food production. There is evidence that ethanol production in the US may be linked to deforestation of the Amazon (Laurence, 2007), direct and indirect land use change and low life cycle emission savings. There is evidence that suggests biofuel crops have been farmed intensively using large inputs of capital, labour, fertilizers and pesticides (Hill et al., 2006). Surface runoff and leaching from agrichemicals such as Phosphorus (P) and Nitrogen (N) pose a threat to surrounding lakes, rivers and coastal environments from eutrophication and biodiversity loss (Hill et al., 2006; Smith et al., 1999). The emission savings after combustion are often contradictory; for example Fortenbery (2005) reports a 79% savings in CO₂ whereas Hill et al., (2006) reports savings as low as 59%. A detailed study by Mortimer et al., (2002) indicates that most emission savings are contested amongst academics because of the ambiguous forms of assessment. Their evaluation suggests the true figures will vary by as much as 20% depending on the production method. Scharlemann and Laurence (2008) theorised that certain biofuels are more damaging to the environment than the fossil carbon incumbent fuel. At the Westminster Biofuels Conference in 2010, issues of accounting for indirect land use change and life-cycle emissions in underdeveloped countries were acknowledged by all speakers. It appears that these issues are of major concern and require addressing. In fact, the European Commission are in the process of shifting its biofuels support policy, including subsidies, towards advanced biofuels that do not have the detrimental environmental effects. The main change has been to introduce legislation to prevent more than 5% of food crops being used for biofuel (Deutsche Welle, 2012).

Dam (2010) identified 67 initiatives that seek to provide sustainability standards for biofuels across all areas of the supply chain. International initiatives include The Global Bioenergy Partnership (GBEP). This is a worldwide partnership involving 23 countries and 12 international organisations.
The initiative aims to develop a methodology for policy makers and stakeholders to assess the greenhouse gas emissions associated with biofuels. The methodology involves a series of voluntary criteria for assessing emissions as well as examples and guidance of sustainable biofuel practice. Another leading global initiative is the Roundtable on Sustainable Biofuels (RSB). This initiative actively encourages stakeholder involvement in decision making over biofuels. The initiative involves farmers, NGO’s, government departments and inter-governmental agencies (IEA, 2011). There are two more notable initiatives, as mentioned in the IEA (2011) roadmap on sustainable biofuels. The first is The International Organisation for Standardisation’s (ISO) initiatives that seek to develop international ‘best practice’ and develop means to make biofuel and bioenergy more environmentally friendly. The ISO standards also aim make bioenergy more competitive with the fossil energy markets (IEA, 2011). The other initiative is The International Sustainability and Carbon Certification System (ISCC). This initiative developed one of the first certification systems for biomass across international boundaries.

As well as the international initiatives, there are also a number of national and regional sustainability criteria that have been developed. Within the EU for instance, the European Union administered the Renewable Energy Directive (RED) to develop criteria for the sustainability of biomass and biofuels. Under the RED, national governments have set binding targets for renewable energy introduction. The RED measures the sustainability of biofuel before it can be entitled to contribute towards the national renewable energy agreements. Under the RED, only biofuels with greenhouse gas emission (GHG) savings of at least 35% are eligible until 2017. The criteria rises to a 50% GHG saving in 2017 and to 60% in 2018. Within the EU, individual nations can also have their own criteria, for example, Switzerland has provided tax benefits for using biofuels that provided a minimum of 40% GHG saving. In the U.S., the Environmental Protection Agency has set challenging targets for biofuel use; 36 billion gallons by 2022. The U.S. uses a system of Renewable Identification Number (RIN) system to track the production and trading of biofuels.

Thus far this chapter has reviewed the issues relating to biofuels used in the road transport sector. It has been shown that the main biofuels adopted by road users are ethanol and biodiesel. The main type of biofuel produced for the road transportation sector is first generation biofuel made from edible food crops however; biofuels producers and governments are encouraging the development and use of non-edible biofuel feedstocks and second generation production processes. The expansion of the biofuels markets has been driven by the perceived advantages of biofuels compared to the fossil fuel counterparts. These advantages include fuel security, emissions reductions in relation to their fossil-fuels and agricultural support. However, the quantification of
environmental benefits is still unclear and there is growing controversy regarding the sustainability of the biofuels industry amid the rapid expansion of the market. Indeed, biofuels have been associated with a series of negative environmental issues such as indirect land use emissions, global food supply pressures and deforestation. Furthermore, due to relatively high costs associated with the production of biofuels, most markets are heavily supported by government policy and economic incentives. These issues combine to constrain the expansion of biofuels.

However, despite current limitations, liquid biofuel markets are growing at an annual rate of between 6-8% per annum and it is apparent that biofuels will continue play an increasingly important role in fuelling the transport sector for many years (IEA, 2009). However, the growth of the biofuels market is not limited to the road transport sector. In recent years other transportation sectors have begun to show a considerable amount of interest in using biofuels as a low carbon alternative to crude oil derived energy sources. One of the most notable sectors to do so is commercial aviation. Indeed, as discussed in chapter 1, the commercial aviation industry is actively pursuing biofuels as a potential alternative to conventional jet kerosene (Daggett et al., 2006; Hendricks et al., 2009; Marsh, 2008). In the next section, the literature related to aviation biofuels will be reviewed.

3.8. Biofuels for Aviation

As discussed in chapter 1, biofuel may offer the commercial aviation industry the ability to avoid rising and volatile costs of jet fuel whilst lowering GHG emissions across the sector. This is particularly important to the industry due to its rapid growth rate (5% per annum) and limited options in terms of reducing aircraft emissions. As a result, recent advances in the field of aviation biofuels have been particularly rapid. Within the last six years developments have progressed from laboratory based research to full ASTM certification of HEFA and BtL fuels. However, despite rapid developments, the process has not been straightforward and aviation biofuels are not yet commercialised. Conventional biofuels that are already commercialised, such as ethanol and biodiesel, cannot be used in jet aircraft because they congeal and freeze at the low temperatures of high altitude flight (Daggett et al., 2006). Other issues with conventional biofuels include the presence of water, metal contaminates and FAME which are incompatible with turbo-jet engines (Dray et al., 2009). Biofuel developers have thus employed advanced processing methods such as hydrotreating and pyrolysis to make their fuels suitable for jet engines and the low ambient temperatures experienced at high altitude. However, these advanced biofuel technologies are associated with a unique set of issues. To explore these issues, the next section will introduce the
main aviation biofuel types available today and will describe the difference between conventional biofuels and biofuels for aviation.

### 3.8.1. Aviation biofuel types

The main processes to produce aviation biofuel involve ‘hydrotreating’ biological oils to make HEFA fuels or performing gasification of biomass feedstocks and the use of the Fischer-Tropsch process (F-T) (CCC, 2009). Both of these techniques produce a bio-derived straight chain paraffinic hydrocarbon known as Bio-SPK. Bio-SPK has chemical properties that are similar to standard commercial jet fuel (i.e. Jet A/A1) and so have much better flow characteristics at low temperatures. In addition, bio-SPK does not contain FAME, water, metal particles or other contaminants that are not compatible with jet engines. HEFA and F-T aviation biofuel are the most common types that have been used in the aviation biofuel testing programmes and they are consequently the fuels which are likely to achieve commercial viability first (SWAFEA, 2011). Other technologies are however in the development stages. These biofuel technologies include alcohol-to-jet, waste-to-jet and methanol-to-jet (CCC, 2009). As mentioned the aviation biofuel processes were developed to overcome compatibility issues with conventional biofuels. However, even after the compatibility issues were resolved, the fuels needed to be officially certified for commercial use.

### 3.8.2. Certification

In the initial stages of the development process, fuel certification was perceived as being a significant barrier to emergence, development and uptake (Kinder et al., 2008). However, after a lengthy process of testing, in 2011 ASTM certification allowed for the use of biomass to liquid biofuels (BtL) and hydrotreated renewable jet biofuel (HRJ/HEFA) for commercial purposes in up to 50% blends with standard fuel. The 50% blend limit was created in order to guarantee the presence of ‘aromatics’ in the fuel; which are essential for the expansion of fuel seals in the engine (but are not present in aviation biofuels) (Corporan et al., 2011).

However, while certification and flight tests proved the performance and safety of the fuels, aviation biofuels are not fully understood in terms of sustainability. Aviation biofuels may be considered to be advanced biofuels or second generation and therefore more sustainable than first generation fuels. However, depending on the feedstock base which is processed; aviation biofuels may not necessarily be classed as being second generation. This is because the processing technique used to produce aviation biofuels can be carried out on edible or non-edible feedstocks. Only non-edible feedstocks would be classified as being second generation (Worldwatch Institute, 2009). Nevertheless, thanks to the ASTM certification of HEFA and FT aviation biofuels, the technologies
have been given the green light to expand into a commercial alternative to fossil jet fuel. The next developmental step involved flight testing.

### 3.8.3. Aviation biofuel testing

Since 2005 there have been a multitude of engine testing demonstrations that have been used as a means to raise awareness about the fuels. A wide variety of airlines have undertaken aviation biofuel trials (Table 3.3). The initial flight trials, before certification, were undertaken by both legacy carriers and low cost using mainly Boeing or Airbus aircraft. The fuels however were sourced from a variety of feedstocks using a number of different blend ratios ranging from 20% to 50%.

#### Table 3.3. Aviation biofuel trial flights before certification (2008-2010)

<table>
<thead>
<tr>
<th>Carrier</th>
<th>Aircraft</th>
<th>Partners</th>
<th>Date</th>
<th>Biofuel feedstock</th>
<th>Blend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Virgin Atlantic</td>
<td>B747-400</td>
<td>Boeing, GE Aviation</td>
<td>23-Feb-08</td>
<td>Coconut &amp; Babassu</td>
<td>20% one engine</td>
</tr>
<tr>
<td>Air New Zealand</td>
<td>B747-400</td>
<td>Boeing, Rolls-Royce</td>
<td>30-Dec-08</td>
<td>Jatropha</td>
<td>50% one engine</td>
</tr>
<tr>
<td>Continental Airline</td>
<td>B737-800</td>
<td>Boeing, GE Aviation, CFM, Honeywell</td>
<td>07-Jan-09</td>
<td>Algae with Jatropha</td>
<td>50% one engine</td>
</tr>
<tr>
<td>JAL</td>
<td>B747-300</td>
<td>Boeing, Pratt &amp; Whitney, Honeywell</td>
<td>30-Jan-09</td>
<td>Camelina, Jatropha and Algae blend</td>
<td>50% one engine</td>
</tr>
<tr>
<td>QATAR airways</td>
<td>A340-600</td>
<td>TBA</td>
<td>12-Oct-09</td>
<td>Alternative Fuel (Gas to Liquid)</td>
<td>50% all 4 engines</td>
</tr>
<tr>
<td>KLM</td>
<td>B747</td>
<td>GE, Honeywell</td>
<td>23-Nov-09</td>
<td>Camelina</td>
<td>50% one engine</td>
</tr>
<tr>
<td>JetBlue</td>
<td>A320-200</td>
<td>Airbus, JAE, Honeywell</td>
<td>By spring 2010</td>
<td>Sustainable feedstocks</td>
<td>NA</td>
</tr>
<tr>
<td>Inter Jet</td>
<td>A320</td>
<td>CFM, SAFRAN, EADS, Honeywell, Airbus</td>
<td>2010</td>
<td>Salicornia (Halophyte)</td>
<td>27% all engines</td>
</tr>
<tr>
<td>Azul</td>
<td>E-Jet</td>
<td>Embraer, Amyris</td>
<td>2010</td>
<td>Sugarcane</td>
<td>NA</td>
</tr>
</tbody>
</table>

Source: Enviro.aero (2012)

After ASTM certification in 2011, commercial trials of aviation biofuel began (Table 3.4). The first commercial trial was completed by KLM in July 2011 flying 171 passengers from Amsterdam to Paris on a waste cooking oil derived fuel (KLM, 2012). Soon after in July 2011, the first long-term trial was undertaken by the German carrier Lufthansa. The trial consisted of a total of 1,187 flights over a six month period operating on Lufthansa’s regular Hamburg- Frankfurt route. The biofuel used was
derived from a variety of plant and animal fats provide by the finish company Neste Oil (Lufthansa, 2012). The first UK commercial aviation biofuel trial occurred in October 2011 when Thomson Airways flew a Boeing 757-200 from Birmingham (UK) to Arrecife, Lanzarote. A case study of this flight trial forms part of Chapter 7 of this thesis.

**Table 3.4 Commercial aviation biofuel trials since 2011**

<table>
<thead>
<tr>
<th>Date</th>
<th>Operator</th>
<th>Aircraft</th>
<th>Biofuel feedstock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jun 2011</td>
<td>KLM</td>
<td>Boeing 737-800</td>
<td>Waste cooking oil</td>
</tr>
<tr>
<td>Jul 2011</td>
<td>Lufthansa</td>
<td>Airbus A321</td>
<td>Jatropha, camelina and animal fats</td>
</tr>
<tr>
<td>Jul 2011</td>
<td>Finnair</td>
<td>Airbus A319</td>
<td>Waste cooking oil</td>
</tr>
<tr>
<td>Jul 2011</td>
<td>Interjet</td>
<td>Airbus A320</td>
<td>Jatropha</td>
</tr>
<tr>
<td>Aug 2011</td>
<td>AeroMexico</td>
<td>Boeing 777-200</td>
<td>Jatropha</td>
</tr>
<tr>
<td>Oct 2011</td>
<td>Thomson Airways</td>
<td>Boeing 757-200</td>
<td>Waste cooking oil</td>
</tr>
<tr>
<td>November 2011</td>
<td>Continental Airlines</td>
<td>Boeing 737-800</td>
<td>Algae</td>
</tr>
</tbody>
</table>

*Source: enviro.aero (2012)*

### 3.8.4. Partnerships

Although all of the aviation biofuel trials involved short term co-operation between airlines, airframe/engine manufactures, airports and biofuels suppliers; some airlines formed longer-term partnerships with biofuel companies in order to guarantee a supply of aviation biofuel. The UK’s largest airline, British Airways, formed a partnership with the America biofuel company Solena group to co-fund the specialised first waste to liquid aviation biofuel plant in east London (BA, 2011). Virgin Atlantic has signed a similar partnership arrangement with the Swedish biofuel company LanzaTech (Biofuelsdigest, 2011).

Thus far this section has reviewed the main technical developments in the aviation biofuel field however; the review has not yet explored the driving and constraining issues affecting its emergence, development and uptake. In the next sections, the factors influencing the development of aviation biofuel will be explored following the PESTLE framework. Drivers are discussed first, followed by constraints.

### 3.9. Aviation biofuel drivers
A number of studies discuss the factors that are driving the development of aviation biofuel. Notable studies include those by NASA in the United States (Daggett et al., 2006; 2008 and Hendricks and Bushnell, 2009). These studies offered a comprehensive review of the current issues facing the aviation industry. Other US research has been carried out by Hileman et al., (2008) in MIT as part of the PARTNER project; and Danigole, (2007) for the United States Air Force (USAF). Developments have also brought the attention of the world’s media, particularly the engine testing demonstrations such as those by Virgin Atlantic and Boeing.

It is asserted that there are three main drivers of aviation biofuels. These are: the rising price of oil, the desire to reduce the negative environmental effects of burning fossil-carbon fuels and a lack of viable alternative low carbon technologies (SWAFEA, 2011; Rye et al., 2010; Hileman et al., 2009 AEF, 2009). These factors are generally agreed within the studies. Other studies however suggest that carbon pricing; energy security and green image may act as additional factors for aviation biofuels (CCC, 2009; Omega, 2009; Bauen et al., 2009). More specific reports associated with aviation biofuels include the E4tech report. The report was commissioned by the UK government and the research consultancy E4tech (2009) to identify a set of key driving factors using interviews with the aviation and fuels industry. The drivers included:

- relative costs and benefits of carbon savings vis-a-vis conventional fuel
- the costs and availability of commercial jet fuel
- compatibility with existing commercial jet airliners
- concentrated nature of fuel purchasing and distribution in the aviation sector
- corporate social responsibility

The factors identified in the E4tech report can be broadly categorised into economic, environmental and technical drivers. The next section will detail the policy factors.

3.9.1. Policy factors

Although policy support has been shown to be fundamentally important for the development of conventional biofuels for road transport, there are few studies which focus their investigation on policy for aviation biofuels. The Omega report produced by a consortium of UK academics looks at how carbon pricing could be used to incentivise the production and uptake of aviation biofuels. The
report found that administering a carbon price would become increasingly affective with carbon prices approaching $100 based on their models (Dray et al., 2009). In reality however the carbon price is well below the reported figures to induce uptake. European policy issues were also addressed by the European Union report SWAFEA, (2011). In this report measures to induce the phased introduction of aviation biofuels to 2020 are described. Policy measures were assessed using scenarios to measure the likelihood of success using each policy. The first included a quota mandate on aviation biofuels. This measure was suggested to ensure a minimum level of fuel to enter the aviation markets. However, the report shows that such a measure would risk higher biofuels prices and thereby the effectiveness of such a measure would be small. The second measure was to use the EU ETS and a limited biofuel price policy. The report found that the ETS on its own will not be sufficient to induce uptake of aviation biofuels, though the policy may go in some way to bridge the gap between the cost of biofuel and Jet-A. The SWAFEA report arguably lacks significant contributions to policy analysis because it is not clear on the exact measures which can be offered or used. The report finds that making the fuels price competitive with standard jet fuel would cause an aggressive uptake of the fuels but fails to suggest a comprehensive policy framework to achieve this. The third suggestion offered by SWAFEA however was one of controlling the trading of EU ETS permits by not allowing trading to static industries. Under current rules, airlines are able to purchase ETS credits from static industry where the carbon price is greatly reduced. This is because the static industry can reduce emissions much more cheaply than the aviation industry can. If however the aviation industry is forced to trade only among itself, the price of carbon will increase significantly. The SWAFEA report calls this a limited carbon market. The SWAFEA report is the largest investigation into policy measures for aviation biofuels. Indeed, in comparison to the rest of the aviation biofuels literature it is comprehensive. This is however only due to the fact that number of other studies examining supporting policy measures for aviation biofuels is very limited. The next section will review economic factors driving the development of aviation biofuel.

3.9.2. Economic factors

There a number of economic factors suggested in the literature though very few are supported with empirical evidence. Most of the studies theorise about potential drivers for aviation by drawing parallels with the conventional biofuels industry. One of the first drivers usually mentioned is oil price. The aviation industry is portrayed as being particularly vulnerable to increases in oil prices. This became visible in 2008 when oil prices rose to unprecedented highs of $147 a barrel (Mazraati, 2010) resulting in dozens of airlines filing for bankruptcy and numerous others being forced to merge with larger carriers (Hileman et al., 2009). All airline sectors were affected. High profile failures included the transatlantic low-cost/charter airline Zoom (Reuters, 2008), business class
operator Silverjet, low-cost long haul airline Oasis Hong Kong and Denmark’s Sterling (Bloomberg, 2008). High oil prices are mentioned in almost all studies concerning aviation biofuels. It appears that biomass derived aviation fuels are being considered as a potential way to decouple the rising price of jet fuel (CCC, 2009). However, it is also mentioned in all the studies that the price of biofuels is higher than the price of standard jet fuel, so the messages in the literature are conflicted. Studies usually suggest that the price of aviation biofuel will decline significantly in the future (Dray et al., 2009; CCC, 2009: Daggett et al., 2007). Other evidence suggests that some of the interest into aviation biofuel and other alternative fuels is driven by concerns over future fuel supply (Bauen et al., 2009), particularly from a military perspective and for oil importing countries such as the US. In fact, there is research which indicates that the United States Department of Defence (DoD) started public research into synthetic kerosene in 2005 owing principally to fuel security concerns (Danigole, 2007). A program called the Joint Battlefield-Use Fuel of the Future (BUFF) was initiated to investigate the potential for jet turbine applications, the program worked with Sasol synthetic fuels International and Sasol Chevron Holdings Ltd, the first company to commercialise synthetic jet fuel from coal (Lamprecht, 2007).

Other studies suggest that economic factors such as carbon pricing⁴ may have an influence on the aviation biofuels. Although this can also be considered a policy driver, carbon prices make the cost of standard jet fuel more expensive, thereby making the carbon price issue an economic driver. The Omega study and the E4tech report carried out for the CCC showed that the costs of the EU Emissions Trading System (EU ETS) will be a potential driver for early adoption of aviation biofuels due to the fact that the introduction of biofuels may an easier way to reduce costs than to investigate increases in efficiency or fleet renewal. Furthermore, under the EU ETS it is suggested that aviation biofuel will be classified as a zero emission fuel. This means that an airline will require no extra credits for its use (Buean, 2009; Anger and Köhler, 2009). The Omega report although failing to recognise the zero accounting procedure, forecast the scale up of aviation biofuels using econometric modelling; this forecast considerable incremental cost improvements and efficiency increases up until 2030. The UK’s Committee on Climate Change (CCC) (2009) carried out similar modelling. The models incorporated learning-by doing elements, complex interactions with global markets as well as the policy influence from the EU ETS into the uptake and development forecasts. However, although the CCC report uses economic factors, it acknowledges that none of these factors is conclusive in determining to what extent biofuels will be used in aviation. Most of the factors are similar to those which attracted the road transport sector. Furthermore, it fails to investigate the

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⁴ Carbon pricing is a system of charging for the emissions output of a company. The carbon pricing system can also incorporate cap on total emissions and/or trading of emissions permits (Bowen, 2011).
impact of economic policy support for the fuels development. This is surprising given the fact that there is a great deal of evidence that conventional biofuels markets have benefited strongly from economic policy support. As well as the economic factors driving the development of aviation biofuel, social factors may be important for the emergence, development and uptake of aviation biofuels.

### 3.9.3. Social factors

Social drivers of aviation biofuels are considered in the literature though it appears that the term is not discussed in isolation. Frequently, social factors are discussed, in combination with economic and environmental issues. Indeed, the main social drivers are perceived as being economic welfare gains attributed to reduction in greenhouse gas emissions and job creation (CCC, 2009). Airlines and governments do consider the corporate social responsibility of aviation. Studies suggest that social factors will play a role in driving aviation biofuels (SWAFEA, 2011; CCC, 2009; Dray et al., 2009; Marsh, 2008). The CCC report found that the corporate social responsibility of airlines does create a weak driver for the emergence and development of the fuels however it may not be as significant as cost saving and energy security. Instead, most aviation biofuel studies mention some form of socio-economic or socio-environmental factors as driver’s aviation biofuels (Daggett et al., 2007; CCC, 2009; Dray et al., 2009). Indeed, it appears that the driving factor is rarely discussed purely as a social issue, particularly considering that the general consumer of aviation has zero control over the purchase of the fuel in the aircrafts. The development of the fuels is driven at the industry level. The drivers are therefore more closely linked with environmental, economic, policy and technological factors. Following the PESTLE framework, the next driver is technological.

### 3.9.4. Technological factors

As well as the policy, economic and social/economic factors, there is an additional reason why the aviation industry needs to develop an alternative fuel. The main reason is related to the technological options available to the industry. At the current time there are few technological options that can drastically reduce emissions and avoid oil price rises while maintaining growth and profitability (Blakey, 2011; CCC, 2009; Marsh, 2008). The aviation industry is heavily constrained by technology in terms of engine and airframe design, as well as the fact there are few alternatives to rapid mass transport (Omega, 2009; Lee et al; 2009). Despite incremental fuel efficiency improvements and reductions in emissions and noise over the past 30 years, the industry is reaching a point of diminishing returns as incremental efficiency gains are overtaken by increasing number of flights (Lee et al., 2009; Dray et al., 2009). This creates a strong demand for alternative fuels which both support fuel security and address environmental concerns while maintaining the use of current
infrastructure and aircraft. Examples of technologies which are not viable include hydrogen fuel and electric propulsion; which are either cost prohibitive or technically not possible with current technology owing to poor power to weight ratios (Dray et al., 2009). However, other efficiency saving technologies such as fleet renewal and enhanced air traffic management procedures (such as continuous decent approaches) are useful measures to adopt as well but, they will not by themselves deliver the considerable reductions in emissions which are required. One of the best ways to address this issue is to operate existing engines and aircraft with lower carbon fuel such as biofuel.

As mentioned in the previous section, a key factor which is addressed in most aviation biofuel studies relates to the environment. Indeed, the environment is a significant factor for aviation biofuels because it is believed that they may lead to reductions of GHG emissions well above those afforded by other technologies.

3.9.5. Environmental factors

The commercial aviation industry is being put under increasing pressure from governments and the general public to address its environmental impacts amid growing concern that aircraft emissions are negatively effecting the environment (IPCC, 1999; Omega, 2009). Some of the aviation biofuel literature discusses the environmental impacts of aviation by showing that the bulk of the atmospheric impacts of aircraft operations are caused by the exhaust gases of aircraft during flight, particularly CO\textsubscript{2} and Nitrous oxide (NO\textsubscript{x}) (IPCC, 1999; Lee et al., 2009). In percentage terms, engine CO\textsubscript{2} emissions are thought to make up around 2-3% of the entire anthropogenic CO\textsubscript{2} emission contributions, depending on which source is used. Emissions from aircraft alter the chemical composition of the atmosphere, thereby contributing to a phenomenon known as radiative forcing (RF) and ozone depletion (IPCC, 1999; Stern, 2006). Radiative forcing is the formal definition adopted by the IPCC to explain the mechanisms for the global warming phenomenon, often referred to as the greenhouse effect. Trace particles of Nitrous dioxide (NO\textsubscript{2}), Sulphur dioxide (SO\textsubscript{2}), Carbon monoxide (CO), methane (CH\textsubscript{4}), Hydrocarbons (HC's) and soot are also present in aircraft emissions though these emissions have less quantifiable effects on the environment (Macintosh and Wallace, 2009). The Intergovernmental Panel on Climate Change (IPCC) carried out a report in 1999 that concluded that global aviation travel contributes around 3.5% of total anthropogenic radioactive forcing (IPCC, 1999). However, although aviation biofuels are not mentioned significantly in these atmospheric studies, the findings from key atmospheric emission studies are frequently acknowledged as being motivations for pursuing low carbon technologies such as aviation biofuel (Marsh, 2008; CCC; 2009; Dray et al., 2009).
As well as the scientific evidence that commercial aviation is affecting atmospheric chemistry, government and industry targets for emission reductions also act to drive the development of biofuels. In the most recent Committee on Climate Change report initiated by the UK Government, it was suggested that the UK aviation industry will be required to curtail aviation growth to 60% between now and 2050 in order to stay within the targets set by the UK government (CCC, 2009). This is despite the projected growth projections of some 200% according the CCC. Globally, the air transport industry is attempting to meet the target of carbon neutral growth by 2020, and the 75% CO₂ reductions established by the European Commission’s Flightpath 2050 report. In these studies, biofuels are seen as a viable addition to the range of emission mitigation methods that the aviation industry is pursuing (EC, 2011). The reports however fail to assess the key challenges involved in the emergence, development and uptake of an aviation biofuel industry. Indeed, although some studies use forecast modelling to assess the likely uptake scenarios for aviation biofuels, there is an almost complete lack of discussion surrounding how, for example, environmental policy may be used to effectively influence the development of aviation biofuels. This is, again, surprising given the fact that there is strong evidence to suggest that environmental policy support and controls on biofuel is essential for the successful development of a biofuels market.

Despite the numerous driving factors for the emergence, development and uptake of aviation biofuels, there are also a number of constraints that must overcome before they can be fully implemented into existing infrastructure. Some of these issues are well acknowledged in the literature and generally agreed by all parties. Others however are not; particularly those which focus on infrastructure, policy issues and the ability of technology to increase efficiency and lower costs soon enough to take advantage of economies of scale. In fact, the number of studies which focus on infrastructural constraints and policy issues, particularly from a stakeholder perspective, is small.

Although there is a general lack of understanding, there is an acknowledgement of several constraining factors affecting aviation biofuels. These issues are expressed in almost all of the studies, though some are now out of date due to development in certification and testing. The next section will review these constraints.
3.10. Constraints to the emergence, development and uptake of aviation biofuel

There are several barriers to the emergence, development and uptake of aviation biofuels, these include high costs (Daggett et al., 2010), land availability issues, issues associated with environmental sustainability, issues associated with policy (SWAFEA, 2011) and issues associated with certification (Kinder, 2009). Some issues expressed in the literature are however out of date due to recent advances in the technologies and certification.

The final section will review the technical factors. Technical factors are commonly acknowledged in the biofuels literature as being significant issues for the emergence, development and uptake of the technology. The technical factors are however usually closely linked to either economic factors such as cost or environmental factors such as emissions. In previous sections, economic, environmental and technical factors have been reviewed showing that various factors act to drive the technology. There has however been little discussion surrounding the influence of policy for aviation biofuels.

3.10.1. Policy factors

With the exception of the SWAFEA report (2011), policy is not discussed in great detail in much of the aviation biofuel literature. This is surprising given the fact that the SWAFEA (2011) study states that the provision of policy is lacking for aviation biofuels. The SWAFEA report mentions that more policy support is required for aviation biofuels however it does not offer comprehensive suggestions of how or where to allocate policies. Other studies such as the CCC (2009) and Dray et al., (2009) cite certain policy issues as being perhaps ineffective such as the EU ETS however, most studies assume that policies will either not needed or the EU ETS will become affective within 10-20 years. The SWAFEA study disagrees with the CCC and Dray et al., (2009) and states that within the EU, more policy support is required for aviation biofuels. The next section reviews the economic issues.

3.10.2. Economic factors

As well as policy issues, other constraints exist such as high costs and low efficiency of the conversion technologies. The SWAFEA report acknowledged that the high costs involved with aviation biofuels are significant constraints for the development of the technology. Furthermore, the issues are uncertain; thereby creating a significant limiting factor for the technology (SWEFEA, 2011). Investment is a further issue which is acknowledged in the report but not supported by any empirical evidence. These issues are considered to be significant; though there is not a great deal of literature
which explores them in detail or that offer solutions. Some reports recommend using policy measures similar to those offered to conventional biofuels as a means of increasing demand for the fuels such as the CCC report (2009) however, again, these reports seldom use empirical research to support their conclusions. The majority of other research is focused on aspects relating to bio-chemistry, feedstock investigations or aeronautical engineering developments i.e. combustion analysis or emissions analysis. It appears that policy issues are the least explored.

3.10.3. Technological factors

The constraint surrounding the need to withstand freezing temperatures at high altitude for instance, which has now been overcome due to new processing techniques, is expressed in Charles et al., (2007); Pahl and McKibben, (2008); Dray et al., (2009); Lee et al., (1997) and Nygren et al., (2009). Other papers, such as Wardle, (2003) offer some of earliest analyses of how small blends of biodiesel may be used in existing airport infrastructure to fuel aircraft. However, Wardle also mentions the potential issues with contamination and logistical issues with separated fuel lines using biofuel in aircraft. Due to the fact that certification was perceived as such as large barrier, these early studies do not portray aviation biofuels in a positive light.

Other studies were more knowledgeable of the certification progress and therefore understood that aviation biofuel production technologies are available. These studies include Daggett et al., (2006) that acknowledges that the use of first generation biofuels for aviation is a non-starter. FAME can freeze at the low temperatures experienced at high altitude, potentially damage the aircraft engine and lead to total loss of power. Daggett et al., (2006) go on to suggest that F-T fuels are the most likely fuels to be used because of the chemical similarities to kerosene. Bio-SPK (HEFA) was also suggested as being the first probable certified aviation biofuel because it is almost chemically identical to kerosene (Kinder, 2009). The study by Daggett et al., (2006) expresses knowledge of the then impending ASTM certification of aviation biofuels and therefore shift their attention towards the need for the fuel to be a compatible with existing infrastructure and mixing facilities. Indeed, it was stated that conditional to all alternative biofuel technologies is the ability of the fuel to be a drop-in replacement for jet kerosene (Daggett et al., 2006). Of particular concern were fuel contaminates a major issue for airlines and engine manufactures. However, few studies actually discuss the issues associated with infrastructure in any detail. Indeed, these issues appeared to be under developed in the literature. Most studies mention the prohibitive costs to convert infrastructure and aircraft technology to support a new fuel supply (Omega, 2009; CCC, 2009; Kinder, 2009) but very few investigate the issues in detail.
After the certification issues, the main constraints include land availability limitations (CCC, 2009; Dray et al., 2009; SWAFEA, 2011). This issue is brought across directly from the conventional biofuels literature considering both technologies will experience similar land availability constraints. However, the feedstock demands for producing aviation biofuels will add a serious strain on supply because the conventional biofuel market is growing at rate of 6-8% per year (IEA, 2009). Current and future production methods and feedstocks for biofuels are acknowledged to be insufficient to supply both the growing road transport sector and aviation (CCC, 2009; Daggett et al. 2007; Omega, 2009). Research from the UK includes the E4tech report which was carried out for the CCC (2009) and the academic Omega research group (2009) who initiated an investigation into alternative fuel options. Blakey et al., (2011) also carried out a detailed evaluation of the various alternative fuels available to aviation; which included a consideration of aviation biofuels.

Other NASA funded research includes; Bomani et al., (2009) who investigate the past, present, and future biofuel alternatives for aviation. They carried out a holistic review of feedstocks and production methods currently available for aviation biofuels and concluded that; although there are many options, the search for the best and most viable is still a global task. The report warns of the potential supply issues with current biofuel technologies in terms of land requirements. However, they also state that algae have the greatest potential to generate biofuel volumes in order of magnitude higher than existing techniques. Hendricks and Bushnell (2009), also NASA research, review the potential feedstocks for aviation biofuel and conclude that the major constraint is actually cost, not technological knowhow. It is found that Bio-SPK and Hydrotreated renewable jet (HRJ) are equivalent in performance to kerosene and there are a number of feedstock options which have the potential to act as complete drop-in replacements.

Daggett et al., (2006) offer a thorough review of the developments in alternative fuels. The study looks at the use of biofuels, synthetic kerosene, methanol, liquid natural gas and hydrogen as potential alternatives to Jet-A. The study found that (at the time of writing in 2006) the only viable option was to use synthetic kerosene derived using the Fischer-Tropsch process, because of constraints with freezing. However, they acknowledge the fact that synthetic kerosene derived from coal or other fossil-carbon fuels will actually have zero environmental benefits compared with conventional kerosene. Biofuels have good potential according to Daggett et al., especially when blended in small quantities such as 5 to 20%. It is unlikely that freezing points will be affected at these concentrations. The study also recognised that first generation biofuels are unlikely to be used because they require a second stage of processing in order to meet the high-performance standards of kerosene. However, the business case amid rising oil prices makes biofuels likely in the near term.
3.10.4. Environmental factors

In terms of the environmental concerns surrounding aviation biofuels, studies acknowledge the controversy which is attached to conventional biofuels. Marsh (2008) reviews the developments and issues associated with both aviation biofuels and synthetic kerosene. Marsh highlights the controversy attached to existing biofuels and indicates that the issues for aviation are complex and uncertain. The study summarised the developments in synthetic kerosene production, citing the US Air Force as a significant driver for the recent developments. Drivers for commercial aviation are discussed briefly, though Marsh refers to these as ‘civil’ drivers. The paper then discusses the leading initiatives and companies involved in research into the conversion technology for both synthetic kerosene and biofuels. Although the paper offers an economic evaluation of the current issues, the conclusions of the study are however that the overall outlook for biofuel in aviation is uncertain and controversial.

The next section will review the future perspectives and recommendations for aviation biofuel which are offered in the literature. This will provide insights into the direction of aviation biofuel development and the expected growth of the industry. For this section, the PESTLE framework will not be used to analyse the issues.

3.11. Future perspectives

Most studies make recommendations regarding the future of biofuels within the commercial aviation industry. Studies such as the CCC investigation model three scenarios for expansion; (1) likely, (2) optimistic and (3) speculative. Their perception of the future of aviation biofuels are based on comparisons of the conventional biofuel industry. Indeed, the modelling methodology involves using existing production possibilities from the conventional biofuels infrastructure. Their investigation found that under a ‘likely’ scenario there will be a biofuel uptake of around 10% by 2050. Under an ‘optimistic’ scenario they assume 20% market penetration by 2050, whereas under a ‘speculative’ prediction they assume a 30% penetration of aviation biofuel. Although the report is detailed, recommendations regarding incentivising or supporting aviation biofuels are absent. The three scenario model is furthermore indicative of the uncertainties surrounding the likely future of aviation biofuel. The CCC report does however conclude that the future technologies need to be supported through continued research and design. The report calls for greater development of these fuels and more research into the development of these advanced aviation biofuels which have higher emissions reductions and do not encroach on the global food supply.
The Omega study carries out a similar modelling investigation to the CCC in their analysis of European Airspace mitigation methods (Dray et al., 2009) however, their findings are much more optimistic than the CCC’s. They assume that a 50-50 blend of biofuel will be available from 2020 onwards. They also find that the use of biofuels will be influenced heavily by the introduction of the EU-ETS and thus further policy incentives may not be needed. This contradicts the SWAFEA study which highly recommends the development of policy measures for aviation biofuel (SWAFEA, 2011). An additional Omega assumption is made that if a large amount of aviation biofuel is taken up by the commercial aviation industry, other emissions mitigation methods will be made redundant, particularly those which are more expensive. The Omega project states also that there is greater research and development needed in the advanced aviation biofuels technologies such as algae-derived biofuels, though there are few policy recommendations given in the report.

Danigole, (2007) US-based study, which was funded by the United States Air Force, investigates future uses of ethanol, terrestrial produced biodiesel, algae oil and biobutanol. The study concludes that support from the US Government and Air Force should be continued and developed based on the energy supply security benefits that the fuels may offer. Indeed, this was the focus of the study Daggett et al., (2006); Hendricks and Bushnell (2009) and Bomani et al., (2009; who make clear recommendations for future research into feedstocks bases, processing technologies and sustainability research surrounding the aviation biofuels. However, again, specific policy measures and government incentives are not expressed in these studies.

The SWAFEA (2011) is the most comprehensive report to date. The report gives clear messages about the need to create more efficient production processes for aviation biofuel with higher transformation yields. The focus of their recommendations is on the advancement of supply; which they see as a significant constraint for the aviation biofuel industry. Recommendations were to introduce a 10% target for renewable energy in all transport sectors and to create a ‘moderate’ goal of between 1-2% uptakes of aviation biofuel in aviation by 2020. The SWEFA report does make it clear that there needs to be affective incentives schemes for aviation biofuels; in particular, the harmonising of policies for biofuel sustainability at the International Civil Aviation Organisation (ICAO) level. Like the NASA funded studies, the SWAFEA report questions the current sustainability assessments of biofuels and recommends the harmonizing of regulations globally. The report also supports the increased stakeholder awareness about aviation biofuel; which the report finds is lacking. The bottom line recommendations from the report are however to direct strategies towards the wider bioenergy sector which needs a comprehensive and long term strategy for the production of biomass which includes aviation biofuels. Although the SWAFEA study is comprehensive and
offers many useful high level recommendations; the report lacks lower level recommendations for stakeholders such as the issues associated with airport infrastructure, airline financing, partnerships with biofuel companies and other business related issues.

3.12. Summary

This literature review has revealed that there are a great number of studies related to conventional biofuels but comparatively few aviation biofuel studies. It has shown that there is an established and growing market for biofuel in the road transport sector due to the benefits of lower emissions, fuel security, and rural economic development. Due in part to the successes of the road sector, other transport sectors are showing interest in using biofuels as a means to lower emissions and improve fuel security. Although the rail and shipping sectors have expressed interest in the fuels, by far the most prominent sector to advocate biofuels has been aviation. Indeed, in the last six years the developments within the field of aviation biofuel have progressed from laboratory based experiments to the certification of HEFA and F-T biofuels for commercial use. However, the speed of these developments have not been supported by research into significant areas such as feedstocks, land availability, policy support, costs reductions and government/industry strategies to support the development of the industry. Crucially, the number of peer reviewed studies within the field of aviation biofuel is extremely limited. Although, the number of studies is growing, there is a lack of empirical stakeholder research and a distinct lack of recommendations for development. Aviation biofuels are currently in a position of being technically viable yet not cost effective enough to be a self-supported market. It is clear that if the aviation biofuel market is to succeed it requires, perhaps, a similar policy support mechanism as that enjoyed by the road transport sector. Although the SWAFEA (2011) study makes this very clear, the area is underdeveloped. Other areas of particular scarcity are studies which look at potential government policy issues. Furthermore, recommendations offered at the stakeholder level (i.e. challenges which will be faced by individual airlines and airports) are very limited. As a result, issues surrounding the development of aviation biofuels are unclear and the technology is arguably not developing in the most efficient manner possible as a result.

In light of these findings, there is a compelling need to pursue further research within the aviation biofuels field. The aim of this thesis is to investigate the factors affecting the emergence, development and uptake of aviation biofuels. At present there are no specific policy frameworks or strategies in place to support the emergence, development and uptake of aviation biofuels. This may be putting severe pressure on the industry at a time when the technologies are entering a vulnerable stage of development. SNM theory furthermore suggests that sustainable technologies
which are radically different from the incumbent, such as aviation biofuel, are even more vulnerable to failure and must be supported into a niche market. The literature review has revealed also that the emergence, development and uptake of aviation biofuel is likely to be an iterative process due to the complexity of the driving and constraining issues facing the technology. Some of the issues have been discussed already however it is clear that there are large gaps in the literature. Although the scope for further research is quite large, of particular interest is the role of the aviation biofuels stakeholder. It is shown that some airlines, without the aid of government, are developing partnerships with the biofuels industry in order to develop their own supply of aviation biofuel while others are forming partnerships and consortia to develop the technology. It appears that government involvement may be lacking. It would be essential to establish the issues which are faced by stakeholders in order to make better recommendations for supporting the development of aviation biofuels.
Chapter 4

Research Methods

4.1. Introduction

In chapter two the theory of Strategic Niche Management (SNM) was presented as the theoretical underpinning to guide the discussion process. This was followed by a review of the issues affecting the emergence, development and uptake of aviation biofuel. It was evident that there is a dearth of academic research in the aviation biofuel field, particularly surrounding issues which are affecting stakeholders such as lack of investment and policy support. Crucially, research is needed to: (1) explore the issues related to the drivers and constraints of aviation biofuel at the stakeholder level and (2) to investigate the potential supporting measures and policies that are suitable for the deployment of aviation biofuels. In Chapter four, the methodological approach used in this thesis is detailed. Firstly, the research aim, research paradigm, objectives, research design and research questions will be discussed before details pertaining to the methods that are used in this thesis are presented.

4.2. Research aim

The aim of this thesis is:

| To investigate the factors affecting the emergence, development and uptake of aviation biofuel |

The research aim is formulated based on a number of factors. The primary factor is the research gap identified in the literature. As mentioned, there is a dearth of stakeholder and policy based research surrounding aviation biofuels. Also, as discussed in chapter two, further research within these areas is needed given the potential environmental and economic benefits that the fuels could have for the aviation sector. Following De Vaus (2001) recommendations for focusing and clarifying ‘the research question’, further factors need to be considered during the formulation of the research aim including: the potential geographical scope of the research, the technological scope of the research area, the time frame available to carry out the research and the unit of analysis of the research.

The geographical scope of this research is international to reflect the global nature of the aviation industry and the geographic spread of aviation biofuel producers. The international nature of the study will also be considered when deciding upon the methods that will be employed. The scope of the research will focus on HEFA and F-T fuels which are tested and fully certified for commercial use.
This is because it is not unreasonable to assume that these fuels are more likely to enter a niche market first; thus they are most pertinent to the research aim. The third factor considered is the time frame of data collection; this factor is considered given that aviation biofuel developments are occurring rapidly. Although a longitudinal aspect to the research design is attractive, due to constraints of time and cost, the research design is chosen to be fundamentally cross-sectional i.e. temporal changes in the aviation biofuels field will not feature in the research aim or objectives. The rationale for this approach is discussed in more detail later in this chapter. The final factor that was considered is the unit of analysis of this study. The unit of analysis for this thesis will be commercial aviation biofuel stakeholders including airlines, airframe and engine manufactures, airports, petroleum suppliers, policy makers, academics and biofuel producers. This will act as a practical unit of analysis in terms of collecting primary data.

With the research aim established, the research paradigm, objectives and research questions can now be detailed. The next section discusses the research paradigm and epistemology.

### 4.3. Research paradigm and epistemology

Before outlining the research methods, objectives and questions; the research paradigm is discussed. The research paradigm describes the way a researcher interprets the world and therefore how they will analyse and discuss it (Guba and Lincoln, 1994). It is very important to understand what the research paradigm of the research is because it will significantly influence the research objectives, questions and research design that are ultimately used. In science and philosophy, investigation is governed by different paradigms (ways of interpreting realities and observations in the world), examples include: positivism, postpositivism, pragmatism and constructivism. Within these paradigms there are different ways of characterising the philosophical grounding of the paradigm. For instance Guba (1990) stated that paradigms can be characterised and separated into ontological, axiological, epistemological and methodological layers. These layers are summarised in Table 4.1.
<table>
<thead>
<tr>
<th>Table 4.1 Research paradigms</th>
<th>Positivism</th>
<th>Postpositivism</th>
<th>Pragmatism</th>
<th>Constructivism</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ontology</strong></td>
<td>Positivists are realists. They state that facts are revealed through experience or observation. Non observable events are not valid for investigation.</td>
<td>Postpositivists are critical realists. They know things exist but the researcher believes that the research themselves influence what they are trying to measure.</td>
<td>Pragmatists will take the most appropriate truth from the observations depending on the context of the research.</td>
<td>Constructivists are known as relativist. They believe that facts are merely interpretations of the researcher’s observations and experience.</td>
</tr>
<tr>
<td><strong>Axiology</strong></td>
<td>Positivists are totally impartial and unbiased.</td>
<td>Postpositivists believe that values can be observed but they should be controlled in understand their influence.</td>
<td>Pragmatists believe that values can be observed but they do not necessarily make them valid.</td>
<td>Relativists think that all research contains values.</td>
</tr>
<tr>
<td><strong>Epistemology</strong></td>
<td>Positivists are objective. They believe they are independent of the observations and therefore have no influence.</td>
<td>Postpositivists are still objective like positives but they believe that replication of results reinforces the observation</td>
<td>Pragmatists are flexible. They are neither objective nor subjective.</td>
<td>Relativists are subjective. They believe the research findings are influenced by the researcher</td>
</tr>
<tr>
<td><strong>Methodology</strong></td>
<td>Experimental</td>
<td>Experimental</td>
<td>Holistic</td>
<td>Hermeneutical</td>
</tr>
<tr>
<td></td>
<td>Testing hypotheses.</td>
<td>Testing of null hypothesis. Research is carried out in natural settings</td>
<td>Researchers are objective and subjective. The researcher includes elements of social understanding</td>
<td>The research investigations the subject by interacting with it.</td>
</tr>
</tbody>
</table>

**Source: Guba and Lincoln (1994); Creswell (1994)**

Due to the fact that the research approach of this thesis will combine qualitative and quantitative data and use a variety of methods including interviews and a case-study (see section 5.5), the ontological stance of the research adopts a predominately postpositivist approach. Postpositivism is a metatheoretical paradigm that posits that knowledge is ultimately based on human conjectures rather than unchallengeable, often quantitative, foundations (Guba and Lincoln, 1994). However, the research also draws upon elements of the constructivist paradigm in recognition that the evidence obtained about aviation biofuels is ultimately subjective individual interpretations, perspectives and stakeholder observations. In this way, the researcher will in some way influence the outcomes of the research. Constructivism however posits that research and investigation should be carried out by interacting with subject. The next section discusses the research objectives and questions.
4.4. Research objectives and questions

The research aim will be realised through five research objectives. These objectives in turn are informed by a series of individual research questions (Table 4.2). The research questions are designed to yield suitable data that can be analysed to adequately answer the research objectives, and in turn address the aim. This follows Creswell’s (1994) suggestions that the research process should be divided into stages; thus creating a procedure which is manageable and systematic.
### Table 4.2. Aim, objectives and research questions

**Aim: To investigate the factors affecting the emergence, development and uptake of aviation biofuel**

<table>
<thead>
<tr>
<th>Objectives</th>
<th>Research Questions</th>
<th>Method/s</th>
</tr>
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</table>
| 1. Situate the emergence, development and uptake of aviation biofuel within existing theoretical literatures on technological change | 1. What are the key stakeholder issues associated with the emergence, development and uptake of aviation biofuels?  
2. What is the state of stakeholder knowledge surrounding aviation biofuel? | Literature review                                                                   |
| 2. Identify the political, economic, social, technological, legal and environmental factors affecting the emergence, development and uptake of aviation biofuel | 3. What drivers, if any, are the most important factors motivating the development and uptake of aviation biofuels?  
4. What constraints, if any, are the most significant barriers to the development and uptake of aviation biofuels?  
5. What support measures are the most important for the development and uptake of aviation biofuels? | Scoping study                                                                      |
| 3. Investigate the relative importance of these factors for the continued emergence, development and uptake of aviation biofuel | 6. What support measures are currently in place to support the commercialisation of aviation biofuels?  
7. How can support measures be used to influence the development and uptake of aviation biofuels?  
8. What role can strategic niche management (SNM) play in the development and uptake of aviation biofuels? | In-depth online Survey                                                              |
| 4. Analyse the support measures currently available for the development of aviation biofuel. |                                                                                     | Case-study & Semi-structured Interviews                                               |
| 5. Make recommendations for strategies that will support the development and uptake of aviation biofuel. |                                                                                     |                         |
Objective 1 - Situate the emergence, development and uptake of aviation biofuel within existing theoretical literatures on technological change

Objective 1 explores the contemporary and historical issues associated with aviation biofuels; this is the starting point of the research process and therefore the broadest research objective. This objective will be addressed through a literature review involving academic, industry and official ‘grey’ literature. The literature review is used to investigate the main factors associated with the emergence, development and uptake of aviation biofuels. The literature review will also be used to identify potential areas of research and so provide a suitable route of enquiry for the rest of the research.

Objective 2 – Identify the political, economic, social, technological, legal and environmental factors affecting the emergence, development and uptake of aviation biofuel

This objective is the second stage of the research process. As mentioned, it is necessary to explore further the issues identified in the literature review. To fulfil objective 2, a scoping study is used. The study involves 12 semi-structured telephone interviews with stakeholders in the aviation biofuels field. During the formulation of the research aim, the unit of analysis was chosen as being the stakeholder. The stakeholders identified using principles from stakeholder theory; a theory which is embedded in the management science literature. This will be discussed in more detail later in the methods section (section 5). The scoping study acts to explore further the issues from the literature and provide a focused route of enquiry for the remainder of this thesis. The scoping study also acts as a platform to obtain more stakeholder contacts for the latter stages of research via the snowballing technique.

The research questions are:

1. What are the key stakeholder issues associated with the emergence, development and uptake of aviation biofuels?
2. What is the state of stakeholder knowledge surrounding aviation biofuel?
The third research objective is to analyse the significance of the issues obtained from both the literature review and scoping study. This entailed analysing the relative importance of the aviation biofuel issues.

**Objective 3 - Investigate the relative importance of these factors for the continued emergence, development and uptake of aviation biofuel**

In the literature review and in the scoping study interviews the relative importance of the issues was not analysed. Analysing the importance of the issues is however essential in the main stages of this thesis where recommendations for supporting measures will be necessary. It will be crucial therefore to enlarge the study to incorporate a greater number of stakeholders which will allow for more robust conclusions to be made. Objective 3 therefore is to enlarge the sample size using a web-based survey and Likert scale questioning. Again, stakeholder theory is utilised to aid in the identification of relevant stakeholders – though this will be discussed in more detail later. The research questions for the web-based survey are:

3. **What drivers, if any, are the most important factors motivating the emergence, development and uptake of aviation biofuels?**
4. **What constraints, if any, are the most significant barriers to the emergence, development and uptake of aviation biofuels?**
5. **What support measures are the most important for the emergence, development and uptake of aviation biofuels?**

After establishing the relative importance of these issues, the next objective is to investigate the various supporting strategies that may be available to support aviation biofuel.

**Objective 4 – Analyse the support measures currently available for the development of aviation biofuel.**

Objective 4 is designed to examine the current level of support available for aviation biofuel i.e. it will seek to identify what research funding, policy measures, grants and stakeholder investment are currently being provided to support the emergence, development and uptake of aviation biofuels. This is examined because the literature review revealed that the success of the conventional biofuel markets was heavily influenced by supporting measures. Objective 4 was fulfilled using a combination of three methods. The first analyses data from the latter half of the web-based survey. The latter half of the survey will attempt to establish what support packages are available to aviation
biofuels and how important these support packages are for the emergence, development and uptake of aviation biofuel. The second uses findings from a case-study of the UK’s first commercial aviation biofuel flight test. The case-study will be used to build an in-depth understanding of a single protected space for aviation biofuel. The data will be used to analyse the issues facing the aviation industry in terms of flight testing, as well as the importance of flight testing for the emergence, development and uptake of aviation biofuels. It will also establish how important the application of flight testing is as a means to support the development of the fuels. This information is particularly important for assessing the suitability of using strategic niche management theory within the context of aviation biofuels. The third method utilises data from a third stage of research in the form of in-depth stakeholder interviews. The interviews will differ from those of the scoping study in that they will provide much more focused questioning orientated towards assessing the support measures available to aviation biofuel technologies. The scoping study interviews provided a broad band of questioning interested in identifying the main driving and constraining issues faced by the industry. The third stage interviews however will explore what type of support measures currently exist and how they are being used to aid or indeed hinder the emergence, development and uptake of aviation biofuels.

The research questions for this objective are as follows:

6. What support measures are currently in place to support the emergence, development and uptake of aviation biofuels?
7. What measures can be used to support the emergence, development and uptake of aviation biofuels?
8. What role can strategic niche management (SNM) play in the emergence, development and uptake of aviation biofuels?

The final objective is designed to narrow the research focus further; this time focusing on recommendations for supportive measures for the development of aviation biofuels.

Objective 5 – Make recommendations for strategies that will support the development and uptake of aviation biofuel.

Objective 5 will focus on how strategic niche management theory (SNM) could be used to overcome the known barriers of high costs, lack of investment and sustainability within a UK setting. The objectives reflect upon the data from the previous four objectives, the SNM theory and the literature will be used to form an objective opinion regarding the way forward for aviation biofuels. The aim is to make specific recommendations for the emergence, development and uptake of
aviation biofuels based on the theory of strategic niche management however; wider recommendations will also be made surrounding the global picture of aviation biofuels.

Thus far this chapter has outlined the research aim; objectives and research questions that are formulated for this thesis. However, as yet there has been no detailed discussion of the research design. The research design will be influenced by the research objectives and questions that have been outlined, however, it is also essential for ensuring that the research aim is successfully realised (De Vaus, 2001).

4.5. Research design

The research design is not a method for collecting data. Research designs differ fundamentally from research methods because they do not describe the approaches of collecting primary data, instead; it describes the structure of the research process. To formulate a suitable research design, the type of research that is required needs to be established. There are fundamentally two types of research - descriptive research and explanatory research.

Descriptive research is research which seeks to establish ‘what’ is happening (Creswell, 2007). The research method is therefore limited to surveying of contemporary and historical evidence and case-studies. Descriptive research asks questions such as ‘how many people use public transport?’ or ‘are Park and Ride schemes profitable?’ Descriptive research can be very important, though purely descriptive research is lacking in one area, the research does not ask ‘why’ something is happening. Research which asks why something is happening is called explanatory research. After something has been adequately described and perhaps established, additional research can be undertaken to ask questions about why the phenomenon occurs. Doing this requires a different set of research and analytical methods; these include identifying causal explanations, measuring statistically significant regression among observations or carrying out theory building or testing (Creswell, 2007).

Considering this information, the research aim of this thesis required descriptive research. The research aims to examine the factors affecting the emergence, development and uptake. This can be achieved using descriptive research, for example; asking stakeholders about the current issues that the sector is facing, by analysing perceptions regarding a particular issue and by assessing documented evidence. However, there are limitations to descriptive research. Although it would seem that purely descriptive research will lead to a limited amount of data to analyse, descriptive research can ask questions such as analyse the relative importance of aviation biofuel issues or describe what is the most important issue facing aviation biofuels. Given that the research is
descriptive, the next stage of the research process involved identifying what type of research design needed to be followed.

De Vaus (2001) describes three main research designs: experimental designs, longitudinal designs and cross-sectional designs. However, the design pursued in this thesis is cross-sectional research. Cross-sectional research has no time dimension; does not require any element of control on the variables being observed and does not require random sampling. Fundamentally, cross-sectional research investigates differences between groups of data, rather than changes over time (De Vaus, 2001); it is therefore well suited to descriptive analysis. Cross-sectional research is interested in describing how and why contemporary phenomena occur based on data collected at one point in time. These research designs are also cheaper and easier to execute. Based on the research aim that was formulated, and the factors that were considered during the formulation of the research aim, a cross-sectional research design appears to be well suited. With the research design chosen, and the previous information considered, the research could begin to be formally organised.

The data collection method was considered in light of the research aim, research design and the availability of data. The main method of data collection for this thesis was in-depth stakeholder interviews. Other methods such as focus groups and the Delphi method were considered however both were deemed impractical owing to time and cost constraints. The use of focus groups would require multiple stakeholders to be organised into a single location and time. This was deemed impractical due to two factors. Firstly the participants were all high-level elite stakeholders. It would be highly unlikely that they would all be able to attend such a meeting together and commercial confidentiality may restrict the information that could be obtained. Secondly, the stakeholders were geographically spread across the world, further inhibiting the ability to easily organise a group discussion around the topic of aviation biofuels. The Delphi method was deemed impractical on the grounds of availability from the stakeholders. Multiple iterations between the stakeholders would require a substantial commitment from the stakeholders. Given that the average stakeholder was in a high level management position, this commitment was deemed unrealistic. It would be much more realistic to gain a one-time focused commitment from a high level stakeholder. Given these considerations, the first step was to formulate research objectives and research questions that would suitably disaggregate the aim into manageable component parts.

The next section provides a description the methods, research objectives and questions that were chosen for this thesis. A more detailed evaluation of the methods is also given in section 5.
4.6. Research methods, objectives and questions

Primary data is obtained using three different methods; semi-structured interviews, a web-based survey and a case study. The following sections will discuss these methods in the order they appear in the thesis. The first is the scoping study and semi-structured interviews.

4.6.1. Scoping study: Semi-structured interviews

The scoping study used semi-structured telephone interviews with 12 aviation biofuel stakeholders (Table 4.3). The interviews were telephone based due to the constraints of logistics and cost. The international nature of the research meant that undertaking face-to-face interviews was financially and logistically impractical. A telephone based system provided flexibility for both the researcher and the stakeholder. The stakeholder could stipulate their own desired time for the interview without causing considerable inconvenience to the researcher. The interviews were recorded using a microphone earpiece device and transcribed after the event. The interviews for the scoping study were carried out between November and December 2010 and averaged 1 hour in length. The questionnaire consisted of 21 standardised open-ended questions presented in a semi-structured manner. The questions were centred on the following four themes; the historical perspective of biofuels; the contemporary issues of biofuels; the issues specific to aviation biofuels, and areas for further research. The questions were purposely broad and open ended. The interview schedule is shown in appendix A.

Table 4.3 Respondents interviewed

<table>
<thead>
<tr>
<th>Respondent</th>
<th>Sector</th>
<th>Job description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>UK Airline</td>
<td>Head of Environment</td>
</tr>
<tr>
<td>B</td>
<td>EU Airline</td>
<td>Director of Environment and Sustainability</td>
</tr>
<tr>
<td>C</td>
<td>UK Airline</td>
<td>Flight Operations Director</td>
</tr>
<tr>
<td>D</td>
<td>UK Airport Operator</td>
<td>Senior Vice President of Environment</td>
</tr>
<tr>
<td>E</td>
<td>UK Petrochemical</td>
<td>Biofuel Public Relations Officer</td>
</tr>
<tr>
<td>F</td>
<td>UK Biofuels producer</td>
<td>Director and Chairman of; (1) a biofuels company and (2) renewable energy company. Academic work.</td>
</tr>
<tr>
<td>G</td>
<td>Aviation Policy Expert</td>
<td>UK Department for Transport</td>
</tr>
<tr>
<td>H</td>
<td>Policy Expert</td>
<td>European Union Renewable Fuels Policy Expert</td>
</tr>
<tr>
<td>I</td>
<td>International Airline Regulator</td>
<td>Assistant Director of Environmental Technology</td>
</tr>
<tr>
<td>J</td>
<td>Academic</td>
<td>Senior lecturer; bioenergy and biofuels research</td>
</tr>
<tr>
<td>K</td>
<td>Research Consultancy</td>
<td>Management Consultant and expert in Bioenergy</td>
</tr>
<tr>
<td>L</td>
<td>Research Consultancy</td>
<td>Management Consultant in Aviation biofuels research</td>
</tr>
</tbody>
</table>
Due to the fact that stakeholders were central to this thesis, their identification needed to be robust. To help with the identification process, stakeholder theory (taken from the management literature) was used to prioritise the most relevant and powerful stakeholder for this study. Stakeholder theory had previously been used to identifying stakeholders within the context of a firm, however, this thesis adapted those concepts to provide a more robust method of identify aviation biofuel stakeholders. The next section will discuss the use of stakeholder theory in more detail.

**Stakeholder theory**

The stakeholders in the scoping study and second stage interviews were identified by adapting principles from stakeholder theory which was taken from the management literature. The interviews were guided by principles from the elite interviewing literature. The next section will describe the process of identifying the stakeholders.

Stakeholder was central to the scoping study; it was therefore crucial that the identification of the stakeholders was robust. A review of the literature acted as the starting point for the stakeholder identification process. However, identifying stakeholders in this instance was challenging because the phenomenon of aviation biofuel was relatively young and rapidly evolving. During the literature review, the names of stakeholders were entered into a database and their contact information, where possible, was recorded. This included: name, corresponding email and industry sector. However, it became apparent that there were a limited number of stakeholders that could be easily identified using this method. One explanation was that because the aviation biofuel phenomenon was relatively new, stakeholders were being purposefully inconspicuous to competitors; either for fear of publishing their position to their competitors or because there was a general lack of industry knowledge about the field of aviation biofuels. It was very likely that there may have been additional interested parties which were non-identifiable in the literature, though they had real expertise within the area of aviation biofuel. For these reasons the identification process needed to follow a more rigorous methodological approach. One option was to take lessons learnt from stakeholder theories, embedded in the management science literature. The next section will discuss specifically how stakeholder theory was used in this thesis. Reviewing the management literature can present useful information to develop a more robust methodology to identify stakeholders. Indeed, the concept of the ‘stakeholder’ is commonly used in management literature within the context of the firm (Mitchell et al., 1997). Stakeholders are identified within the framework of an organisation; i.e. people or other firms and organisations that are associated with one organisation. Definitions of the stakeholder are traced chronologically by Mitchell et al., (1997) who finds that, despite many different definitions, the ideas of Edward Freeman (Freeman and Reed,
1983; Freeman and Evans; 1990) have become the seminal classifications for management scholars. Freeman’s original definition described the stakeholder as any person or group who can ‘affect’ or ‘be affected’ by the achievement of the organisations objectives. Freeman’s definition was broad and subsequently criticised by management authors for its simplicity and ambiguities (Mitchell, 1999; Donaldson and Preston, 1995). Mitchell et al., (1997) offers a critique of the definitions for the ‘stakeholders’ though finds that there are major variations in the definitions and identification processes. For example Clarkson (1995) choose to define the stakeholders as voluntary or involuntary ‘risk-bearers’ associated with a firm’s actions. In this context, if the firm succeeds in a business venture the risk bearer will also stand to succeed. Conversely, Mitchell et al., (1997) shows that others attempted to make the definition much narrower; indicating that a stakeholder must have legitimate, ‘non-trivial relationships with an organisation’. Further, Savage et al., (1991) discuss the fact that the stakeholder must have an ‘interest in the action of an organization’ and perhaps more crucially, have the ability to influence it.

Stakeholder theory had been used in the management literature to identify and analyse the role of the stakeholder within the context of the firm. Due to the complexity of the issues within stakeholder theory it had been asserted that almost anyone could be classed as a stakeholder. However, there were common attributes to all stakeholder theories which were synthesised by Mitchell et al., (1997). Mitchell categorised the main constructs and definitions of the stakeholder theories to find there is in fact three main attributes of the stakeholder; (1) Power; (2) Legitimacy and (3) Urgency. These three attributes were ultimately used to aid in the search and identification of aviation biofuel stakeholders for this thesis. The next section will provide an overview of the three attributes.

Power, although defined in many ways, is in this context based on utilitarian and regulatory power. Utilitarian power is the ability to exploit financial resources and/or knowledge. Utilitarian power is also about assessing the power of the company to push the product to market or influence its uptake. Using an example within the context of this thesis; British Airways and Boeing have a strong financial position and relatively high level of expertise in the aviation biofuel area; this is due to their previous experience within the fields of aviation and biofuels. Both companies also command a high degree of financial and market power within their respective areas i.e. airlines and airframe manufactures. This increases their level of power within the context of the stakeholder and thus would make them a more attractive candidate to pursue for this thesis compared to a small national airline with no previous experience in the aviation biofuels field. Regulatory power is also important for the identification process. For example, within the context of this thesis fuel standards are
significant barriers to overcome for aviation biofuels. In this way all fuel standards agencies such as ASTM and DEF-STAN⁵ are deemed powerful stakeholders. Furthermore, due to the importance of government policy and regulations, policy makers are also powerful stakeholders.

Legitimacy is used by Clarkson (1995) to describe the level of interest that the stakeholder has in the firm. The legitimacy concept is constructed around the idea that commitment to the firm can also be interpreted as financial risk. Using this concept within the context of aviation biofuels, it will be possible to determine the legitimacy of the stakeholder’s interest in aviation biofuel. Although it was deemed impractical to determine the precise level of financial investment that has occurred in the aviation biofuels field, where possible financial investment will be assessed. If financial information is not available, the legitimacy attribute will be assessed based on the duration of interest in the aviation biofuels field. This was carried out by reviewing the literature. A firm which has a longer history of interest with aviation biofuels will be regarded to have a higher legitimacy than a newer entrant with relatively less experience. Similarly, a firm which is heavily invested in aviation biofuels will have a higher legitimacy than a firm which is less financially exposed and thus has less risk attached to the success of the venture. The final attribute is urgency.

Urgency is less important than the other two attributes for identifying a stakeholder in stakeholder theory. However, in this research it will be used to help establish the stakeholders which are deemed more pertinent to the aviation biofuel phenomenon at the present time. Firms which have a greater urgency to commit to aviation biofuels may have a greater understating of the issues which the industry is facing and thus will be of importance to this study. An indication of the urgency of the firm will also help to refine the stakeholders from the survey stage to the interview stage. This can be made by assessing their financial commitment where possible and their intentions to commit to more action within the aviation biofuels field. Using techniques derived from stakeholder theory this thesis can identify with respect to their importance for the success or failure of aviation biofuel. The next section will describe the process of identifying stakeholders.

**Stakeholder identification**

The identification process was conducted in three discrete stages. The initial stage was to review the biofuel and aviation literature in line with Freeman’s broad classification of the stakeholder; this was used to ascertain groups considered ‘influential’ or potentially ‘influenced’ by the adoption of aviation biofuel. At this stage the potential stakeholder sectors were organised into six groups; (1) commercial air lines; (2) airframe and engine manufacturers; (3) biofuel companies; (4) petrochemical firms, (5) academics and (6) policy advisors and regulators. These acted as the starting

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⁵ DEF-STAN is the UK equivalent of the ASTM certification. It is the commercial fuel specification for safety.
point for the stakeholder identification process. The next stage involved a search of the peer reviewed literature, newspaper articles and online documents to obtain, where possible, contacts and email addresses of stakeholders within each of those sectors. Articles related to aviation biofuels which had been written by aviation biofuel stakeholders took priority due to their suggested technological knowledge in the field. Stakeholders that were mentioned in either peer reviewed papers or the grey literature were ranked in terms of the number of times cited in different pieces of literature, thereafter stakeholders were ranked in terms of their company’s power and urgency in the field. The contacts are placed in a data base as described earlier in this chapter. In conjunction to the literature search, biofuel and aviation related conference attendance was utilised to act as a platform for networking with stakeholders and broaden the sample. This was effective at obtaining direct face-to-face contact with high level management stakeholders and the snowballing technique offered an excellent way to gain access to stakeholders which were not published or mentioned in the literature search. The conferences that were attended all specialised in biofuel, aviation or environmental issues. They included the World Biofuel Markets Conference (Amsterdam, 2010), the Westminster Energy, Environment and Transport Forum: Biofuels conference (2010), the Westminster Energy, Environment and Transport Forum: Aviation Conference (2011) and the Carbon Conference (London, 2012).

Using these techniques a population of stakeholders was developed, the objective was to obtain an equal number of stakeholders from each relevant sector (i.e. airline, airport, biofuel producer etc.) thus providing a fair cross-section of the current issues. The actual requests sent to stakeholders were consistent and systematic. The stakeholders were emailed with an opening request which included details of the research being undertaken, the questions that would be asked and the time frame in which the research would be started. If there was no reply within one week, a reminder email was sent. This process was repeated a maximum of four times. In some cases, a phone call was used to remind the stakeholder of the email request.

Thus far the nature of stakeholder theory and its roles in identifying the stakeholders for this thesis have been detailed. However, there has been little discussion about the actual interviewing process or the design of the questionnaire (Appendix A).

**The interview process**

The interview process needed to make special consideration for the type of stakeholders that were being interviewed. This is because the majority of stakeholders that will be interviewed for this study
are known as ‘elites’ in the interview literature (Berry, 2002). There are several useful insights that can be drawn from elite interview studies.

Considering that the interviewees are elites i.e. they are people with power within their organisation or with detailed levels of knowledge of a particular field, it was necessary to use principles from the elite interviewing literature. Consideration was made about how to gain access to the stakeholders. Harvey (2010) recommends that using the stakeholder’s social networks is effective. In this research, personal attendance at conferences acted as an important and effective social networking platform. Harvey also recommends that background information about the company and stakeholder should be obtained before the interview. Harvey (2010) goes further in saying that to obtain elite stakeholders the research needs to be highly flexible in terms of time frames for the interview and the level of questioning that is allowed. The research should also be completely transparent in the questioning. Finally, for networking or face-to-face interviews, having good ‘etiquette’ and being smartly dressed and professional is essential.

**Online survey of aviation biofuel issues**

The second stage of primary data collection builds upon the findings of the scoping study to analyse the relative importance of the issues associated with emergence, development and uptake. The purpose was to obtain ordinal data which could be used to assess the relative importance of specific issues. The survey was used to enlarge the number of stakeholders that took part in the study in order to provide more detailed insights about the issues facing the aviation industry. The questions were informed by the findings of the scoping study. Web based surveys offers several advantages over telephone, post-based, and face-to-face surveys (Dillman, 2000). Firstly, they remove costs involved with postage, paper and data entry. They also reduce the time required to carry out the administration of the survey. Furthermore, the ability to send emailed reminders makes following-up on respondents much easier, quicker, and more cost efficient (Dillman, 2000).

The stakeholders were categorised and coded into industry sectors and emails were sent to the stakeholders with details of the study and an upcoming survey. A pilot survey was then designed using the Bristol Online Survey (BOS) service provided by Bristol University. The pilot survey was sent to the scoping study respondents from the previous stage of research in the expectation that they would offer recommendations for improvement before it was sent to the main participants. In light of suggestions received, changes were made to improve presentation, alter the question format, and revise the question order to make it more logical. The BOS platform allowed the survey to be distributed securely and efficiently using a web portal. The survey was customised with
Loughborough University’s logo and adopted a distinct ‘house’ style that was designed to facilitate easy comprehension and completion (Figure 4.1).

**Figure 4.1.** Screengrab of aviation biofuel survey (full survey appears in Appendix B)

When the changes were made, the actual distribution process took place. This involved sending individually addressed emails to 150 key stakeholders identified from the aviation biofuels literature and through conference attendance (See section 5.5.7). The stakeholders were located in 20 different countries, although 70% were from the EU or USA. The emails included a non-expiring link to the survey page which allowed the respondent to complete the survey in their own time. When the respondents completed the survey, the BOS program remotely stored the survey data and coded the responses for analysis online. The data could be accessed at any time after the survey was made active. If there were no logged responses from certain respondents within 2 weeks, a reminder email was sent. This was repeated three further times before the stakeholder was taken off the reminder list. The survey employed Likert scale questioning organised into five main sections: commercial environmental challenges facing aviation issues, drivers for emergence, development and uptake, constraints to emergence, development and uptake, strategies to support aviation biofuels and predictions for future emergence, development and uptake. The commercial aviation issues and constraints sections used Likert scale questions ranging from not at all serious to very serious. The drivers and strategies sections used an importance Likert scale ranging from very unimportant to very important. The future emergence, development and uptake sections used a likelihood scale from very unlikely to very likely. Within each section between 7 and 26 factors were tested.

The next piece of primary data was obtained via 25 in-depth semi structured interviews.
4.6.2. Second stage interviews: Semi-structured interviews

Semi-structured interviews were also used in the second stage of interviews. These interviews would identify the limitations of the support strategies available to the sector, as well as stakeholder recommendations for changes. The questions would act as a validation stage, validating the research findings up to this point and furthermore focusing the generalisations. The second stage of interviews took place between October and December 2011. The interviews were recorded via Dictaphone, transcribed manually and coded in the same manner as the scoping study. A list of the stakeholders interviewed is provided below (Table 4.4).

Table 4.4. Interview respondents

<table>
<thead>
<tr>
<th>Sector</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airline A</td>
<td>Environmental manager</td>
</tr>
<tr>
<td>Airline B</td>
<td>Environment Director</td>
</tr>
<tr>
<td>Airline C</td>
<td>Environmental manager</td>
</tr>
<tr>
<td>Airline D</td>
<td>Environmental manager</td>
</tr>
<tr>
<td>Airline E</td>
<td>Environmental manager</td>
</tr>
<tr>
<td>Airline F</td>
<td>Senior lecturer; bioenergy and biofuels research</td>
</tr>
<tr>
<td>Airframe Manufacture A</td>
<td>Senior Vice President of Environment</td>
</tr>
<tr>
<td>Airframe Manufacture B</td>
<td>Biofuel Public Relations Officer</td>
</tr>
<tr>
<td>US Government official</td>
<td>Aviation Policy analyst</td>
</tr>
<tr>
<td>UK department for transport</td>
<td>Aviation policy analyst</td>
</tr>
<tr>
<td>International aviation body</td>
<td>Deputy director</td>
</tr>
<tr>
<td>Fuel standard agency</td>
<td>Manager</td>
</tr>
<tr>
<td>Renewable Energy Association</td>
<td>Biofuel policy advisor</td>
</tr>
<tr>
<td>Petrochemical major A</td>
<td>Biofuels</td>
</tr>
<tr>
<td>Petrochemical and biofuel producer</td>
<td>Biofuel expert</td>
</tr>
<tr>
<td>Petrochemical major B</td>
<td>Biofuel department</td>
</tr>
<tr>
<td>Biofuel agency</td>
<td>Biofuel expert</td>
</tr>
<tr>
<td>Aviation biofuel company</td>
<td>Director</td>
</tr>
<tr>
<td>Aviation biofuel producer</td>
<td>Director</td>
</tr>
<tr>
<td>Airport</td>
<td>Flight Operations Director</td>
</tr>
<tr>
<td>Engine Manufacture</td>
<td>Director</td>
</tr>
<tr>
<td>Environmental Consultant</td>
<td>Consultant director</td>
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<tr>
<td>Aviation academic</td>
<td>Researcher</td>
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<td>Consultancy</td>
<td>Consultant</td>
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<td>Environmental consultant</td>
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This was followed by a case-study of the UK’s first commercial aviation biofuel flight trail. The case study would form the platform for the final piece of data collection.
4.6.3. Case-study

The case study was undertaken to establish the specific issues related to the commercial testing of an aviation biofuel. This would fulfil objective 4. It was useful to understand the issues faced by aviation biofuel stakeholders during the creation and execution of aviation biofuel test flights, as well as the outcome of such testing. The data obtained from a case study could be used to aid in the identification and assessment of support packages for the development of the fuels, especially in relation to strategic niche management theory which supports the idea of nurturing demonstration and testing programmes. Case studies incorporate the collection of qualitative and/or quantitative data often using multiple methods of data collection. Case study research can be made up of a single case or draw from multiple replicated cases (Johansson, 2003). Case studies are not used to make generalising conclusions about populations; they are instead used to obtain detailed information about individual objects of study (Yin, 1994). The nature of data collection and the methods used are therefore essential in attempting to make robust theoretical conclusions and recommendations about a particular case.

The commercial testing of an aviation biofuel incorporates a variety of stakeholder parties including: a biofuel producer, airline, airframe and engine manufactures and airports. The following section outlines the formulation of the case study. The stakeholders were, again, obtained from the larger stakeholder identification process outlined in the scoping study section. It was highlighted that within the stakeholder database, there were a series of stakeholders that had worked together to undertake the UK’s first aviation biofuel flight test. It was therefore possible to group these stakeholders together into the form of a case-study.

The stakeholders were the following:

1) Aviation biofuel specialist
2) Airport
3) UK Airline
4) Airframe manufacturer

With these stakeholders identified, they were emailed individually with the proposition to carry out a case-study of the flight trail. The participants agreed based on the condition that the information would be non-commercially sensitive and that the names of the companies were not published. This condition was therefore considered carefully in the data collection process. The next section outlines the methods used in the case study.
Case-study method

The first method used was a combination of telephone and face-to-face interviews. The airport and airline were both interviewed face-to-face, whereas representatives from the airframe manufacturer and biofuel specialist were interviewed via telephone due to the fact the companies were based overseas. The interviews were recorded using a microphone and transcribed manually. The questions were separated into three main stages; the issues associated with the preparation and planning of the aviation biofuels trial; the issues faced during the execution of the trial and the likely issues facing trials in the future. The question schedule can be seen in the appendix of this chapter.

In addition to the interviews, publically-available documentation regarding the test flights was also obtained from the parties involved. Also, additional information was also included from online sources which covered the aftermath of the trial including environmentalist backlash. The data taken together formed a picture of the aviation biofuel trial. The final stage of the primary research also involved semi-structured interviews however; these interviews had a much more specific focus compared to the previous interviews that were undertaken. They were interested in obtaining data that would validate the previous findings up to this point, as well as provide data to allow recommendations for support policies to be made.

Although semi-structured interviews were also used in the scoping study, the final stage of research utilised the method again in a dual role: (1) to provided robust data to make recommendations for creating supportive measures for aviation biofuels and (2) to further explore the issues already identified in the first pieces of research. This would fulfil objective five.

The stakeholder identification process differed from the scoping study; survey and case study. On this occasion the stakeholders were obtained from the online web-based survey responses. The final questions of the survey asked the respondents whether they wished to take part in further research in the form of an interview. In total, 25 respondents agreed to take part in further research. As well as being convenient to the researcher, the stakeholders that agreed to take part in further research, according to stakeholder theory, had much greater ‘legitimacy’ and ‘urgency’ with respect to perceptions of aviation biofuels. This would increase the robustness of the final piece of data; thus providing more reliable recommendations.

The preceding sections of this chapter outlined the methods of data collection. The data will be used to answer the aim of this thesis i.e. to investigate the issues associated with the emergence,
development and uptake of aviation biofuels. The final section of the methods chapter will provide discussion towards a new framework for conceptualising aviation biofuels development.

4.7. Towards a new framework for conceptualising aviation biofuel development

In chapter 2, it was revealed that SNM theory offers several useful insights into the emergence, development and uptake of aviation biofuel. Indeed, SNM theory is specifically designed to analyse and explain the development of emerging sustainable technologies within technological regimes which are stubborn to change such as aviation. However, SNM may not be adequately equipped to address the multitude of issues influencing the development of aviation biofuels. Firstly, SNM does not adequately consider the differences between system and sub-system issues in the same way, for example, that technology readiness levels (TRL) does. SNM also takes a narrower view of the development process of an emerging technology compared to the IEA model (IEA, 2009) and diffusion theory (Rogers, 1995). SNM essentially focuses on one period of ‘niche market development’. SNM does not fully take into account the processes before or after a strategic niche market has developed. In addition, it does not fully consider the action of change agents, the action of social norms or mass adoption and saturation of the market. Indeed, despite the advantages of SNM, there may be room to improve the theory.

With this in mind, this thesis will employ a new model which combines aspects of SNM theory with the IEA model, diffusion theory and insights of technology readiness levels (TRL). The model will consider the development of aviation biofuel technologies over five distinct phases similar to the IEA model discussed in the literature review (Figure 3.8). However, the third phase of development in the IEA model, which previously was a stage involving basic policy incentives and protection provision, will be replaced by recommendations from Strategic Niche Management (SNM). The phases of aviation biofuel emergence, development and uptake within this new model will be: invention, R&D, strategic niche management, pervasive diffusion and saturation (Figure 4.2). The model is represented graphically in Figure 4.2. The purple line represents the emergence, development and uptake of the technology following a typical S-shaped diffusion curve. As mentioned in chapter 2, the S-shape is commonly used to represent the diffusion of new technologies (Rogers, 1995) and it is expected that aviation biofuels will follow a similar curve. Evidence from the literature review showed that conventional biofuels have been analysed and discussed using the s-shaped diffusion curve (IEA, 2009). However, unlike the smooth curves seen within much of the diffusion theory literature, this model assumes an evolutionary economic
perspective where the development and diffusion of the technology is expected to be non-linear. This is represented by the jagged red line in Figure 4.2. The red line represents the iterative path of development which is typical of emerging sustainable technologies, especially those which encounter a large number of driving and constraining issues such as biofuels.

**Figure 4.2 Model of aviation biofuel emergence, development and uptake**

![Model of aviation biofuel emergence, development and uptake](image)

Finally, the model will consider the development of aviation biofuels as being driven and constrained by a series of factors working at different levels. The literature review revealed that biofuels are affected by a number of issues. For instance, changes in environmental government policy and the development of supply chains. Within this model, government policy drivers are considered to be system-level drivers acting at a high-level whereas supply-chain development is considered a sub-system driver. Differentiating between these drivers will provide deeper insights into the issues affecting the emergence, development and uptake of aviation biofuel. In Figure 4.2, the system and sub-system drivers are represented by the blue and red triangles. The triangles interlock to reflect the fact that, despite working at different levels, the issues are inherently linked to one another as well.
This model will be used to analyse the emergence and development of aviation biofuel technology as well as to make SNM recommendations to support its widespread uptake. With this model in place, the findings from the first stage of research (the scoping study) can be discussed.
Chapter 5

Scoping study: Identifying the factors affecting the emergence, development and uptake of aviation biofuels

5.1. Introduction

This chapter presents the findings and analysis of 12 semi-structured interviews with key senior European aviation biofuel stakeholders (Table 4.3). The chapter is structured thematically based on the PESTLE framework. This chapter seeks to confirm several key drivers identified in the literature as well as identifying new drivers. It will reveal that many driving factors are closely interlinked. The latter half of the chapter will present the constraining issues. Again, it will be revealed that there are a number of key challenges associated with the development and uptake of aviation biofuels.

5.2. Findings

A summary of the drivers and constraints for aviation biofuels is shown in Table 5.1. Issues are ranked by frequency with which they were mentioned by the respondents and discussed with reference to the PESTLE framework.

Table 5.1 Summary of factors

<table>
<thead>
<tr>
<th>Drivers for aviation biofuels</th>
<th>Constraints for aviation biofuels</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Need for reducing emissions (12) Env/Pol</td>
<td>1. Feedstock supply (12) Env</td>
</tr>
<tr>
<td>2. Oil price and fuel security (12) Econ</td>
<td>2. High costs and funding (12) Econ</td>
</tr>
<tr>
<td>3. Carbon price (8) Env/Econ</td>
<td>3. Environmental sustainability (12) Econ</td>
</tr>
<tr>
<td>4. Lack of alternative technology (8) Tech</td>
<td>4. Policy incentives (8) Env</td>
</tr>
<tr>
<td>5. New growth markets for biofuels (4) Econ</td>
<td>5. Fuel consistency and infrastructure (1) Pol</td>
</tr>
<tr>
<td>6. Green Public Relations (4) Social</td>
<td></td>
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</table>

Env=Environmental, Econ=Economic, Pol=Political, Tech=Technological (PESTLE framework)
5.3. Factors driving the emergence, development and uptake of aviation biofuel

Respondents were asked to describe what they perceived to be the most significant factors driving the commercialisation and emergence, development and uptake of aviation biofuels. The study makes no attempt to differentiate between drivers for the development of the fuels and drivers for the commercialisation and uptake of the fuels. This is because the interview data revealed that the drivers for the development of aviation biofuels i.e. the research and design and demonstration phase were ultimately very similar to drivers for the commercialisation of the fuels. Following the PESTLE framework, the first themes to be discussed are political and environmental drivers.

5.3.1. Political and environmental drivers

There were a number of political and environmental factors driving aviation biofuels. The primary political and environmental factors are related to emissions reductions. Although emission reductions could be considered to be purely environmental, the need for commercial aviation to reduce emissions is actually driven by environmental policy measures such as the EU ETS. Political and environmental drivers are vitally important for the emergence, development and uptake of aviation biofuels. All 12 respondents discussed the need to reduce emissions. Airline respondents emphasised the fact that emissions reductions are a primary driver of biofuel, noting that the reductions are either voluntary targets set by the sector, or result from the imposition of legislative control such as carbon pricing. These results confirm the literature findings however the scoping study respondents appeared to place more emphasis on political and environmental issues compared to the literature. None of the studies from the literature review for instance suggested that aviation biofuels are being driven primarily by political and environmental issues. The CCC report (2009) and SWAFEA (2011) states that the EU policy environment for aviation is becoming significantly more challenging in terms of environmental control and that this is creating a need to lower emissions. The need to reduce emissions was better expressed in SWAFEA (2011) though this scoping study has revealed that the issue of environmental policy is far more complex than the SWAFEA report suggests. For instance, the SWAFEA report does not discuss how policy will affect individual airline business models, or how it will affect fuel suppliers and aviation biofuel supply chains.

All respondents in this study however stated that the need to reduce emissions is significant due to the fact that the policies will ultimately increase costs for the airlines. Interestingly, airline responses varied in terms of the carrier’s business model. This is not picked up in the extant literature; there
are no known aviation biofuel studies which discuss airline business models. This study revealed that, as well as discussing the importance of environmental policy for the long term development of aviation biofuel, the two legacy carriers (i.e. those that operate full service hub and spoke networks) both emphasised that the environmental performance of the biofuels was paramount.

“Research is driven by the prospect for reducing our carbon footprint” (Respondent A) and: “...when we talk about our target we talk about our carbon footprint. In our company the main one is the green credentials. It’s about the environment” (Respondent B).

Curiously, the two legacy carriers were seemingly reluctant to admit that part of their motivation was also commercial, even though they discussed the fact that the policies will increase costs for the airlines. The legacy carriers did not emphasise any potential economic benefits of the fuels, in fact they avoided the issue entirely when asked to elaborate. Conversely, the low cost carrier indicated that the need to reduce emissions using biofuels was driven purely by costs and not necessarily by emissions. The low cost carrier placed more emphasis on the fact that the industry is being “forced” to reduce emissions because of carbon pricing such as the EU ETS, and that biofuels are a potential low cost near term solution. Respondent C stated:

“It became apparent if we wanted to reduce carbon output as an airline we need to try and use biofuels; which under the EU ETS are carbon neutral. That’s when we started to really look at the idea of using biofuels”.

The remaining respondents from the aviation sector (D and I) shared similar views to the legacy carriers; placing greater emphasis on the environmental benefits of the fuels rather than any political or economic benefits. However, the non-aviation respondents concurred with the low cost carrier; suggesting that the aviation industry is reducing carbon emissions essentially due to the external pressures from carbon legislation and public pressure to reduce aircraft emissions. Furthermore, a minority of the non-aviation stakeholders expressed concern for the airline industry’s true intentions for using biofuels as an environmental measure. It was suggested that, despite the aviation industry’s claims, the industry does not adequately understand the true sustainability of the fuels given the relative infancy of the technology. It appears then that although all parties are interested in a reduction of aircraft emissions, the underlying desire to reduce emissions is not necessarily voluntary. It may be safe to assume that the real driver is as a result of political and economic pressures. These issues are no adequately discussed in the literature. Marsh (2008) does express concern regarding the social responsibility of using aviation biofuel to reduce costs in light of their environmental concerns. However, the issue has not been tackled head on in
any study. This is despite the fact that the aviation biofuels are often perceived as being associated with food price rises and other environmental degradation.

These findings are interesting because political and environmental issues are acting both at the system level and the sub-system level. In other words, some stakeholders are being driven principally by the high level environmental policy changes such as the introduction of the EU ETS and other policy changes, while others are being driven by sub-system drivers such as company targets to reduce emissions. Of course, the company targets to reduce emissions will also be influenced by the high level policy changes as well but the respondents were reluctant to admit this in this study. This highlights a greater degree of completely in the issues than the literature chooses to express. If the understanding of these issues is not adequate, this will have an impact on the current provision of environmental policy and supportive incentives for the emergence, development and uptake of aviation biofuels.

The next factors identified included oil price, fuel security, carbon pricing and business opportunities. These factors are not exclusively economic, nor are they exclusively political. For this reason, the next section reviews economic and political drivers together.

5.3.2. Economic and political drivers

Economic and political drivers featured heavily in the discussions. The main issues which were discussed were system level drivers such as oil prices and energy security. Although they are acting as a strong aviation biofuel driver, they are also driving industry wide changes in technology, air traffic management and pricing. All of the respondents in this study suggested that oil prices and fuel security are significant drivers for the development of aviation biofuel. Rising and volatile oil prices globally have caused the aviation industry to re-evaluate its commitment to fossil-based fuels. This has helped put biofuels at the forefront of strengthening fuel security and reducing exposure to rising oil prices. This driver is also linked to national policies. The literature showed that governments such as the U.S are encouraging alternative energies from an energy security perspective. This is chiefly a system level driver because national and international political agendas will be encouraging all sectors of the economy to reduce oil dependency. These system changes are however very much more powerful as a driver of biofuels that other sectors. This is because the aviation industry has very little option but to continue to use existing jet engines for the next 50 years, this necessitates the so called drop-in technologies such as aviation biofuels. This also represents an interesting dynamic between the system-level changes in policy which are driving the need for alternatives to fossil-carbon oil, and the sub-system level drivers which are actually
necessitating biofuels. Although some of the literature does express the difference between the two drivers (SWAFEA, 2011; CCC 2009; Daggett et al., 2007), no studies explicitly discuss the implications of this in terms of policy support. This is something which will be discussed later in chapter 8. The relationship between energy security and national policy is discussed in most aviation biofuel studies but there are few studies which discuss the contrast between European policy and US policy in terms of aviation biofuel. It is discussed briefly by the CCC report (2009) and SWAFEA (2011) though there are no studies which have empirically assessed the impact that these are having on aviation biofuel development.

In this study, the majority of respondents were confident that rising oil prices will make biofuels price competitive with crude oil within the next decade, though the specific costs associated with biofuels remained unclear. Oil price and energy security factors were also acknowledged to be inherently geopolitical and so may vary significantly between regions. Stakeholders did not elaborate on this issue but they did acknowledge that, for countries that are net importers of oil, rising oil prices and fuel security will be key drivers for the emergence, development and uptake of aviation biofuels nationally and that governmental incentives such as carbon pricing combined with oil price rises will be sufficient to induce uptake.

It was apparent that stakeholders are unclear about the timeframes surrounding oil price and energy security benefits however. Some respondents; such as Respondent F, stated that the supply constraints for oil represent an imminent threat to the industry:

“...the physical shortages [for oil] are real going forward to 2012 and 2014... [The aviation industry] is worried that there will not be sufficient fuel to supply enough for aviation in 2015. It will run out or be too high in price.”

This respondent was referring to his previous work as biofuel producer and past collaborative ventures with commercial airlines and oil producers. Conversely, however, the aviation sector respondents perceived oil price and supply as being a long term driver of the fuel and not in their view a “significant near term influence”. The airline respondents acknowledged that, although short-term temporary fluctuations in supply are possible, the threat of global peak oil or significant supply obstruction was not imminent. This view does not align with the consensus view of the literature which assumes a growing pressure on rising oil prices but not a short term influence on the fuel. Despite the fact that the price rises of 2008 is mentioned as a turning point in the need for development aviation biofuels (Mazraati, 2010; CCC, 2009) the majority of the oil price forecasting including CCC (2009), Defra (2008) and IEA (2008) assumed a slower rise in oil prices. However, the
IEA (2004) study did predict a peak oil supply of 2020, causing significant increases in oil price from that year. Indeed, much of the literature focused on decreasing aviation biofuel prices amid consistent increases of oil prices (Daggett et al., 2007). All other respondents agreed that in the long run view, which was not specified, oil price and energy security will be significant drivers of the fuels. Again, there was a difference in response from the legacy carriers and the majority of the other respondents. The legacy carrier placed greater emphasis on emissions than issues associated with oil price and fuel security, though the respondents were fully aware that these issues will become important drivers. The next economic and political issue to be discussed is carbon pricing; this issue was mentioned by two thirds of the respondents. Although it has already been mentioned in previous section, it requires elaboration.

According to the respondents in this study, carbon pricing is expected to be a driver for aviation biofuels within the European Union; though it will also act as a growing factor world-wide. Eight respondents indicated that carbon pricing will be a significant driving factor for the development and uptake of aviation biofuels, though initially only in regions influenced by environmental policy. Most respondents referred to the EU Emissions Trading Scheme (EU ETS). The main driver comes from the fact that biofuels could offer a monetary cost saving attributed to foregone carbon credit purchases (i.e. carbon permits which did not need to be purchased). Biofuels are expected to yield considerable carbon emissions savings over their life cycle due to the carbon dioxide sequestrated during the growth phase of the biofuel feedstocks. Of course, if the price of aviation biofuel is above the combined price of jet fuel and carbon, they will be substituted by the market for carbon credits and aviation biofuels will not be adopted. At the time of data collection, a quarter of all respondents stated that carbon prices within the EU ETS were too low to facilitate commercialisation and market uptake, and that there is confusion as to how significant the carbon pricing driver will be in the long term. Furthermore, whilst some stakeholders considered the EU ETS as a driver, policy experts and fuel consultants were unsure of the short-term benefits of the EU ETS. Respondent J stated:

“It is a very difficult question because we don’t know what the premium on the biofuels is likely to be. We don’t know how effective the teeth in the ETS are going to be and we don’t know what the oil price is going to be”.

Indeed, although carbon pricing theoretically creates a strong incentive to adopt a low carbon technology, in reality the influence of the policy will be governed by factors including: the price of carbon, the price of jet fuel, the price of aviation biofuel and the level of other incentives that are available. These factors are difficult to predict therefore significant uncertainties remain about the short term impact of the EU ETS and other carbon pricing mechanisms as a driver of biofuels. In the
literature, almost all studies mention the influence of carbon pricing either in the form of the EU ETS or in discussion about future policy changes. The E4Tech report carried out by the CC showed that carbon prices rises within the ET ETS will drive aviation biofuels in the near term. This is due in part to the zero accounting procedure applied to aviation biofuels within the EU ETS. As the literature review states however, there are very few studies, with the expectation of the SWAFEA (2011), which attempt to investigate the impact of carbon prices. SWAFEA finds that carbon prices will factor significantly in the business case for aviation biofuels but not at current prices. A fall in aviation biofuel prices and a rise in oil and carbon price is still required.

Respondents expressed further issues from the fact that biofuels are accounted for as zero carbon within the EU ETS (i.e. whilst using aviation biofuels, regardless of the true carbon emission savings of the fuel, the airline will not be required to surrender any carbon credits). This was described as being a “worrying issue” by a number of respondents because evidence suggests that life cycle emissions savings can vary considerably depending on the feedstock base, the production method, and the transportation of the final fuel. Having a zero accounting procedure gives no incentive for airlines to use the most environmentally friendly aviation biofuels. Although some respondents acknowledged this accounting loop-hole could be a significant incentive for the early adoption of aviation biofuels, the policy experts and the bioenergy academic were unsure of its strength as a long-term driver, even stating that it could be detrimental to the environmental credibility of both the EU ETS and the use of aviation biofuels. It was acknowledged that, in the absence of a mandate, biofuel producers may well chose to produce fuels that have the greatest profit margins and the lowest environmental benefits. This potential situation was described by the policy experts, bioenergy academic and research consultants. Indeed, there are few studies which address this issue and no studies which have looked at the wider political and environmental impact of this loop. There is certainly more research which needs to be done in this area.

A final issue related carbon prices arises from the fact that the life-cycle emission savings that are currently attributed to different aviation biofuels are not yet adequately understood. Although this is an environmental issue it was acknowledged in relation to carbon pricing. It was said that this issue will exacerbate uncertainties associated with the impact of carbon pricing as a driver for aviation biofuels and may potentially lower the environmental credibility of aviation biofuels. Again, this is a totally new issue identified by this scoping study. There are no studies which attempt to investigate the impact of environmental concern surrounding the zero accounting loop-hole.

Emphasis thus far has been to look at the ‘demand side’ i.e. the aviation industry, as the main driver of aviation biofuel. However, the role of the producer; i.e. the supply side, is also important.
Respondents in this scoping study stated that the supply side drivers were important for the widespread certification of the fuels and they will continue to be significant for the anticipated eventual commercialisation of the fuels. This is an underdeveloped area in the literature. In fact there are very few studies which focus on the supply side i.e. the producer’s view of the drivers of aviation biofuel. The unexploited market for aviation biofuels is a potentially lucrative growth area for biofuel. Respondent G described aviation biofuels as providing “new opportunities for petrochemical companies” and Respondent J stated that the biofuels sector has experienced significant growth in investment from the major oil companies in recent years in part because of the options in terms of secondary products (such as bio plastics and gases that biofuels can offer):

“The territory is absolutely enormous, the complexity of the biological system is so much broader than the complexity of any of the other renewables; which in one sense means that the options open for technological innovation are also so much broader”.

Biofuel producers may also be estimating that a cost premium will be available for the aviation biofuels. Respondent B stated:

“I am completely sure that the demand [for biofuels] is strong. Considering the price is right and that the specification is right, I think a small premium is OK. But I think it won’t be much”.

The statement is indicative of the strong demand that is perceived by the petrochemical and biofuels companies, and the fact that the biofuel industry anticipates that a premium may be available. The next sets of drivers are technological drivers. The most frequently discussed driver is a lack of alternative technologies. This driver refers to the fact that the aviation industry has very few technological options to reduce emissions and enhance fuel security.

5.3.3. Technological drivers

Thus far three drivers of aviation biofuels have centred on aviation industry ‘needs’ brought about by wider system-level changes in policy and economics. These changes have enforced the need to reduce emissions, the need to reduce exposure to oil price and the need to enhance energy security. However, there is also a very significant sub-system driver at work. Biofuels are also considered essential to meet emissions targets given a lack of alternative technologies available to the sector (see section 2.17.3 Chapter 2). Indeed, the aviation industry’s position is rather unique in this respect because other transport sectors have much better options to reduce emissions. Aviation has an interesting relationship between the system-level drivers which are bringing about a need to
reduce emissions and the sub-system drivers which are necessitating the use of a low-carbon fuel. The lack of technological options available to the sector was expressed as a key driver for biofuel uptake by eight of the respondents. Most of these respondents indicated that other transportation sectors such as road transport and rail have considerably better options to reduce carbon emissions in relation to aviation, and thus it is no surprise that the aviation industry has started to consider biofuels as a potential solution. Respondent A stated:

“There has been a growing view that [biofuels] can play a large role for the aviation sector; the primary reason for this is the fact we do not have an alternative. We will be using a liquid fuel for the next 50 years; we cannot use solar power or nuclear power. They have got to be liquid based fuels”.

Respondent J described the situation of aviation in this statement:

“There is no other option really, there is a lot of discussion about electric vehicles in the road transport sector, and there are a range of alternatives for electricity in the road sector. But, you can’t drive electricity into the aviation sector. [The aviation sector is where]... the potential benefits of biofuel are most clear in terms of energy density of the fuel and the compatibility of the existing fuels”.

Another respondent from a biofuel production background spoke at length about the key benefit of using a liquid hydrocarbon fuel for commercial air travel. The respondent stated that aircraft design and the capability for high speed long distance travel has being heavily influenced by qualities of liquid hydrocarbon fuels i.e. a high energy density to volume ratio. The respondent stated that this is a key feature in favour of aviation biofuels because evidence suggests that aviation biofuels have equal or greater energy densities per volume compared to jet kerosene. Other technologies such as hydrogen and electric power are not viable in relation to liquid hydrocarbon fuels for this reason. The next driver is ‘new growth markets for biofuels’. This driver refers to corporate motivation to invest into aviation biofuel technologies.

The last group of drivers to be discussed are social drivers. Although social drivers were not explicitly mentioned, respondents did refer to the green public relations benefits. This is the closest the respondents came to discussing a social driver apart from the environmental benefits attributed to the fuels.
5.3.4. Social drivers

Four of the 12 respondents considered green Public Relations (PR) as a potential driver for the fuels. Most of the discussion from the respondents however was given to the possible economic gain for airlines that might be attributed to a greener public image. Respondent I stated that green PR will have an effect on demand for aviation biofuel owing to the fact that airline emissions are highly visible to the public. Interestingly however, none of the airlines stated that green PR is a significant driver for market uptake. This view was shared by the academic Respondent J who stated: “I don’t think it is purely green wash. I think that they have got some really difficult questions to answer in the aviation sector and they [biofuels] are potential solutions”. However, Respondent G warned that biofuels may be sending out the wrong message about aviation, as many environmental groups are ‘anti-biofuels’ due to issues relating to land use change and food price increases. The legacy airlines however were adamant that the industry will not pursue aviation biofuels unless they are proven to be sustainable as it would be counterproductive to do so. The literature made little reference to the fact that legacy carriers were more likely to state green PR as a driver for aviation biofuels. Green PR is discussed by Marsh (2008) as a potential driver of the fuel however the overall sentiment is one of scepticism towards using biofuels as a PR tool. This sentiment was of course shared by respondent G. In terms of the driving the emergence, development and uptake of aviation biofuel, it appears that green PR is not playing a significant role in either creating the system level driver or in terms of driving lower level industry decisions to pursue aviation biofuel. This may be a reflection of some of the environmental issues associated with aviation biofuel, which are still uncertain.

Thus far this chapter has focussed on the drivers for commercialisation and uptake of aviation biofuel, finding that the drivers are rooted in system-level changes in economics and policy. These changes create a need for emissions reductions and avoiding oil price rises. There are also sub-system drivers at work as well. These include the lack of alternative technologies issues and the opportunism for new markets for aviation biofuel. However, despite the driving forces, there are also several issues which are acting to constrain the commercialisation and uptake of aviation biofuels. In the next section the constraints of aviation biofuels will be discussed.

5.4. Factors constraining the emergence, development and uptake of aviation biofuel

Although the constraints associated with the uptake of the fuels differ slightly depending on the technology and the specific stage of development for each technology, within the scope of this chapter the analysis will be focused on the drivers and constraints for established and proven
technologies such as BtL fuels and HEFA. The first drivers to be discussed are economic and environmental issues.

5.4.1. Economic and Environmental

There were a number of economic and environmental drivers discussed by respondents. The biggest issue was however inadequate feedstock supply. This issue may be considered an economic and environmental constraint because it affects the price and sustainability of the aviation biofuels. Indeed, it is the most complex and perhaps the most severe issue acting to constrain the emergence development and uptake of aviation biofuels. All of the respondents in this study acknowledged that the issue of feedstock supply is a significant constraining factor. Limitations on available productive land and controversy associated with food prices were regarded to be the most significant issues affecting the supply of feedstock for aviation biofuel. Limited land resources was stressed as being inherently regional in scope, with certain regions such as Eastern Europe, the Americas and Australia acknowledged as being regions that have a reasonable potential for developing aviation biofuels. Western Europe was mentioned as the most constrained area in terms of feedstock production. The issue of food prices will also impact on feedstock supply. It was acknowledged that food prices and other effects associated with ‘food policy’ will affect the availability of land to grow biofuel crops. This is particularly the case for feedstocks including camellia and oil seeds. There are of course feedstocks that do not require land such as algae or municipal waste. It was acknowledged that these feedstocks are being considered in regions restricted by space. Indeed, BA and Solena are developing the UK’s first waste to liquid plant in East London.

Other issues linked to limited feedstock supply are created by policy incentives that are currently being offered to road based biofuels and not to aviation biofuels. Half of the respondents acknowledged that aviation biofuels, at the time of data collection, do not have the same incentives for production as road based biofuels. Indeed, feedstock production for road transport is still growing as a result of strong policy incentives and mandates for that sector, thus the supply to the aviation sector will be limited unless production is increased further. Respondent H acknowledged that the demand for biofuel within the road transport sector as a result of mandates is too high to allow any of the biofuel supply to be directed to aviation. This follows from the comments made by Respondent E, who stated that there is a strong rational for restricting investment in aviation biofuels at this time because of the unfavourable policy for aviation. Respondent E stated that mandates for road transport fuels, certainly within the EU, are considerably more attractive from both the economic and the environmental perspective:
“Demand for ground fuels via regulation in the EU and elsewhere means that every drop produced is needed to meet the legal requirements for petrol and diesel. Producing far more for aviation - assuming the right fuel could be developed - could disrupt the attempt to ensure the right balance of food versus fuel”.

The next constraints are related to the cost of biofuel and funding that is available to construct production facilities.

The high cost of biofuels was mentioned by all respondents in the scoping study as a major constraint. The cost of biofuels is of course linked to feedstock prices, energy inputs, the financing of production facilities; the price of oil and government policy. Much of the aviation literature focuses on the cost issues and at the time of writing aviation biofuels are too expensive to compete with the price of fossil-oil based jet fuel. Cost reductions are consequently considered essential according to all 12 respondents. Respondents acknowledge that a component of the cost constraint issue is associated with the size of the production facilities needed, and the perceived lack of government and private funding. The facilities for producing BtL or F-T need to be very large and thus will require major capital investment and off-take agreements\(^6\) between the producer and the airline. Funding for production facilities is an issue that was highlighted by a majority of the respondents. Government funding is highlighted as being particularly important though lacking, and most respondents noted that the private sector was also under-investing due to uncertainty of profitability of the technology. Respondent A stated that there is an issue with respect to gaining momentum and confidence for private investment; this is, again, linked to the incentive schemes and government backing that is offered to the industry. Investment is acknowledged as being heavily reliant on reducing risk by diversifying the fuels that are being produced at one location. It is indicated that a possible solution is to produce several different types of biofuels within a single facility, for instance; bio-jet for the aviation sector, diesel for the road sector and crude fractions for the marine sector. In general however, there is need to build confidence in the market to allow momentum to be generated in the near-term to speed up the commercialisation process according to respondent A. This will in turn lead to more private investment into the area and faster uptake. Respondent A is adamant that this could be achieved by aligning the incentives for aviation biofuels with those of road transport biofuels. The next group of issues considered to be a significant constraining factor is related to the sustainability of aviation biofuels.

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\(^6\) An off take agreement is an agreement or guarantee made by an airline to buy a certain volume of fuel from the producer when the plant is operational.
5.4.2. Environmental constraints

Environmental sustainability was a key issue acknowledged by all 12 respondents in the interviews and a topic of lengthy discussion for a couple. The policy experts were sceptical of the environmental credibility of the fuels, believing that biofuels are being used as the environmental ‘silver bullet’ for the sector (as the industry does not appreciate the true sustainability of the fuels). Other respondents mentioned that the underlying factors that will dictate the sustainability of aviation biofuel expansion are often overlooked. Sustainability constraints are more complex than they initially appear because the ‘real’ issues are associated with the rate of expansion of demand for feedstocks created in relation to the capacity of the biosphere to compensate for it.

According to Respondent J, the rate of expansion is a key constraint for the sustainability of the entire system in terms of its net impact:

“If the net increase in demand for feedstocks rises within a certain rate it will probably be within the capacity of the biosphere to compensate for that; global carbon stocks will not be too adversely affected. If the rate of demand is really quite aggressive then we could have problems depending on how the technologies are deployed; in terms of the amount of feedstock available and the price, and also the global carbon stocks in the biomass”.

Other factors that affect sustainability according to the respondents include land use changes caused by biofuel production. Land use change is another area of significant controversy and uncertainty, due to the disparate accountability procedures which are undertaken globally. Indeed, the fact that carbon emissions from land use change cannot be accurately measured reduces the legitimacy of using aviation biofuels as a means to reduce aircraft emissions. In light of these concerns the sustainability of the fuels is of paramount importance according to all of the respondents. It was acknowledged by most of the respondents that the aviation industry needs fuels which are shown to be sustainable in terms of the life-cycle emissions and the net impact on the environment. The respondents did not however elaborate on the methods for ensuring sustainability. The next theme is that of policy incentives, or rather, the lack of policy incentives offered to aviation biofuels.

5.4.3. Policy constraints

In the preceding sections it was shown that there are several constraints and issues associated with the commercialisation and uptake of aviation biofuel. Most of these issues however are dependent on the availability of policy incentives, or more precisely a lack of policy support. It has already been
suggested that the mandates applied to the road sector in the EU will limit the production capability of aviation biofuels. Indeed, within the EU, there are no direct policy incentives available, even the EU ETS is not directly about biofuels and several respondents indicate that the EU ETS would not facilitate much uptake because the carbon price at the time of data collection was too low. Respondent K stated: “Legislation in terms of the EU ETS won’t facilitate much commercialisation. But it might cause [market] growth if the price is high enough”. It was acknowledged by all respondents that a fundamental constraining issue, certainly within the EU, stems from the fact that there are unequal policy incentives offered to the aviation sector in comparison to the road sector, and there is a need to build equal and universally accepted accounting procedures between all end users of biomass.

There are also several issues associated with the EU ETS specifically, which together contribute to a wider policy incentive constraint. The first issue is the fact that biofuels are considered to be polluting fuels within the scheme. This is due to a technicality which states that the carbon content should be accounted for at the point of source; which for biofuels is technically zero because the crop has sequestered the carbon in the growth stage. This is a significant issue because the EU ETS scheme would therefore not prioritise/incentivise the use of sustainable biofuels over non-sustainable ones. Furthermore, without proper accounting procedures the true emissions output of the aviation sector will be difficult to quantify and thus manage effectively. Respondent J stated that:

“...that is a big problem [referring to the zero carbon in EU ETS]; because there is no way to calculate the impact back at where the feedstock arises... [A] big issue is building the same accounting procedures or equivalence in the accounting procedural in between these different supply systems for these feedstocks and biofuel bioenergy and all other forms of biological use”.

The second issue is due to the fact that the EU ETS is geographically constrained by the EU region and thus there is no global policy incentive for the fuels that is aligned with the rest of the world. Currently in the U.S, biofuels will be able to be used to contribute to airlines renewable fuel obligations but carriers are calling for a globally aligned legislative framework which may include a global carbon pricing policy or mandate. Respondent J stated:

“... [There is a need to] draw equivalence into the accounting procedure across all the sectors. Also to find ways to incentivise good innovation - and by good I mean - in terms of the sustainability performance for the fuels”.

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Indeed, the issues associated with inadequate policy incentives are serious; however they are not being focused on in any of the aviation biofuels studies. The SWAFEA study (2011) is the first attempt at investigating the policy issues associated with aviation biofuels however even this study lacks a comprehensive set of policy recommendations for aviation biofuels, especially at the national level. The final constraints relate to fuel consistency and infrastructure. These issues may be considered technological constraints.

5.4.4. Technological constraints

Fuel consistency is an issue which was discussed in detail by Respondent F, but not mentioned in detail by any other respondents. According to the respondent, if the aviation biofuel varies chemically as a result of the small scale production and/or as a result of the feedstock base, it will affect engine performance and maintenance of the engines, as well as impact on the safety of the fuels. Conversely, it was agreed by all the other respondents that the issue of fuel consistency and safety were almost entirely resolved and, at the time of writing, there are no safety issues that have arisen from the use of aviation biofuels in trials. Constraints related to infrastructure were mentioned by three respondents but not seen as a major issue by the other respondents which included the three airlines. The respondents acknowledged that sometimes the literature and media can be misleading in their description of aviation biofuels because they reflect upon conventional biofuels that are used for road transport (which are not suitable for aviation’s requirements).

Although the industry is portrayed as pursuing fuels which are ‘drop-in’, meaning that they can be used in existing infrastructure, in reality some infrastructural adjustments are still needed. Airports typically do not manage the fuel supplies to airlines; this is done by the third party fuel supplier themselves. Assuming there is not a uniform uptake, a 50/50 biofuel and jet fuel mix would need to be supplied using a separate system to allow the airline to account for the fuel it is purchasing. Furthermore, there was a lack of understanding from a number of respondents with regard to the actual certification issues relating to using aviation biofuels within existing infrastructure. This follows from respondents A, B, C and J who commented that the most likely scenarios are a separated supply chain designated fuel bowers or pipelines. There may also be an issue associated with the chain of custody of the fuels, however respondent A stated that the standard procedures that are in existence already will likely be carried over to the biofuels supply chain. The final section of this chapter will summarise the findings of the scoping study.
5.5. Summary

This scoping study has revealed that the drivers and constraints for aviation biofuels are much more complex than the literature suggests. Although the empirical findings from this study have confirmed a number of issues, the study discovered that there is significant amount of uncertainty surrounding the importance and severity of the issues. The scoping study showed that the drivers of aviation biofuel are better understood as combination of system level changes in economics and policy combined with one fundamental technological constraint. At the system level, emissions policy such as the EU ETS and rising oil prices are driving the need to reduce emissions however, at the subsystem level, technological constraints in terms of aircraft design are necessitating the use of biofuels. The scoping study also showed that additional drivers come from the commercial opportunities created by new markets for biofuels and potential green PR benefits which may arise from the use of biofuels. These issues are not well investigated in the literature despite the fact that these sub-system drivers may be far more important for the development of a niche market for the fuel, for instance in the development of a market or the testing the fuels. Some evidence from this study does however confirm that the main drivers of aviation biofuel stem from three broad industry needs; (1) to reduce emissions; (2) to avoid high oil prices and carbon prices and (3) to maintain the use of existing engines and infrastructure because of lack of viable alternatives. These drivers more or less align with the literature, though it appears that the need to reduce emissions is slightly understated in the literature and it appears also that the interplay between the issues is more important than first thought.

The most significant constraints revealed in this chapter include: a lack of feedstocks, high costs, low funding, and concerns about environmental sustainability concerns, a lack of policy incentives and fuel (in)consistency and infrastructure. Again, the main constraining issues are economic, environmental, political and technological. The most significant constraint to aviation biofuels appears to be the availability of feedstocks which is both an economic, environmental and technological issue. This issue in itself is a complex problem because the availability of land is not the only issue; there also needs to be careful consideration of food production, impacts associated with land use change and the biofuel technology being used; these issues in turn create uncertainty and further constraints associated with aviation biofuels. The study also revealed that there is an almost complete lack of aviation biofuel incentives in relation to the road transport biofuels, especially within the EU; meaning that many of the constraints are intensified and even more difficult to overcome. For instance, a lack of policy support in the form of mandates, subsidies or tariffs will increase the price of the technology. This in turn will reduce the economic viability of the fuels. This is a common issue in new technologies but the price of the technology is likely to reduce over time.
However, without careful consideration for these issues, the emergence, development and uptake may be slowed.

Within the EU, the aviation biofuel industry is currently relying on the combination of falling biofuel costs and rising oil and carbon prices to overcome the cost constraints. The power of the EU ETS in terms of its capacity to influence the uptake of biofuels is unclear. At the time of writing the cost of carbon is significantly lower than is required to create an incentive to produce aviation biofuels. Furthermore, although the zero accounting loop-hole for biofuels may act as an incentive for the use of biofuels in the short term, it will create difficulties in accounting for the true carbon emissions of the industry. If this zero accounting procedure should continue in the long-run, and given that no other region adopts a carbon pricing policy, there is a strong chance that the pattern of uptake in the EU vis-à-vis other world markets may be influenced. However, until concerns surrounding cost, sustainability of the fuels and longevity of policy support are addressed, aviation biofuels will not form a significant share of the aviation fuel market. These are longer term system changes which could create a widespread market demand for the fuel. This is needed to push the development of aviation biofuel from its very limited niche market into a widespread commercial market.

With regard to recommendations, almost all respondents in this study suggested that further scientific research is required to establish new feedstocks and production technologies that utilise non-edible forms of biomass including wastes. This is an on-going challenge for the entire bioenergy industry as pressures for land and suitability increase. The current status of the advance biofuel technologies such as, lignocellulosic biofuels and ethanol-to-jet are developing quickly; however, the biggest constraint to these technologies is their comparably high production costs in relation to the hydrogenated vegetable oil technologies. Respondents also acknowledged that it is essential that research to establish a robust sustainability criteria and accounting procedure for aviation biofuels is undertaken. More research is required to verify the life-cycle emissions attributed to aviation biofuels before there will be significant support for increasing production from government and private investment. The sustainability of the fuels itself is not the issue; it is the lack of understanding and uncertainty from the legislators and governments about how you qualify for them that is a constraint for aviation biofuel. Finally, a review of the policy incentives that are available to aviation biofuels is required. In particular, work needs to be carried out to align the policy incentives offered to road transport with aviation.
Chapter 6

Findings from the online survey

6.1. Introduction

This chapter presents the findings and analysis of the internet based survey of 44 aviation biofuel stakeholders. The aim of the chapter is to analyse the relative importance of the key issues obtained from the literature review and scoping study (Objective 3). The scoping study and literature review did not seek to obtain empirical data that could be used to interpret the severity of the issues. However, understanding the relative importance of the issues is essential for forming recommendations to promote the emergence, development and uptake of aviation biofuels. Crucially, it allows policy makers to understand which issues should be addressed first to support the commercialisation of the technology. The chapter will be arranged into five sections. The first investigates the importance of contemporary environmental challenges facing commercial aviation, and the technologies that are proposed to mitigate them. In section two, the driving factors are analysed in terms of their importance at motivating the emergence, development and uptake of aviation biofuels. In section three, constraining factors are analysed in terms of their severity as barriers for the emergence, development and uptake of aviation biofuels. In section four, existing strategies (including policy measures, government incentives, and demonstration plants) are investigated in terms of their importance at supporting the development of the technology. Section five, discusses the stakeholder forecasts and for the development and uptake of aviation biofuels. A final section will review the stakeholder’s perceptions regarding future aviation biofuel production and the likely time frame for commercial viability.

The survey yielded a response rate of 29% (44 completed responses from a population of 150). However, only 23 respondents chose to reveal their industry sector in the completed responses. Seven airlines, five biofuel producers, three petrochemical companies, two academics, two airports, one engine manufacture, one airframe manufacture, one NGO and one environmental consultancy acknowledged there details. Although the response rate was low, the data was still able to provide useful indication of the relative importance of aviation biofuel issues.

As described in the methods chapter (Section 5.7), the survey used mainly Likert scale questions to determine the relative importance of individual issues. The Likert scale was aggregated and coded by the author and the modal and median scores for the individual questions were calculated. The mode
represents the most common Likert ranking that was given for a particular question, while the median represents the middle value. A simple average (median) cannot be used with Likert scale questioning because of the ordinal nature of the data.

The first section reviews stakeholder perceptions surrounding the current environmental challenges and commercial pressures facing the aviation industry. The section reveals the technologies that the stakeholders perceive to be important to address these issues. It will be shown that most of the serious issues are related to fuel price, fuel security and the environment. It will also be shown that although there are a number of different technologies which are being used to address these issues, aviation biofuels appears to be one of the most important technologies.

6.2. Current industry challenges

Respondents were asked to rate the severity of fuel costs, profitability, airport capacity, the global economic downturn, future fuel supply, air quality, noise and future airport capacity. All of these issues were acknowledged in the literature review and scoping study interviews as being important issues for the aviation industry. All the issues addressed in the survey were rated as being at least fairly serious, though by far the most serious issue facing the aviation industry was fuel cost. The least serious issues identified in the survey were air quality around airports and airport capacity (Figure 6.1). The proceeding sections will then review each issue within their core themes following the PESTLE framework, starting with the most significant - economic industry challenges.
6.2.1. **Economic**

The most significant industry challenge expressed by the respondents was fuel costs. Fuel cost was reported to be very serious. In total, 32 respondents indicated that fuel costs were a very serious issue for the aviation industry; nine indicated that fuel costs were a serious issue, while three indicated that the issue was fairly serious. No respondents indicated that the issue was not very serious or not at all serious. The survey also suggested that stakeholders were anticipating rising fuel costs within the next 10 years. Indeed, when asked about how likely a fuel cost increase will be within 10 years, 29 respondents indicated that it would be likely and 15 suggested it would be fairly likely. Fuel costs are mentioned in the literature review as being perhaps the most significant issues facing aviation today. The scoping study revealed that the European aviation stakeholders are particularly worried about the fuel cost increases which are expected in the future. This survey evidence found that all of the aviation respondents (i.e. airlines, airframe manufactures and airports)
and the academic interpreted the issue of fuel costs as very serious. All of the biofuel and petrochemical companies however stated that the issues were only serious. This could indicate that the biofuel/petrochemical industries are not fully aware of the aviation industry concerns about fuels costs. The next most serious issue for commercial aviation was future fuel supply/security.

Future fuel supply represented the second most serious issue in this section. However, while it also achieved a modal score of very serious, the median score fell equidistance between ‘very serious and ‘serious’ (See Figure 6.1). This was caused by a larger range in the data and a lower proportion of ‘very serious’ scores. In total, 22 respondents indicated that future fuel supply was very serious; 15 respondents indicated it was serious; while five respondents indicated it was fairly serious and two respondents indicated it was not very serious. Interestingly, in this question, the aviation respondents and petrochemical/biofuel respondents provided closer results. All the aviation respondents, petrochemical and biofuel producers stated that the issue was very serious. The two academics however stated that the issue was serious. The survey also suggested that most stakeholders are uncertain about the future supply security risks. OPEC supply obstructions were rated as being neither likely nor unlikely in the next 10 years by 90% of the respondents. This corresponds with the scoping study and the literature which suggests that fuels security is indeed inherently uncertain but serious. The next issue is the global downturn in economic activity.

Global downturn in economic activity was the third most serious issue, achieving modal and median scores of serious. 10 respondents suggested that the global downturn in economic actively was a very serious issue while twenty respondents indicated it was a serious issue and 14 indicated it was fairly serious. No respondents stated that the issue was not serious or not at all serious. The survey also suggests that a significant proportion of stakeholders are anticipating further economic recessions in the next 10 years. Seven respondents indicated that further recessions in the next ten years are very likely, while 14 indicated that the threat is likely. The issue of global economic downturn was not significantly featured in the scoping study as a driver for aviation biofuels however; it was mentioned by the stakeholders as being a serious issue facing the industry. In terms of the sector responses, all of the aviation respondents stated that this issue was very serious whereas the petrochemical, biofuels and academics rated the issue as only serious. Unfortunately, none of the respondents who rated the issue as fairly serious specified their company and sector. The next issue was profitability. Profitability was of course affected by the global economic downturn, however, the rating of profitability was less severe.

Profitability was ranked as the fourth most serious issue in this section. The modal result for profitability was very serious however; the median result was only serious. The lower median score
was caused by seven respondents rating the issues as only fairly serious. Although 21 respondents indicated that profitability was a very serious issue; sixteen respondents indicated it was serious and 7 respondents indicated it was fairly serious. This reduced the median score. The six airlines all stated that profitability was very serious while the other aviation industry respondents rated the issues as serious which correspond with the scoping study and the literature. However, two biofuel companies rated profitability as being only fairly serious for the aviation industry. Profitability is of course a complex issue. However, profitability will be inherently linked to the fuel cost increases which are expected by almost all of the respondents from the survey (section 6.2.3). As shown, thus far the main challenges have all been economic. The next most serious challenge for the industry was aircraft emissions i.e. environmental.

6.2.2. Environmental

The most serious environmental issue was the need to reduce aircraft emissions. Modal and median scores were both ranked as serious. 12 respondents indicated that aircraft emissions were very serious and 17 respondents indicated that aircraft emissions were serious. All of the aviation industry respondents stated that aircraft emissions were very serious. This corresponds with the scoping study; which indicated that the issue was perhaps the most important of issues. However, because 14 respondents indicated that aircraft emission were only fairly serious, the overall seriousness of the issue was lower than fuel prices, fuel security, profitability and the global economic down turn (Figure 6.1). Interestingly, two petrochemical companies rated the issue as being fairly serious which appears to contradict the scoping study findings. The scoping study found that aviation issues were understood by the petrochemical company thus they should have realised the significance of the rapidly growing emissions problem. The last two issues from this section of the survey were airport capacity and air quality around airports. Although both issues achieved modal and median scores of fairly serious, they both had high ranges; indicating less consensus about these issues. However, air quality around airports and noise did appear to be slightly more serious than airport capacity. Air quality and noise had seven very serious rankings and 15 serious.

The key findings from this section are that the aviation industry is clearly prioritising economic issues in terms of costs, fuel supply, and the global economic down turn and profitability. This corresponds with the aviation biofuel literature which suggested that fuel price is by far the biggest concern for the sector. This section also adds to the evidence from the scoping study which indicates fuel security is an important issue. The scoping study revealed that fuel security is a highly serious issue for the commercial aviation sector. Aircraft emissions were however still ranked as being an important issue for the future of the sector. Air quality around airports and airport capacity were by
far the least serious issues however, they were nonetheless considered to be at least fairly serious. The next section will investigate how important different technologies are perceived to be for the long-term sustainability of the commercial aviation industry.

6.3. Commercial aviation technologies

The findings associated with aviation technologies indicated that there are a number of important technologies for the long-term sustainability of the commercial aviation industry. Figure 6.2 summarises the technologies and their perceived importance. With the exception of electric powered aircraft, the technologies were rated as either ‘very important’ or ‘important’. The following sections will review each technology in order of their importance.

Figure 6.2. Potential Commercial Aviation Technologies

Figure 6.2 - Diagram shows potential technologies or enhanced practices may be used to mitigate against the current aviation industry’s environmental issues. 1 = Very unimportant, 2 = unimportant, 3 = Neither unimportant nor important, 4 = Important, 5 = Very important.
6.3.1. **Biofuels**

Respondents reported that biofuels are a very important technology for aviation, giving modal and median scores of very important. Although enhanced air traffic management and new engines and aircraft also obtained the same score, because biofuels had the lowest range and the highest total number of very important scores, it has been ranked as being marginally more important in Figure 6.2. Biofuels achieved 32 very important responses and 12 important responses. All of the aviation industry respondents and the biofuel companies rated the technology as being very important. This result corresponds with the scoping study findings but does not necessarily agree with the literature. The literature places slightly more emphasis on incremental aircraft improvements and ATM rather than biofuels. The petrochemical companies and academics shared the literature’s uncertain view and rated the technology as being either important or neither important nor unimportant. Although by far the majority of respondents rated the technology as being very important, there may have been some bias due to the type of the stakeholders which were selected. That being taken into account, no stakeholders, which included NGO’s and environmental groups (which were known to be against aviation biofuels according to the scoping study), indicated that aviation biofuel is not important for the long-term sustainability of the industry. The next most important technology was enhanced air traffic management.

6.3.2. **Enhanced air traffic management (ATM)**

This enhanced air traffic management procedure obtained modal and median rankings of very important. However, the procedure had a higher range of ratings and a lower proportion of very important ratings, thus it has been deemed less important than biofuels. In total, 25 respondents rated the technology as being very important while 18 rated it as important. One rated it as neither unimportant nor important. In terms of sectors, the aviation industry respondents, academics and NGO’s rated the procedure as being very important. These respondents agree with the literature findings which revealed ATM to be a significantly important procedure for reducing emissions (CCC, 2009; Dray et al., 2009; Lee et al., 2009). The biofuel and petrochemical companies rated the procedure as being important as well. Although this indicates that the respondents were aware of some of the benefits of ATM, it may reveal that they are somewhat less informed about the significant advantages of ATM. The next technology is new engine and aircraft designs.

6.3.3. **New engine and aircraft**

This technology was rated as being only marginally less important than enhanced air traffic management. Although it had modal and median scores of very important, the technology had a
larger range of responses. 23 respondents rated it very important, 19 as important, one ‘neither unimportant nor important’ and one as unimportant. In terms of industry sectors, the responses matched those of the ATM question. All of the aviation industry responses, as well as the academics and NGO rated new engines and aircraft as very important. The biofuel and petrochemical rated it as being important. The next two issues will be discussed together: retrofitting of existing aircraft and synthetic jet fuel

6.3.4. Retrofitting existing aircraft and Synthetic jet fuel

Although both technologies achieved modes and medians of important (Figure 1), retrofitting of existing aircraft ranked higher overall due to a lower range and the fact it had more very important responses. Retrofitting technologies (such as winglets) had 15 very important ratings, 22 important ratings and six neither unimportant nor important. However, synthetic jet fuel obtained 5 very important responses, 19 important responses, 13 neither unimportant nor important responses and three ratings of unimportant and very unimportant each. Interestingly, there were differences between the aviation sectors responses and the petrochemical/biofuel responses. The aviation respondents rated retrofitting of existing aircraft slightly above synthetic jet fuel whereas the petrochemical and biofuels companies rated the issues the other way around. This may be a direct reflection of the sector’s expertise in aircraft and fuelling. Although the difference between very important and important is not particularly discernible, it may add to the evidence that the two sectors are not communicating affectively about their ideal solutions for the aviation industry. The next two technologies from Figure 1 are electric powered aircraft and hydrogen powered aircraft.

6.3.5. Electric and hydrogen powered aircraft

The final two technologies were electric powered aircraft and hydrogen powered aircraft. Electric aircraft achieved a modal and median score of neither unimportant nor important however the technology had a high range. Respondents rated both technologies very important and very unimportant. The majority of the ratings however were either neutral or negative. For instance, although five respondents indicated that electric powered aircraft would be important and two respondents indicated it would be very important, 17 respondents rated the technology as being neither unimportant nor important for aviation, 12 respondents rated it unimportant and 8 rated it very unimportant. The high range of data may indicate that the respondents were distinctly unsure about the benefits of the technology or they may have been confused about the rating scale. Hydrogen powered aircraft showed a similar range of responses, though the modal score was calculated as unimportant. Hydrogen powered aircraft achieved 13 unimportant ratings, 12 neither
unimportant nor important ratings and nine very unimportant ratings. However, like electric aircraft it also achieved a reasonable amount of positive scores. Six respondents rated it as ‘important’ and the remaining four respondents rated it as very important. Unfortunately, the respondents who rated the technologies as very important and very unimportant did not indicate their sector. Nonetheless, judging by the range of responses it is clear that the benefits of these technologies are misunderstood by the majority of the stakeholders.

In this section it was revealed that the most important technologies for the aviation industry are biofuels, air traffic management and engine design and aircraft. These technologies provide fuel efficiency savings, fuel security benefits, reduction in emissions and more efficient use of air space. They therefore act to prevent the most serious issues that the commercial aviation industry is facing. According to this survey these issues are: fuel prices, fuel security and aircraft emissions. These findings closely align with the scoping study and literature though there were some differences in responses between aviation industry responses and the biofuels and petrochemical companies.

Thus far this chapter has reviewed contemporary commercial aviation issues and technologies. It can be seen that certain issues and technologies are considered to be more important than others (Figures 6.1 & 6.2). It has also shown that certain issues achieve a higher degree of consensus among the respondents, perhaps indicating a degree of certainty about those issues. The next section of this chapter will review the driving factors associated with aviation biofuels.

6.4. Drivers

In total 26 drivers were identified in the literature review and scoping study; these were tested to determine their relative importance. Figure 6.3 (over page) shows the 26 drivers arranged from most important to least important moving clockwise from the top. With the exception of four, all the drivers attained modal and median scores of either ‘important’ or ‘very important’. Six drivers achieved a very important rating, while 17 achieved an important median score. The following sections will review the drivers thematically following, again, the PESTLE framework. A summary of the main themes can be seen in Table 6.1 (over page).
Table 6.1. Driver themes

<table>
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<th>Theme</th>
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| Political and legislative | Public funding  
Incentive schemes  
Strong government targets  
Well defined environmental policy  
Public private partnerships  
Emissions reduction legislations |
| Economic            | Rising jet fuel prices  
Access to private funding  
Commercial opportunities for biofuel companies  
Rising oil prices  
Volatility of oil jet-fuel price  
Volatility of oil price  
Fuel security concerns  
Commercial opportunities for airlines  
Rural economic development  
Commercial opportunities for oil companies  
Low labour costs  
Low land costs |
| Social              | Corporate social responsibility |
| Technological       | Compatibility of existing engines  
Experience with existing biofuels |
| Environmental       | Land availability for feedstock  
Climate for growing feedstock  
Availability of fertilisers  
Productive soils |

6.4.1. Political and legislative drivers

Some of the top ranking drivers from the survey were political and legal issues. High ranking drivers included access to public and private funding, incentive schemes, strong government targets, public private partnerships and emission reduction legislation. Access to public funding was ranked as the most important driver in the survey (Figure 6.3). It attained median and modal scores of very important and it had the lowest range in the data set. In total, 25 respondents rated it as being very important and 19 rated it as important. However, while the stakeholders perceived public funding to be fundamentally important for the technology’s development, the scoping study showed that it will be likely that there will be insufficient government financing for aviation biofuels in the next year. This data shows that although there is a clear perceivable need for greater public funding, most stakeholders are pessimistic of public funding being actually offered. In most extant studies, access to public financing is not discussed explicitly. Reports such as CCC (2009) and Dray et al., (2009)
discuss policy issues such as carbon pricing and incentive schemes but direct public funding is not investigated. SWAFEA (2012), which offer the most comprehensive review of the public funding arrangements, finds that public funding is occurring but the level of funding is generally inadequate. This survey appears to confirm this. The next most important driver ranked by the respondents is incentive schemes.

Figure 6.3 Aviation biofuel drivers

Diagram shows aviation biofuel drivers. 1 = Very unimportant, 2 = unimportant, 3 = Neither unimportant nor important, 4 = Important, 5 = Very important.

Incentive schemes, although not specifically defined in this survey, achieved a mode and median score of very important. The range of responses was marginally higher than access to public funding so the overall ranking was calculated as being marginally less important. Although more respondents (29) indicated that incentive schemes were very important, five respondents rated incentive schemes as being neither important nor unimportant. All of the aviation sector respondents and the biofuel sector respondents believed that incentive schemes were clearly necessary for aviation biofuels. However, the academics and NGO rated the issues as being important and the petrochemical companies rated the issues to be neither unimportant nor important. The literature
reveals that incentive schemes are currently inadequate but that economic instruments such as the EU ETS will act a long-term driver of the fuel (SWAFEA, 2011; CCC, 2009). The scoping study on the other hand revealed that a significant constraint of aviation biofuel development is in a lack of policy/incentive support. It appears that the survey respondents were ranking the driver as being ‘very important’ conditional of acting having adequate levels of support. The next policy driver is strong government targets for emission reductions. This is an issue which has major linkages with the environmental theme.

Strong government targets for emissions reductions obtained responses spread between very important, important and neither unimportant nor important. 23 respondents rated it as important, 16 as very important and 5 as neither unimportant nor important. In the scoping study however, respondents stated that this issue was an important driver of aviation biofuels because it sent a clear signal to airlines to reduce emissions. The scoping revealed that the issues are actually more complex since airlines are voluntarily reducing emissions as well. The literature aligns more closely with the scoping study results. In almost all studies, strong government targets are expressed as being ‘needed’ or ‘required’ to increase the chances of development and uptake. However, in most studies it is made clear that government support must be monitored and if support is offered, well defined environmental policies must be implemented too. By coincidence, this is the next issue within this theme.

Well defined environmental policies rated lower overall importance compared to ‘strong government targets for emissions reductions’, despite the fact they are very similar issues. The modal and median score for well-defined environmental policies was calculated as being important; with 23 of responses rating the driver as important, 19 rating it as very important and two responses rating it as neither unimportant nor important. The lower score may however be due to ambiguity between ‘well defined environmental policies’ and ‘strong government targets’ for emission reductions. It may also be due to uncertainty surrounding the current level of policy support associated with aviation biofuels. Additional data from the survey showed that stakeholders perceived the current level of policy support to be lacking; this aligns with scoping study findings and the main literature sentiments. When asked if there were ‘too few policy incentives for aviation biofuel’ the responses generally agreed with the statement. 12 respondents (27%) indicated that they strongly agreed with the statement, while 17 (37%) indicated that they agreed with the statement. The fourth political and legislative issue is public private cooperation.

Public private cooperation was rated as important or very important by the majority of the respondents. For instance, 22 respondents rated the issue as being important and 19 respondents
rated the issues as being very important. However, one respondent rated it as neither important nor important and two others rated it as unimportant. This reduced the median value and lowered the overall importance of the issue in this section. The fact that public private partnerships are at least perceived as important by the majority is a good indicator that stakeholders ‘want’ to develop partnerships. This sentiment is also expressed in the scoping study by the biofuel producer and international aviation authority director. Interestingly, public private partnerships are not commonly discussed in the literature. This is surprising given the fact that a number of industry partnerships which have been formed (BA – Solena, Virgin Atlantic – Lanza Tech etc.). Indeed, it appears that literature is very far behind the developments. This is also a reflection of the sheer pace of development in the aviation biofuel field.

The next theme to be explored is economic drivers. These factors were generally ranked quite highly in the survey, apart from the issues of low labour cost, low land prices and commercial opportunities for oil companies. The highest ranking economic issue was increasing jet fuel prices. This was an issue which was raised as being the most important issue in the literature and perhaps the second most important issue from the scoping study.

6.4.2. Economic drivers

Economic drivers represented the majority of issues in the aviation biofuel survey (Table 6.1.). The most important issue discussed by the respondents was rising jet fuel prices. Rising jet fuel prices obtained a modal and median score of very important in the survey. 24 respondents rated rising jet fuel prices as very important, while 15 respondents rated it as important. The remaining 5 respondents rated the driver as neither important nor unimportant. Rising jet fuel prices could be described as being marginally less important than incentive schemes due to the fact that only 55% of respondents rated the drivers as very important. Interestingly, the biofuels companies and the aviation industry respondents had similar responses, each rating the issues as very important, while the petrochemical companies, academics and NGO’s rated the issues as only important. Unfortunately, the 5 neutral responses for rising jet fuel prices did not reveal their job title or sector. The survey showed the respondents believe that there will be increases in jet fuel prices in the next 10 years. A majority of respondents (59%) rated the likelihood of rising jet fuel prices as being likely while 36% rated it as very likely. The survey results align with the scoping study findings; all of the respondents in the scoping study mentioned rising fuel prices as being an important driver however almost all of them also stated that the increases in the next 10 years were very likely. These findings unsurprisingly matched those of the literature and the scoping study. The price of jet fuel will be one of the overriding factors that an airline will consider when buying biofuels. It was stated clearly in
the scoping study by two airlines that there would not be a premium available for the fuels. This is generally the sentiment of the literature, as well as this survey. Rising jet fuel prices was ranked highly as a result. The next issue is access to private funding.

Having access to private funding is crucial for the development of aviation biofuels. The driver was ranked as important overall in the survey. The responses ranged between 3 likert scale questions but 25 respondents rated the issue as important and 16 rated it as very important. Additional data suggests that the stakeholders believe that the likelihood of obtaining sufficient private financing is very low. In other words, the respondents are suggesting that companies that are blessed with having a private financier will be better off. It is difficult to make comparison with the literature here because there is such limited investigation in the economics of aviation biofuels. Although there are a number of industry journals which quote private funding from various sources and companies, there are not peer reviewed studies into these matters. Needless to say, private financing of aviation biofuel testing projects appears to be the most common, with the addition of government finance being a rare blessing. The next economic issue to be discussed is commercial opportunities for biofuel companies.

Although this driver obtained a mode and median of very important, the fact that the driver achieved fewer very important scores and more neutral scores increased the range in the data. In total, 22 respondents stated that it was a very important driver, 13 respondents rated it as important while 8 respondents rated it as neither important nor unimportant. One respondent, who was from an airline, did not answer this question. Unsurprisingly, all the biofuel companies stated that the commercial opportunities for biofuel companies were very important drivers for aviation biofuel. The majority of the airlines as well as the NGO and academics concurred with the biofuels companies. However, the petrochemical companies rated the driver as being important. In fact, throughout this survey the petrochemical companies have generally rated the issues no higher than important in the Likert scale. This is an indication of their more sceptical attitude towards aviation biofuel. The scoping study revealed that European stakeholders do perceive the commercial prospects of biofuels as being a driver for the fuel. The survey data adds to this evidence. Unfortunately the literature scarcely talks about commercial opportunities. Studies such as CCC (2009), SWAFEA (2012) and Dray et al., (2009) mention corporate social responsibility as a driver, but there is little discussion of the actual possibility of commercial ventures. This is despite the fact several airlines have invested in aviation biofuel flight trials as well as co-funding of production facilities. Based on these industry investments, the commercial opportunities issue is likely to be true. The next driver is volatility of jet fuel price. Volatility of jet fuel price and volatility of oil price
are both important drivers which are frequently mentioned in the peer-review literature however, according to this survey, jet fuel prices are marginally more important than oil prices. This is not picked up in the literature or the scoping study. Volatility of jet fuel price achieved a median and mode of important. 22 respondents rated it as being important and 17 rated it as very important. Five respondents gave a neutral response. Volatility of oil price showed a very similar response to volatility of jet fuel prices; though only 21 respondents rated it as important, 19 rated it as very important and four as neither unimportant nor important. As mentioned, it is difficult to differentiate between the importance of these two drivers using this data alone. However, it is clear that volatility of jet fuel price and oil price are important drivers. Additional data from the survey showed that the likelihood of having increased volatility in oil prices was likely however, the range of responses to this question was relatively high given the inherent uncertainty in forecasting oil prices. The next issues are fuel security concerns.

Fuel security is an extremely important driver in the literature and scoping study though it is ranked 13th in this survey. The lower ranking in the survey was due to six respondents that rated the issues as neither important nor unimportant. The issue overall achieved a mode and median of important with 20 respondents rating the issue as an important driver, 18 as a very important driver and six as neither important nor important. Unfortunately, the six respondents that rated the issue as neither important nor important did not indicate their sector so it is hard to speculate as to the reason why fuel security was not universally agreed as a very important driver. The survey did however reveal that almost all the respondents were unsure of future OPEC supply obstructions and respondents were furthermore reluctant to predict the likelihood of significant new oil discoveries in the next 10 years. This factor may indicate that the range in the survey results is due largely to uncertainty among aviation biofuels stakeholders. Fuel security has featured as a major system level driver of aviation biofuel in the literature and scoping study. The next issue in this section is the inclusion of aviation into the EU Emissions Trading System (ETS).

This driver had a median and mode of important but the number of important and very important ratings was lower than the previous issues. 18 respondents rated the issue as being important and 12 rated it as very important however, 11 respondents indicated that it was neither important nor unimportant. Interestingly, the aviation respondents did not rate the driver as highly as the rest of the respondents. The airlines, airframe and engine manufactures all rated the issues as being neither important nor unimportant. This concurred with the scoping study which indicated that the aviation sector believe that the EU ETS will not be affective as a driver for aviation biofuels owing to the relatively low carbon price. The academics, NGO and petrochemical companies however rated the
issues as important. These respondents align more closely with the literature which suggests the EU ETS could act as a significant driver. It appears that the non-aviation respondents are much less informed about the specific policy issues associated with aviation industry and biofuels.

Economic development benefits attributed to aviation biofuels is a key driver in the literature, though it did not feature significantly in the scoping study. The survey results appear to align with the literature however; one respondent did rate the issue as being unimportant. Rural economic development achieved a mode of neither unimportant nor important but a median of important. The results were slightly skewed towards the important side of the scale. 9 respondents rated the issues as very important, 15 respondents rated it important while 18 respondents rated the issues as being neither unimportant nor important. Predictably, the biofuel companies all rated the issue to be very important, while the aviation respondents, NGO and academics rated the issue as being neither unimportant nor important. This may indicate that the non-biofuel sector respondents are less perceptive to the importance of economic development for emergence, development and uptake. The next issue is commercial opportunities for oil companies.

Commercial opportunities for oil companies did not feature heavily in the scoping study or the literature. In the survey, the issues obtained a modal rating of neither unimportant nor important but a median equidistant between ‘important’ and ‘neither important nor unimportant’. The lower median value is due to the fact that the responses were skewed towards the very important side of the scale. In total, 8 respondents rated the issue as very important, 14 as important, two as unimportant and three as very unimportant. The final two issues are low labour costs and low land costs. These two issues shared almost identical responses from the survey.

These issues obtained modal and median scores of neither unimportant nor important. Almost all of the respondents rated these issues as being neither unimportant nor important. Indeed, it appeared that most respondents were generally unclear about these issues. The scoping study did not feature low labour costs and low land prices as being an important issue. The next section will review the technological drivers.

6.4.3. Technological drivers

The most important technological driver was the attributed to the compatibility of aviation biofuels with existing engines and airframes. It achieved a modal and median score of very important though the driver had the large range due to a single respondent stating that compatibility was very unimportant. However, the overwhelming majority rated the issue as either very important or important. 25 respondents rated the driver as very important, while 17 rated it important. The single
very unimportant rating was actually given by an airline respondent who later commented that his response was to indicate that the issues of compatibility had been completely resolved. This aligns closely with the literature findings and the scoping study. It appears that compatibility issues have more or less been resolved. The next issue concerned knowledge transfers and their influence as a driver.

This issue was used to establish whether there was any important knowledge transfer that could be utilised from countries or businesses that have prior experience with existing biofuels. According to the survey response, having experience with exiting biofuels was important for the development of newer aviation biofuel technologies. The issue had a modal and median score of important and the main responses were skewed towards the important and very important scales. However, there was a large range in the data. 14 respondents rated the issues very important, 19 respondents stated that the issue was important while six respondents rated it neither unimportant nor important and three respondents rated it very unimportant. There were also differences between sectors. The biofuel companies all rated this issue to be very important; indicating that experience with existing supply chains associated with conventional biofuels is perhaps convertible to aviation biofuels. However, the aviation respondents, NGO and academics appeared to have different views because their responses all resided in neither important nor unimportant. This may reveal that the non-biofuel companies are not astute to the specific issues associated with emergence, development and uptake. The next section will discuss the social drivers.

6.4.4. Social drivers

Corporate social responsibility achieved a mode and median of important. 19 respondents rated the issue as important, 11 rated the issues as very important, four as neither unimportant nor important and three as very unimportant. Although the overall ranking of this issue was lower, certain responses in the survey did match those of the scoping study findings. Firstly, the scoping study indicated that green PR and corporate social responsibility would be an important driver for airlines to adopt aviation biofuels (Section 3.3.6). In the survey, this concurred with the responses from the airlines, airports and academics. Secondly, in the scoping study the NGO respondents believed that green PR and corporate social responsibility would not be a significant driver for aviation biofuels due to the fact that the potential issues associated with food prices and sustainability. This aligns precisely with the response from the NGO who rated the issue as being very unimportant in the survey.
6.4.5. **Environmental drivers**

According to the responses, an appropriate climate for growing feedstocks is an important factor driving aviation biofuels. The issue obtained a modal and median score of important from the survey data and a range of responses between three Likert scales. In fact, 27 respondents rated the issue as important and three as very important. The remaining 14 respondents however rated the issues as neither unimportant nor important. It should be noted that this driver is dependent on the feedstock being grown. For instance, the climatic conditions required to grow sugar cane will be vastly different from those to produce camellia. Indeed, the biofuel companies in this study recognised this and ranked the climate factor as neither unimportant nor important. However, notwithstanding the biofuel company responses, ‘climate’ is a vitally important factor to consider for most crop based biofuels and therefore an important driver for the fuels development in certain regions. This issue was not captured at all in the scoping study, though certain papers evaluate the effect of climate on aviation biofuel potential (Daggett et al., 2006).

Land availability for feedstocks had a higher range of responses than the previous drivers discussed, though the modal and median scores were still rated as very important. 24 respondents rated it as very important, 16 important, three neither important nor unimportant and one unimportant. This driver is however dependent on certain technologies i.e. those that require land to crow crops. This must be taken into account when comparing this issue with the other driving issues. Interestingly, there was a clear difference between industry sectors. The biofuel companies generally stated that land availability for feedstocks was much less important than the other stakeholders. The aviation, petrochemical, NGO and academics respondents however all ranked the issue as a very important driver. It appears that the non-biofuel respondents are less aware of the advanced aviation biofuel technologies such as algae which do require significant land resources.

The issue of feedstocks availability obtained a median of important but a modal score of neither unimportant nor important. 18 respondents rated the issue as neither unimportant nor important; though 16 rated it as being important, seven respondents rated it as a very important driver and two respondents rated it as unimportant. The range of answers may be explained by the fact that productive soils will vary between regions and thus respondents from different regions will perceive the issue as a more or less important. Unfortunately, the respondents did not choose to indicate their location in their survey results. This issue is also, like availability of fertilises, technology dependent i.e. the issue is only relevant for land based biofuel crops. Indeed, the biofuel companies and the academics all rated this issue as being neither unimportant nor important while one biofuel company rated the issue as unimportant. Again, this suggests that biofuel companies may be
focusing on non-land based feedstocks for the future aviation biofuel production. The issues of ‘traditional’ nitrogen fertilisers, productive soils and land are also less relevant for feedstocks such as algae and municipal waste.

6.4.6. **Additional drivers**

In total, only four respondents acknowledged additional driving factors in the survey. Information gathering and dissemination of aviation biofuel testing was mentioned by one airline respondent. The respondent stated that stakeholders should share more information with one another to encourage emergence, development and uptake of aviation biofuel. Two other respondents, one airline and one biofuel producer, suggested that peak oil is a significant driver for aviation biofuels. Although this issue is closely linked to fuel security, peak oil is a particularly severe scenario in which oil demand outstrips oil supply leading to rapidly increasing prices of oil (see section 2.6.1). Finally, an airframe manufacture stated that the military involvement in aviation biofuels had a major driving affect for aviation biofuels. Although this was also revealed in the literature review, it did not feature in the scoping study.

6.4.7. **Summary of drivers**

The drivers section (6.4) revealed that 23 of the 26 driving factors were either very important or important drivers for the emergence, development and uptake of aviation biofuels. There appears to be a group of six driving factors that are perceived to be the most significant factors. These factors are: access to public funding, the use of incentive schemes, rising jet fuel prices, commercial opportunities for biofuel companies, land availability for feedstocks and compatibility with existing engines. These driving factors obtained the highest modal and median ratings and the lowest ranges. Although there were subtle differences between sectors, the respondents generally concurred with another on these issues. These findings align with the scoping study findings; which valued the needs to reduce emissions, oil price, fuel security and carbon price as the most significant driving factors for emergence, development and uptake (section 3.3). The survey data did however obtain evidence that the military adoption of the aviation biofuels is a very important and perhaps overlooked driver for emergence, development and uptake. It was not mentioned significantly in the scoping study. The driving factors appear to be mainly political and economic factors, with environmental issues acting comparatively less in comparison with the EU scoping study. However, this does align better with the literature which indicates that the EU region is facing very different issues compared with than the rest of the world. This is because the survey incorporated stakeholders from the EU, North
and South America, Asia and Australasia. This finding will be discussed further in chapter 7 which draws upon a larger number of in-depth interviews.

Thus far this chapter has reviewed the contemporary issues facing aviation, evaluated the relevant technologies which are being used to address these issues and explored the drivers of aviation biofuel. The next section of this chapter will review the seriousness of issues that are constraining or challenging the emergence, development and uptake of aviation biofuels. The issues will be reviewed in the same format as previous sections i.e. starting with the most serious issues and ending with the least serious.
6.5. Constraints

The survey looked at 22 of the most frequently asserted constraints based upon the literature and scoping study findings. Although the seriousness scores ranged from very serious to not very serious, over half of the constraints were rated as either very serious or serious (Figure 6.4). The range of responses associated with constraints was generally higher than in the driver section, indicating a greater level of uncertainty and/or lack of consensus among the stakeholders. The following sections will review constraints thematically following PESTLE (Table 6.2), starting with the most serious according to the respondents – a lack of policy.

Figure 6.4 Aviation biofuel constraints

Diagram shows aviation biofuel constraints. Ranked in order of importance in clockwise fashion. 1 = Not at all serious, 2 = Not very serious, 3 = Fairly serious, 4 = Serious, 5 = Very serious.
Table 6.2. Thematic representation of constraints

<table>
<thead>
<tr>
<th>Theme</th>
<th>Constraint</th>
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<tr>
<td>Political and legislative</td>
<td>• Lack of policy incentives for aviation biofuel</td>
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<td></td>
<td>• Lack of financial support from governments</td>
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<tr>
<td></td>
<td>• Uncertainty of the duration of government policy support</td>
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<tr>
<td></td>
<td>• Uncertainty surrounding the EU ETS</td>
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<td></td>
<td>• Lack of aviation fuel tax</td>
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<tr>
<td>Economic</td>
<td>• Relatively high feedstock prices</td>
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<td></td>
<td>• Relatively high production costs</td>
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<td></td>
<td>• Lack of investors support</td>
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<td></td>
<td>• Relatively low jet fuel prices</td>
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<td></td>
<td>• Uncertain production costs</td>
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<td></td>
<td>• Uncertainty of oil prices</td>
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<td></td>
<td>• Uncertain carbon price</td>
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<tr>
<td></td>
<td>• Protection of market by oil majors</td>
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<tr>
<td>Social</td>
<td>• Potential negative environmental image</td>
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<tr>
<td>Technological</td>
<td>• Potential modification of infrastructure</td>
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<td></td>
<td>• Freezing point of aviation biofuel</td>
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<td></td>
<td>• Molecular consistency of different biofuels</td>
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<td></td>
<td>• Contamination concern</td>
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<td></td>
<td>• Lack of 100% blend certification</td>
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<tr>
<td>Environmental</td>
<td>• Lack of feedstock supply</td>
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<td></td>
<td>• Stability of feedstock supply</td>
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<td></td>
<td>• Competition with food production</td>
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6.5.1. *Political and legislative constraints*

Lack of policy incentives obtained median and modal scores of very serious. Of all the constraining issues, it obtained the highest number of very serious ratings - 24. The issue also obtained 10 serious ratings and seven fairly serious ratings. In terms of sector, the biofuel, aviation and NGO respondents all rated the issue as being very serious while the academics rated it as important. The general consensus across all sectors indicates that a lack of policy incentives is a significantly serious issue for the emergence, development and uptake of aviation biofuels. In comparison to the scoping study, the survey results indicated that the lack of policy incentives is perhaps more serious than first thought. For instance, in the scoping study, feedstock supply, and high costs of funding and environmental sustainability were all perceived to be more serious than a lack of policy incentives (See section 3.3). The difference may be a reflection of the fact that the survey captured stakeholders from a larger geographical area in comparison to the scoping study which, in contrast, had a European focus. This may suggest therefore that the policy environment within Europe is perceived to be better than other areas of the world. Unfortunately, no geographic analysis could be
made with the survey data due to the fact that a majority of stakeholders chose not to acknowledge their locations.

Lack of financial support from governments was an issue which obtained a modal score of very serious and a median score of serious, though the responses were more widely spread than the other constraints. 18 respondents rated the issues as very serious, 13 as serious, 7 as fairly serious and 6 as not very serious. The biofuel and aviation industry respondents appeared to give more severity to the issue compared to the airlines, NGO and academics. However, the difference was not significant. The range in the scores may instead be an indication of uncertainty surrounding this issue or a misunderstanding of the question. This survey also showed that while financial support from governments is lacking, the duration of any government support is also not well understood. 18 respondents stated that uncertainty surrounding the duration of future government support was a very serious issue. 10 rated it as a serious issue, 14 rated it as fairly serious and one as not very serious. The duration of government support was mentioned in the scoping study but not elaborated on. These survey results strengthen the scoping study findings nonetheless. This issue obtained a modal and median rating of serious, though 12 respondents still rated the issue as very serious. In total, 12 respondents regarded it as very serious, 17 as serious, 7 as fairly serious and 6 as not very serious. Despite the large range, the issue is serious and it corresponds with the previous findings from the scoping study. The scoping study revealed that the policy is likely to be much less effective than the literature suggests (section 3.4.4).

Other policy constraints included the inability to impose a fuel tax on aviation. Although this issue did not feature heavily in the literature review, it was mentioned briefly by a stakeholder in the scoping study. It was therefore tested in this survey. The fact that the aviation industry cannot place a direct tax on aviation fuel and therefore not offer a tax rebate for aviation biofuel was not a particularly significant constraint according to the survey. This issue obtained a modal and median score of fairly serious though the range of the responses was high. In total, five respondents rated the issue as very serious, 8 serious, 14 fairly serious, 12 not very serious and 5 not serious at all. The significant spread of answers may be a result of the international nature of the survey or a lack of understanding with regards to aviation fuel regulation. Nonetheless, one airline respondent added further comments to this question; stating that there is already a tax on aviation fuel in some respects when air passenger duty (APD) is considered. The respondent suggested that APD could be manipulated to create an incentive for aviation biofuels. The respondent did not elaborate further on his comment. The next group of constraints are economic issues.
6.5.2. Economic constraints

There were a series of economic constraints associated with aviation biofuel. Relatively high production costs were however the most serious according to the survey. This issue obtained a mode and median of very serious. In total, 23 respondents rated the issue as very serious. However, a larger proportion of respondents rated the issues as fairly serious and not very serious. 14 respondents rated the issue as fairly serious and 2 respondents rated the issue as not very serious. The high range may have been due to the fact that certain respondents had greater knowledge of the costs associated with aviation biofuels i.e. biofuel, airframe and engine manufactures. Indeed, these respondents all rated the issues as very serious, whereas the academics and NGO; which perhaps have less knowledge of the financial issues, rated the issue as only fairly serious. This may indicate that while most aviation biofuel stakeholders are well informed, not all stakeholders are aware of the severity of certain constraining factors. The next issue is lack of investor support.

Lack of investor support obtained a modal score of very serious and a median of serious. The lower median value was caused by a larger range of responses for this issue. The issue obtained 19 very serious responses, 14 serious responses and 11 fairly serious responses. In the literature, lack of investor support is not significantly investigated however the scoping study revealed that lack of private investment is a serious issue. The scoping study also revealed that government funding is perhaps a more serious issue because this is exacerbating the private investment shortfall. The survey results also revealed that lack of financial support from governments is a serious issue.

In the scoping study, the issue of low jet fuel prices was described as a constraint by all of the respondents. The price differential between the costs of biofuel and the price of jet fuel is currently too large to allow aviation biofuel to be viable (CCC, 2009). In terms of the severity of the issue, the survey obtained modal and median ratings of serious. The ratings ranged from very serious to not very serious. 6 respondents rated the issues as very serious, 17 as serious, 15 as fairly serious and 5 rated the issue as not very serious. The range of responses indicates a degree of uncertainty surrounding this issue however the survey also showed that respondents suggested that a significant increase in the price of jet fuel is expected in the next 5-10 years. This will reduce the severity of the jet fuel price issue over time. Indeed, this concurs with the literature findings and the scoping study. Although the price differential today is not competitive, the price of jet fuel is expected to continue to increase as the price of aviation biofuels declines. Uncertain production costs were the ninth most serious issue affecting the emergence, development and uptake of aviation biofuels.
Uncertainty surrounding production costs was perceived to be a serious constraining issue for the emergence, development and uptake of aviation biofuel. Uncertain production costs achieved a modal and median score of serious. In total, nine respondents rated the issue as very serious, 15 as serious, 16 as fairly serious and two as not very serious. In terms of sector, uncertainty surrounding costs was perceived to be more constraining by the airlines and NGO's compared to the academics and biofuels producers. Two biofuel producers actually chose not to answer this question; this is almost certainly due to the commercial sensitivity of the issue.

Another economics issue was possible protection of the fossil fuel industry by the major oil producers. This issue attained a modal score of serious and a median between fairly serious and serious. In total, four respondents rated the issue as very serious, 17 rated it as serious, 11 as fairly serious, six as not very serious and five as not serious at all. Although the issue had a large range of responses, half of the respondents that rated the issue as ‘not at all serious’ were from the biofuel industry and the respondents that rated the issues as ‘very serious’ were all either airlines or airframe and engine manufactures. Interestingly, the petrochemical companies rated the issues as fairly serious. This may suggest that some petrochemical majors are sceptical of entering into the aviation biofuel market. The next two issues relate to carbon pricing. As mentioned in the scoping study, carbon pricing should be acting as a driver for the fuels, however, it may also act to constrain aspects of the emergence, development and uptake of aviation biofuels.

An uncertain carbon price is a serious constraining issue for aviation biofuels. It may create greater uncertainty about the viability of the fuel and therefore prevent investment. This issue attained a modal score of serious and a median score of between serious and fairly serious. In total, 5 respondents rated it as very serious, 17 as serious, 13 as fairly serious and 8 as not very serious. Although there was a relatively high range of responses to these questions; the aviation, biofuels and NGO all stated that the issue was serious. As well as uncertain carbon pricing, respondents also indicated that low carbon prices are a serious issue for emergence, development and uptake. This issue was first revealed in the scoping study in section 5.3.2. In the survey, low carbon prices attained a modal and median score of serious. Seven respondents rated it as very serious and 10 serious however, 21 respondents rated the issues as fairly serious while the remaining six respondents rated it as not very serious. Low carbon prices were mentioned by almost all of the scoping study respondents. The next group of issues are social constraints.
6.5.3. **Social constraints**

The only social constraints associated with using biofuels were the potential negative environmental effects of using aviation biofuels. However, stakeholders in this study rated these issues as not very serious. This finding is contrary to the scoping study findings. One NGO scoping study respondent spoke at length about the fact airlines needed to be cautious of this issue. The scoping study respondents stated that the airlines were not aware of the true environmental impact of aviation biofuels and for this reason should not pursue aviation biofuels. Furthermore, there is a wealth of literature which questions the sustainability of biofuels for road transport biofuels, particularly first generation biofuels. This issue is also underdeveloped in the aviation biofuel literature. For example, there are no existing studies which have attempted to capture either the aviation industry’s perceptions about sustainability or the general public’s perception regarding the aviation industries uptake of aviation biofuels. It can be speculated that the aviation industry is not concerned with the sustainability of the aviation biofuels due to the fact that the industry actively expresses their intentions to pursue second and third generation feedstocks and production technologies for aviation biofuels. Thus far, political, economic and social issues have been discussed. The following section will now discuss technological constraints.

6.5.4. **Technological constraints**

Although early aviation biofuels studies indicated that the infrastructural issues would be significant, since ASTM certification the infrastructural constraints have not been perceived to be significant in the literature (CCC 2009; Dray et al. 2009). However, one scoping study respondent indicated that fuel consistency and compatibility with existing infrastructure would be an issue (section 3.4.5). In the survey, potential modification of infrastructure was rated relatively highly as an issue constraining the emergence, development and uptake of the fuels. It achieved a modal rating of very serious and a median score of serious. The range of responses for this question was particularly high; answers ranged from very serious to not serious at all. However, additional data from the survey indicated that respondents may have misunderstood the question. One respondent added extra comments stating: “I have rated this issue as not at all serious because we are only looking at drop-in fuels”. The freezing point of aviation biofuels was an issue which received a mixed response from the stakeholders. The issue obtained a modal score of very serious however, due to the mixed responses; the median score was calculated as falling equidistant between serious and fairly serious. 17 respondents indicated it was a very important issue while 10 respondents rated it as not at all serious. It appears that the answers were widely spread due to confusion about the question. It is likely that stakeholders interpreted the question as relating to conventional biofuels (which do have
a serious freezing issue) or ASTM certified biofuels such as HEFA or F-T fuels (which do not have an issues with freezing). Indeed, two respondents from the airframe manufacturing industry added comments stating that the reason they rated this question as ‘not at all serious’ was due to the fact that HEFA and F-T are not affected by a constraint of freezing. Other issues which obtained large ranges included the protection of oil markets by major oil companies.

FAME contamination was perceived as being fairly serious. The issue attained a modal score of serious though a median score of fairly serious. Although nine respondents rated the issue as very serious and 12 rated it as serious, six rated it as fairly serious, 9 as not very serious and 8 as not at all serious. The significantly high range clearly indicates uncertainty among the stakeholders and/or a misunderstanding about the question. However, the aviation, biofuel and NGO respondents appeared to understand the issue by rating it as very serious.

The issue of fuel consistency was mentioned by a single biofuel producer in the scoping study. However, all the biofuel companies in the survey rated this issue as not at all serious while the remaining respondents rated it as fairly serious. Although this survey cannot be conclusive, this may indicate that the issue is perhaps not significant.

A lack of 100% blend certification was the only issue in the constraints section to obtain a modal and median score of not serious or fairly serious. The issue obtained nine serious ratings, 10 fairly serious ratings and 20 not very serious ratings. This result appears to show that the existing 50% blend limit for HEFA and F-T fuels will not affect the emergence, development and uptake of aviation biofuels. Additional constraining factors were identified by six stakeholders.

6.5.5. Environmental constraints

Competition with food production is a prominent issue in the literature. It is an issue which is also a prominent part of the conventional biofuel debate. This issue was also acknowledged in the scoping study. The issue obtained a modal rating of very serious and a median of serious though the range of answers was high. Answers ranged from very serious to not serious at all. In total, 13 respondents rated the issue as very serious, 12 as serious, 7 as fairly serious, 11 not very serious and one respondent rated the issue as not serious at all. The airlines, engine manufactures academics and NGO all rated the issue as very serious, while the biofuel companies rated the issue as either serious or fairly serious. Although the majority of the respondents clearly perceive competition with food production as a serious issue, the survey also revealed that the perceived likelihood of aviation biofuels causing food prices increases was inherently uncertain. The majority of respondents rated the scenario of food price increases as neither unlikely nor likely.
The issues of lack of feedstock and the uncertain feedstock supply was considered very serious in the survey. This aligned much more closely with the scoping study and the literature review. The issues are a combination of technological and environmental constraints. Technically, there is still a great deal of work to done to achieve feedstocks which can yield high amount of fuel per unit of land. This is work that is on-going. The issue is also positioned within environmental concerns about the effect on the environment, the potential of land and the effect of land use change. This issue is therefore a complex constraint which may require further research. These issues are also described extensively in the scoping study findings (Section 3.4.1.) and the literature (Section 2.18). Both issues obtained 23 very serious ratings, nine serious ratings, 10 fairly serious ratings and 5 not very serious ratings. All of the aviation sector responses rated the issues as very serious while the academics and NGO rated the issues as serious. Interestingly, two biofuel companies rated these issues as not very serious. This may indicate that, while the issue is clearly perceived as serious by the majority of stakeholders, certain biofuel companies (perhaps those which are utilising waste to liquid routes) are not being constrained by this factor. The final section reviews additional constraining factors mentioned by stakeholders.

6.5.6. Additional constraining factors

In total, three additional constraints were revealed. The factors were all rated as being very serious. One biofuel respondent revealed that competition for biofuel from other transportation sectors would be a very serious issue. This corresponds with the view of the petrochemical company from the scoping study. According to the petrochemical company, the road sector will heavily restrict the feedstock supply available for aviation because of the policy incentives to produce road biofuels are so much higher (Section 3.4.4). One respondent decided to reiterate the fact that price was the biggest constraint even though it featured in the main survey as well. The respondent emphasised the issue by writing: “1) Price, 2) Price, 3) Price”. Finally, one NGO respondent indicated that uncertainty surrounding the carbon calculation of aviation biofuels will be a serious constrain for emergence, development and uptake. This is because the airlines and biofuels companies will not be able to globally verify the emissions savings.

6.5.7. Summary of the constraints

The constraints section revealed that, although there are almost 30 constraints in total, the most important constraining issues are: lack of policy incentives, lack of feedstock supply, stability of feedstock supply and high production costs. These constraints can be considered the first order constraints according to this study and may well be the ones which need to be addressed first before the emergence, development and uptake can begin. The issues generally correspond with the
scoping study findings however more concern is placed on feedstock supply in this survey than high costs. The second order constraints are: lack of financial support from governments, lack of private investor support, uncertainty of the duration of government support, competition with food production and potential modification of infrastructure. These issues are also clearly important for emergence, development and uptake however they can be grouped together as achieving modal scores of very serious but medians of serious. There are some interesting nuances in the data, stakeholders rated ‘lack of policy incentives’ as being the most constraining factor however, they rated ‘lack of financial support from governments’ slightly lower. It appears then that direct investment in the form of payments or cash funding is less desirable than incentives for governments, though the exact incentives were not defined in the question. In general, the stakeholders had more varying perceptions about constraining factors compared to the drivers. Indeed, there were larger ranges observed in that section of data. This may be an indication of uncertainty surrounding constraining factors.

Thus far this chapter has reviewed current commercial aviation issues and technologies, aviation biofuel drivers and aviation biofuel constraints. Although limited sector analysis can be made due to a lack of data, the findings have revealed that certain issues are more important or more serious than others based on the modal and median scores. The chapter has yet to discuss any strategies which may be available to support the development of aviation biofuel. The next section will therefore review how important different strategies are for facilitating the future adoption of aviation biofuels.
6.6. Strategies to support aviation biofuel

This section presents the findings associated with strategies that can be used to support the emergence, development and uptake of aviation biofuels. The strategies ranged in importance from very important to neither unimportant nor important (Figure 6.5). The following sections will review strategies in themes following PESTLE. A summary of the issues can be seen in table 6.3.

Figure 6.5 Strategies to support aviation biofuels

Diagram shows aviation biofuel drivers. 1 = Very unimportant, 2 = unimportant, 3 = Neither unimportant nor important, 4 = Important, 5 = Very important.
Table 6.3. Thematic representation of strategies to support aviation biofuels

<table>
<thead>
<tr>
<th>Theme</th>
<th>Constraint</th>
</tr>
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<tbody>
<tr>
<td>Political, legislative and technological</td>
<td>• Foster research into improving the quality and quantity of feedstocks</td>
</tr>
<tr>
<td></td>
<td>• Fostering research into improving the production process</td>
</tr>
<tr>
<td></td>
<td>• Encourage stakeholders to commit to robust international sustainability criteria</td>
</tr>
<tr>
<td></td>
<td>• Enforcing a global carbon pricing policy</td>
</tr>
<tr>
<td>Technological</td>
<td>• Potential modification of infrastructure</td>
</tr>
<tr>
<td></td>
<td>• Freezing point of aviation biofuel</td>
</tr>
<tr>
<td></td>
<td>• Molecular consistency of different biofuels</td>
</tr>
<tr>
<td></td>
<td>• Contamination concern</td>
</tr>
<tr>
<td></td>
<td>• Lack of 100% blend certification</td>
</tr>
<tr>
<td>Economic and Political</td>
<td>• Lowering the risk of public investment</td>
</tr>
<tr>
<td></td>
<td>• Establishing coalitions between supply chain stakeholders</td>
</tr>
<tr>
<td></td>
<td>• Government backed bank loans</td>
</tr>
<tr>
<td></td>
<td>• Increase investor awareness</td>
</tr>
<tr>
<td></td>
<td>• Use government backed bank loans for plant construction</td>
</tr>
<tr>
<td></td>
<td>• Introduce take on aviation fuel</td>
</tr>
<tr>
<td></td>
<td>• Reduce incentives for road transport fuel</td>
</tr>
<tr>
<td>Economic</td>
<td>• Coalitions and partnerships</td>
</tr>
</tbody>
</table>

6.6.1. Political, legislative and technological strategies

Most strategies could be grouped into political, legislative and technological. Fostering research into improving the quality and quantity of feedstocks was rated as the most important form of support for aviation biofuel emergence, development and uptake. It obtained a modal score of very important and a median score equidistant between very important and important. In total, 15 respondents rated the strategy as being very important, 22 rated it as being important and six as neither unimportant nor important. These findings align with the literature and scoping study. The literature review revealed that research is already occurring in the fields of improving quality of aviation biofuels technologies (CCC, 2009; Daggett et al., 2007) and in the scoping study stakeholders suggested that further scientific research is needed to establish new feedstocks and production technologies for aviation biofuels. It is clear that the majority of stakeholders perceive current aviation biofuel technologies as underdeveloped and far from their potential. The next issue is related to fostering research into feedstocks however, it relates to research into the production pathways for aviation biofuels.

Fostering research into production pathways was rated as an important strategy for the emergence, development and uptake of aviation biofuels. It obtained modal and median ratings of important in
the survey and a low range of responses. In total, 14 respondents rated the strategy as very important, 18 as important and four as neither unimportant nor important. The biofuel and academic respondents rated the issue are very important while the aviation and NGO respondents rated the issue as important. Again, like the previous issue, this aligns with the literature and scoping study, indicating that continued research is clearly still needed. The next strategies are economic issues, or have a strong economic focus.

6.6.2. Economic and Political

The most important economic strategy rated by the stakeholders was to lower the financial risk of investment in aviation biofuels. This can be achieved in several ways including produced government backed loans, low interest loans. Although this strategy obtained a modal score of very important and a median score of important, this issue was ranked lower than fostering research because it had a larger range of responses. Two anonymous respondents rated the strategy as being unimportant and six rated it as neither unimportant nor important. Conversely, 16 respondents rated the strategy as very important and 12 rated it as important. Interestingly, the aviation, biofuel and NGO respondents all rated the issue as being very important while the petrochemical academics rated the issue as important. The fourth most important strategy to support emergence, development and uptake is an issue which was frequently asserted in the scoping study though it obtained mixed responses from the survey respondents.

Using subsidies to lower the price of aviation biofuel had a mixed response in the survey. Although it achieved a median rating of important, the modal rating was calculated as neither unimportant nor important. Seven respondents rated the strategy as very important and 15 as important however, eighteen respondents rated the issues as neither unimportant nor important and three as unimportant. Although the range is high, the data suggests that the issue is important. This corresponds with some of the evidence from the scoping study. Scoping study respondents acknowledged that policies are required to address the higher price of aviation biofuels compared to jet fuel as well as to address the balance between road biofuel policy and aviation biofuel policy. The next policy is to provide government backed bank loans.

A government backed loan is essentially low risk credit that is more easily attainable for start-up biofuel companies to help them build a biofuel plant or fund the supply chain development. This strategy obtained a median rating of important however a modal score of neither unimportant nor important. In total, 12 respondents rated the strategy as being very important, ten as important and the remaining 13 as neither unimportant nor important. Although this issue was mentioned in the
scoping study as a potential strategy to help emergence, development and uptake, it does not appear to be a significant strategy according to these survey results. The range of the results is however quite large so this may indicate that stakeholders were unsure about the benefits of the strategy. The next group of strategies can be described as being explicitly political and legislative.

6.6.3. Political and legislative

Respondents were asked to rate how important it would be to encourage the development of robust international sustainability criteria. It appears that the strategy is indeed important for emergence, development and uptake. The strategy attained a modal and median score of important from the survey. 13 respondents rated the strategy as very important, 14 as important and the remaining 10 rated the strategy as neither unimportant nor important. This issue was something which has major importance for the conventional biofuel sector as well. The need to obtain internationally transferrable accounting procedures is a key factor in the literature (see Dermibas, 2008). The issue was also described by respondents in the scoping study as being essential for aviation biofuels due to the international nature of the industry. A global carbon pricing policy was the sixth most important strategy according to the survey results.

Using a global carbon pricing policy to support the development of aviation biofuel was rated as being an important strategy for supporting aviation biofuels. The strategy achieved a modal and median score of important. Despite getting two unimportant ratings, the majority of responses were in the important and very important range. In total, seven rated the strategy as very important, 16 rated it as important and 11 rated it as neither unimportant nor important. Interestingly, the seven airline respondents all rated this strategy as being very important whereas the other sectors rated the strategy as being either important or neither unimportant nor important. Although generalisations are hard to make with a sample size this small, it does appear that that carbon pricing policies are favoured by the airline sector as a means to encourage emergence, development and uptake. The next strategy focuses reducing incentives for road transport biofuels.

Reducing incentives for road transport biofuels achieved modal and median scores of neither unimportant nor important. In total, two respondents rated it as being very important and 11 as important however, 22 respondents rated the strategy as neither unimportant nor important, two as unimportant and 1 as very unimportant. The results indicate that, although it would be logical to reduce incentives for road biofuels in order to address the balance between the policy incentives, the stakeholders are pessimistic of the implementation of this strategy. Predictably, the biofuel companies all rated this strategy as unimportant or very unimportant. It is understandable that the
biofuel companies do not want to reduce their overall market for biofuels by reducing incentives for their products. The final strategy is to introduce a tax on aviation fuel.

This strategy achieved a modal and median score of neither important nor unimportant. However, more respondents rated the strategy as important and very important compared to reducing incentives for road based biofuels. In total, three respondents rated the strategy as very important, nine as important, 15 as neither unimportant nor important, seven as unimportant and four as very unimportant. Predictably, all of the airlines in the survey rated the issue as unimportant while the biofuel companies rated it as important. The academics, NGO’s and petrochemical companies however rated the issue as neither important nor unimportant. These results suggest that a tax strategy will not be beneficial for the airline industry, whereas the biofuel companies appear to see the benefits of introducing a tax rebate system. Thus far the strategies have focused on political or legislative themes, or a combination of political and economic themes. The next strategies can be considered explicitly economic because they relate to privately run coalitions to streamline aviation biofuel developments.

6.6.4.    Economic

Coalitions and partnerships were regarded as being very important for the development of aviation biofuels. Although ten respondents rated this strategy as being very important, the modal and median scores were both calculated as being important. In total, ten aviation stakeholders rated it as very important while 15 respondents, which included 5 biofuels companies and an NGO, rated it as important. 13 respondents, including 3 petrochemical companies and 2 academics, rated it as fairly important. One anonymous respondent rated this issue as unimportant. Although there is a high range of responses, the results indicate that establishing coalitions is perceived to be important for the emergence, development and uptake of aviation biofuels. However, given the evidence that coalitions and partnerships between the aviation sector and biofuels sector are already happening, it is surprising that the issue did not reach a higher position in terms of importance. The literature review showed that within the UK, BA and Solena have formed a partnership to build the first UK aviation biofuels plant. In Australia, Virgin Atlantic has formed a partnership with Lanza tech to establish a biofuel plant. Furthermore, biofuels supply chains in the U.S, Brazil and Asia have been set up in an attempt to streamline the emergence, development and uptake of aviation biofuels.

Increasing investor awareness of aviation biofuel is the next most important strategy in the survey. Increasing investor awareness was very important according to the respondents. This strategy achieved a mode and median of important however; an equal number of respondents rated the strategy as being very important and important. The mode and median scores will have been
affected by the fact that not all the respondents answered this question. In total, this question had 37 responses out of 44. There is no clear indication as to why some respondents did not rate this question. Nonetheless, the strategy obtained 14 very important ratings, 14 important ratings, eight neither unimportant nor important ratings and one unimportant rating. None of the respondents chose to add extra details with regard how best to increase investor awareness. As well as increasing investor awareness, extra funding is required from governments.

6.6.5. Additional strategies

There was one additional strategy acknowledged in the survey. An airframe manufacturer representative stated a key supporting strategy would be to determine where the emissions reductions from biofuels are most affectively served. The respondent stated:

“It needs to be proven that the use of biofuel in aviation is more valuable than for ground transport. It makes no difference if CO2 is saved on the ground by automobiles or in the air by airplanes. However, emissions (e.g. PM, HC) reduction in cars on the ground is better for human health than for airplanes at cruise”

6.6.6. Summary of support strategies

The most important support strategies for aviation biofuels appear to be: fostering research into improving quality and quantity of feedstocks, fostering research in product and process, lowering the risk of public investment and committing to robust international sustainability criteria. These four strategies correspond with the findings from the SWAFEA study (2011); the NASA research and the UK’s CCC report which recommend more research into feedstocks and biofuel technology, as well as better accounting procedures for biofuels. The fifth most important strategy, enforcing a global carbon pricing policy, appears to be more important than the literature assumes. The idea of enforcing a global carbon policy is however briefly mentioned in the aviation biofuel literature in the CCC (2009) report and the SWAFEA (2011) report. Establishing coalitions that encompass all aspects of the supply chain is a strategy which is actually taking place. Indeed, the CAAFI and SAFUG coalitions are examples of this type of strategy. It is interesting then that this strategy was not ranked higher by the majority of stakeholders. Issues which were not expressed in the literature include lowering the risk of public investment and assessing whether aviation emissions are more harmful than road transport.
Thus far this chapter has reviewed the findings for contemporary aviation issues and technologies, aviation biofuel drivers, aviation biofuel constraints and strategies’ to support aviation biofuels. The final section of this chapter will review some predictions about the uptake potential of the fuel.

6.7. Predictions for future development and uptake

In the final sections of the aviation biofuel survey, respondents were asked to indicate the likelihood of certain scenarios occurring. Some of these have already been discussed as additional data related to either drivers or constraints. However, respondents were also asked about the likelihood of certain aviation biofuel production volumes. Respondents were asked to indicate how likely it would be to achieve aviation production volumes of 1%, 5% and 10% of global jet fuel demand within the next 10 years. The results are summarised in figure 6.6. The figure shows that the most likely production volume will be a 1% replacement of global jet fuel demand. In total, 13 (29%) of respondents indicated that 1% of global jet fuel would be very likely, 15 (34%) assumed it would be likely and 14 stated it would be neither likely nor unlikely. A 5% replacement had a much large spread of answers but mainly neither likely nor unlikely. Finally, a replacement of 10% of aviation fuel demand was predicted to be unlikely according to the survey results. The majority of respondents rated the scenario as unlikely or very unlikely (Figure 6.6).
The other prediction tested was a time frame for commercial uptake (Figure 6.7). Given that most respondents had already predicted a 1% replacement of jet fuel demand within 10 years, one would assume the majority of respondents would make a prediction for commercial uptake to happen before this period. As expected the modal and median scores were 5-10 years. 20 respondents predicated that aviation biofuels will be commercial adopted in 5-10 years, eight in less than a year, five in 2 -5 years and 4 indicated that it will be adopted in either over ten years of 1- 2 years. The results also therefore indicate that production will increase rapidly from years 5- 10 given that most respondents predicted a 1% replacement of biofuels within 10 years.
6.8. Survey summary

This chapter has shown that by using Likert scale survey questions it is possible to rank aviation biofuel issues in terms of importance, seriousness and significance. It is also possible to categorise the main issues using the PESTLE framework. The survey revealed that by far the most significant issues are economic and political issues. Over 60% of the most important issues facing aviation biofuels are either political and legislative, or purely economic. The third most important theme emerged as being environmental. These findings reflect the main messages from the aviation biofuel literature which suggests that the price of aviation biofuels is indeed the most significant constraint. The survey findings do however appear to place less significance on the environmental issues, this differs from the scoping study. It may be that the scoping study revealed an essentially Eurocentric view of aviation biofuels, a view where stronger political and industry pressures are driving the development of aviation biofuels.

The survey also revealed a number of new and interesting support strategies which are currently being used or are planned to be used. These include the need to lower risk on public investments,
the need to establish collations between supply chain stakeholders and the need for an international sustainability criteria. These are issues are very briefly mentioned in studies such as SWAFEA (2011) and the CCC report (2009). This survey has revealed that industry leaders are seriously considering supporting each other in partnerships and coalitions. This is also reflected in industry actions documented by industry journals. Test flights involving collaborative efforts with a number of supply chain stakeholders are already occurring. High profile examples include the Lufthansa aviation biofuel trial (Lufthansa, 2012), the British Airways and Solena partnership (BA, 2011) and the UK flight trial involving collaboration between airline, biofuel producer, airport and engine manufacturer. These flights trials are examples of stakeholder collaboration in pursuit of more rapid development of the technology. The effectiveness of the collaborative efforts is not yet known but this will be discussed in greater detail in the next chapter where a case study of the UK’s first commercial aviation biofuel flight trial is analysed.

Finally, the survey has offered stakeholder predictions regarding the likely production volumes of aviation biofuel, as well as the likely time frame of commercial viability and uptake. This is something which is altogether missing from existing studies. There is no known stakeholder analysis of uptake predictions for aviation biofuels. The survey revealed that there is a great deal of uncertainty surrounding the uptake of aviation biofuels, but the main consensus is around 5-10 years. This supports the findings from Dagget et al., (2008) and the SWAFEA report (2011). The data can still be used to inform discussion surrounding supportive strategies such as incentive policies and funding for the technology, particularly for prioritising support towards addressing certain serious constraints.

The next stage of research builds upon this data by investigating further the support measures available for the development and uptake of aviation biofuel (Objective 4). Although chapter 6 touched upon some of the supporting measures for aviation biofuel, it did not seek to provide a detailed evaluation of the issues associated with implementing and managing such measures. This information will be essential to develop strategies and recommendations for the continued emergence, development and uptake of aviation biofuels (Objective 5).
Chapter 7

Strategies to support the development and uptake of aviation biofuels

7.1. Introduction

This chapter builds upon the drivers and constraints data from the previous pieces of research to investigate the support measures available for the development and uptake of aviation biofuel (Objective 4). Although support measures have been briefly discussed in the literature review and survey chapters, the subject requires expansion using in-depth semi-structured interviews. Furthermore, this chapter provides analysis of stakeholder recommendations for future support measures for aviation biofuel.

The chapter is separated into two main sections. The first section presents the findings of 25 semi-structured interviews with key stakeholders in the aviation biofuel field (Table 4.4). The findings are organised into four core themes: drivers, constraints, existing support strategies and recommendations (See Table 7.1). Within those four themes, the various issues will be categorised and analysed based on the PESTLE framework. The chapter begins by highlighting the complexity and interdependency of key factors that are driving the development of aviation biofuels. This is followed by a discussion of the issues which are constraining the wide-spread commercial uptake and continued development of aviation biofuels. The third theme will explore the strategies that address these issues. The chapter concludes by making recommendations that would support the continued emergence, development and uptake of aviation biofuels. Existing strategies are discussed in this chapter as well as proposals for entirely new strategies.
Table 7.1 Main issues from interviews

<table>
<thead>
<tr>
<th>Theme</th>
<th>Driver</th>
<th>Constraint</th>
<th>Existing support constraint</th>
<th>Recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Political and Legal</td>
<td>- Energy security</td>
<td>- Unfavourable legislation</td>
<td>- ICAO and IATA backing</td>
<td>- Increase government funding</td>
</tr>
<tr>
<td></td>
<td>- Legislation</td>
<td>- Strict environmental hurdles</td>
<td>- Incentives and legislation</td>
<td>- Legislative incentives</td>
</tr>
<tr>
<td></td>
<td>- Need to reduce emissions</td>
<td></td>
<td>- National government initiatives</td>
<td></td>
</tr>
<tr>
<td>Economic</td>
<td>- Energy security</td>
<td>- High costs</td>
<td>- Commercial aviation led strategies</td>
<td>- Increase private investment</td>
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<tr>
<td></td>
<td>- Potential surplus supply of road sector biofuel</td>
<td>- Lack of investment and funding</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>- Industry led initiative</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Social</td>
<td>- Need to reduce emissions</td>
<td></td>
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<tr>
<td>Technological</td>
<td>- Lack of alternative technology</td>
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<tr>
<td></td>
<td>- Sustainable feedstock availability</td>
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<tr>
<td>Environmental</td>
<td>- Need to reduce emissions</td>
<td>- Sustainable feedstock availability</td>
<td>- EU ETS</td>
<td>- Better sustainability criteria</td>
</tr>
</tbody>
</table>

7.2. Drivers

The interviews identified eight key drivers for the development and uptake of aviation biofuels. Several of the drivers crossed over one or more PESTLE themes. For this reason, the issues will be discussed in groups following Table 7.1. The first group of drivers are political and legal drivers.

7.2.1. Political and legal drivers

As mentioned in the previous sections of this thesis, a significant number of respondents mentioned policy and legislation in relation to other drivers such as the need to reduce emissions. Discussing the specific political and legislative drivers is therefore vitally important. The main legislative drivers that were mentioned were the EU ETS, Dutch subsidies and the recent ICAO resolution to encourage nationally orchestrated airline industry emissions reduction strategies. The first driver to be discussed is the EU ETS.
The EU Emissions Trading System (EU ETS) was by far the most deliberated legislative driver. In total, twenty respondents mentioned the EU ETS as an important driver for aviation biofuel, either in combination with other drivers or exclusively. Most respondents stated that the legislation is predominantly a long-term driver because the price of carbon is currently too low. This view is expressed in numerous studies, most notably in the CCC report (2009), Dray et al., (2009) and SWAFEA (2011). The EU ETS was described in two main ways: either as a threat to the profitability of the aviation sector and/or as an opportunity to reduce the aviation industry’s emissions. EU respondents tended to cite the environmental benefits of the EU ETS, whereas U.S respondents tended to cite the financial burden it will impose. All respondents understood that the EU ETS will fundamentally affect the industry. Airport A stated:

“Emissions are going to start costing airlines money because of increased costs of carbon. I know for a fact that some airlines don’t think about the EU ETS as an environmental issue, they think about the extra costs”

In contrast to EU airlines, North American respondents stated that US airlines are not subjected to significant environmental legislation nationally, and the main threat was perceived to be almost exclusively the EU ETS. Non-EU respondents also generally discussed their concerns about the possible introduction of emissions trading systems in other world markets. For example U.S. Engine manufacturer G stated:

“...there is no domestic policy for reducing emissions that is being worked currently...but, the airlines are very worried about a spread of the ETS kinds of system globally that will wind up the price of fuel...”

These findings were not revealed from the scoping study or survey, nor did they feature as any point of discussion in the literature. This may indicate that the current level of research surrounding the drivers of aviation biofuels is somewhat superficial and the issues at the industry level have not been adequately researched.

The second legislative measure that was discussed was a Dutch subsidy for aviation biofuels. Three respondents mentioned that the Dutch government had equalled the road biofuel incentives with those of aviation biofuels. This had created a small amount domestic demand for the fuels in that region. One respondent mentioned that is was an important driver locally for the industry, but not significant on a global scale. Nonetheless, it featured as the first step towards equating the incentives and may act as a signal for other EU regions to equate their domestic policies in the future. The only study to mention the adoption of Dutch aviation biofuels subsidies is SWAFEA
(2011) though no analysis of its affect it made. The lack of literature reporting is undoubtedly a reflection of the infancy of the subsidy. The respondents from this study revealed that the subsidy had been in place for less than a year at the time of data collection.

The third legislative driver which was acknowledged related to ICAO’s recent environmental resolution. One academic stated that ICAO had recently created a resolution that states that every member country must provide an action plan outlining the ways they intend to reduce aviation emissions. The UK academic spoke at length about how this is a positive move towards creating a global policy towards emission reductions. The respondent mentioned that up until now, ICAO’s influence on environmental matters had been lacking and this is a significant indication that ICAO may begin ensuring countries are using appropriate measures to reduce emissions. Academic A stated:

“*This year it was for the ‘first’ time that a resolution on the environment was made – the first time! So now every country must send an action plan for climate reduction to ICAO for them to review. This is a good start*”

Again, this driver is not formally expressed in the literature due to the relative infancy of the action. Many papers mentioned IATA and their pro-active approach towards emission reductions and aviation biofuel, though ICAO appears to be less dominant in terms of its influence on aviation biofuel development. This, as the academic respondents suggested, is likely to change with the introduction of the national action plans that are overseen by ICAO. The next group of drivers are explicitly economic drivers.

7.2.2. Economic drivers

Economic drivers of aviation biofuel included energy (in)security, high oil price and volatility and new market opportunities. Energy (in)security was mentioned by all 25 respondents as a potential driver of aviation biofuels. Energy security is an issue which features heavily in the literature, as well as the scoping study and survey. It was acknowledged as being the most significant by U.S and Brazilian respondents. The U.S respondents spoke at length about the energy security benefits of the fuels and the ability to avoid oil imports using biofuels. Energy security was also acknowledged to act as a major driver within the U.S from a military perspective. Four respondents acknowledged that military demand for aviation biofuels within the U.S. may act as a catalyst for both the development and eventual uptake of the fuels in the commercial sector:
“From the military side, military customers are interested in the commercialisation of biofuels from a supply assurance perceptive, so fuel supply security. They don’t want their fuel supply disturbed in the future.” [Engine manufacturer B]

Outside of the U.S. too, securing energy supplies is very attractive to governments both from an economic and a commercial perspective. Airframe manufacturer B acknowledged that the energy security benefit aviation biofuel could confer represents a significant benefit for national governments and policy makers. Reducing oil imports furthermore benefits national economies by creating additional labour demand for the production domestic biofuel. Despite the advantages, most respondents saw energy security as more of a long-term benefit that would manifest in ten to twenty years’ time. Issues of oil supply and security were reflected in the discussion about oil prices and price volatility which were recognised as constituting another important driver. This finding was not picked up from either the scoping study or survey, nor is it mentioned in much detail in the literature. Most studies either look at specific regions such as the UK (CCC, 2009) or U.S. (Daggett et al., 2007). There are indeed a lack of studies which investigate and compare the individual drivers of nations. This may be affecting policy decisions associated with aviation biofuels and thereby increasing uncertainty surrounding policy.

Oil price rises and oil price volatility were identified as long term drivers by almost all of the respondents. This correlates with the scoping study, survey and much of the literature. Oil price appears to be portrayed as a vitally important driver for the short term and long-term development or the fuels. Some respondents from this stage of data collection mentioned that the initial interest in biofuels followed the 2008 price spike, but this was denied by others. Oil prices were normally mentioned as a long-term driver in connection with carbon price rises. Indeed, the combined effect of oil price rises and carbon legislation was often discussed as creating an important driving force.

It was also suggested that oil price volatility will play a larger role than oil price in the short-term and long-term according to a quarter of the respondents. One possible explanation was expressed by an EU airline respondent. The airline stated that aviation biofuel producers will seek to match the price of jet kerosene, minus whatever carbon price is attached to the fuel in the future. This means that there will be no spot price incentive for using aviation biofuel compared to kerosene. The incentive instead comes from the fact that aviation biofuels may be more stable in price. If this were the case, the aviation biofuel would be favoured for short term flexible purchase agreements. Although this is not definitive from the interviews, it is an interesting finding to discuss with respect to the long-term perspectives for the aviation industry. Oil price volatility was not discussed in the scoping study however studies such as SWEFEA (2012) and Dray et al., (2009) mentioned the issue as being
important for the uptake of aviation biofuels. The survey did however find that oil price volatility was important for the development of aviation biofuel but less important that rising oil prices and legislation. Interestingly, as well as avoiding high and volatile costs, aviation biofuels were discussed in terms of the ability to create new business opportunities for either airlines or biofuel companies.

Five respondents stated that the potential business opportunity that aviation biofuels may create is a clear driver for the fuel. However, the economics of the fuels at present were still undesirable and it will take several years before the fuels become profitable. Nonetheless, the technology was championed by certain individuals. One respondent who offered particularly good insights into this issue was an airline that was working with a biofuels producer. The airline stated that although the costs involved with producing the fuels today are high, in the long-run there is a clear economic case to support biofuels.

“We might lose money in the short term but in the long term the benefits are very large, we believe.” [Airline A]

An academic respondent was also confident that the technology had clear economic advantages in the long-run, referring to their experience in researching the economics of the fuels in Europe. The academic was confident that the fuels are a good economic venture due to the fact there is simply no alternative sources. Other respondents described the need to support the technologies in their early stages in order to scale up production and reap greater benefits of economies of scale from the technology later. For example airline B stated:

“...it takes a long time. But if we start the work now it will pay dividends in the future. First you’ve got to get the process right, and then you’ve got to get the network together for the raw product.”

However, at present the production volumes of the fuel remain small. Indeed, it appears that although the business opportunity that aviation biofuel presents is apparent there is still more effort required to scale up production. The next driver to be discussed is industry led initiatives.

“The aviation industry is driving this more than anything else; more than investors, more than governments; even more than the fuel industry” [Airline T]

Despite there being a number of economic sectors involved in the development of aviation biofuels, around half of respondents agreed that the aviation industry is playing a leading role in developing aviation biofuels. They are doing this in three main ways. The first is through initiatives such as the Sustainable Aviation Fuel Users Group (SAFUG) and the Commercial Aviation Alternative Fuels
Initiative (CAAFI) among others. These are initiatives which seek to encourage dialogue between stakeholders and governments, as well as encourage investment in the technologies. The second way is through airline producer partnerships; where certain airlines are planning to produce their own fuel by forming a co-funding agreement with biofuels producers; such as in the case of British Airways and Solena. The third main way is by forming consortia of airlines, biofuel producers and feedstock growers that can streamline the development stages of new fuels and create sustainable supply chains. The importance of aviation led initiatives has strengthened considerably since the certification of HRJ and F-T biofuels in 2011.

The actions described above support the technology. According to twelve respondents, the development of consortia created high profile interest in the fuels from investors, airlines and producers of the fuels. Although the support is still limited, these initiatives appear to be creating a positive signal about the benefits of the fuels which is driving the fuels development further. Some respondents stated that the predominant work that had been carried out was organised by the aviation industry i.e. airlines, engine manufacturers and airframe manufactures. Indeed, Boeing and Airbus were cited as being particularly supportive of aviation biofuel development.

One of main reasons for this was the perceived lack of involvement of major oil companies.

“We were waiting for the big oil companies to come in and help us. However, I think what emerged was a fairly consistent feeling across the airline industry that we can’t wait for big oil, so there are a number of airlines now that are getting involved in the manufacture of the fuels themselves.” [Airline A]

However, although further evidence suggests that the airlines had a pioneering role to play in driving the initial interest in the fuels, there are in fact several sources of evidence for petrochemical interest in the fuel. Five respondents, all of which offer services to airlines, acknowledged that their initial interest in the fuel only came about after the airline industry approached them regarding advice or services. For example, aviation biofuel producer A stated that their initial venture into aviation fuels only came about after it was made apparent that a niche market existed for the fuels.

“...we already designed the technology so we had the possibility to also provide jet fuel, but we saw the road sector as the main user. The [aviation] market came to us.... they came to us pretty quickly after we announced our production capacity etc.” [Biofuel producer A]

A similar statement was made by another leading petrochemical provider. There initial interest into the market was made after the aviation industry approached them.
“Our customers are demanding this stuff [aviation biofuels] and being the leading supplier of jet fuel in Europe and Africa; our key customers are basically the one that are asking for this. So we ought to have a response.” [Petrochemical A]

In summary, the interviewees identified that industry led initiatives are important drivers for aviation biofuels. Industry led initiatives are effective in three ways: they form industry initiatives such as CAFFI and SAFUG; they form producer and airline partnerships such as the BA and Solena Project and they form supply chain consortiums of producers, airlines and feedstock producers. Although the majority of respondents were positive about the aviation industry’s initiatives and interactions with aviation biofuel related industry, almost all respondents said that the current effort is still insufficient to induce the commercialisation of the fuels. The stakeholder opined that energy (in) security and increased legislative support (in the form of incentives and government funding) would be vital.

Finally, an additional driver was mentioned by one for the petrochemical majors which was anomalous but worthy of discussion here. The petrochemical major referred to the fact that a surplus of road based biofuels may be made available to aviation fuel producers.

One petrochemical major stated that there is a possibility that excess supply of road based biofuels, mainly from the U.S., may create an incentive to shift supply to aviation. The respondent stated:

“Too much biofuel entered into the US road fuels market recently, so there is sign of oversupply being a possibility. There might be room to put some extra supply into aviation in the future. That is not the case for the UK though.” [Petrochemical A]

Although this was acknowledged by only one respondent, it described a situation in which road transport biofuel will be over supplied because of reduced demand, which was alluded to by other respondents in this study. It was thought that over time, the demand for road based biofuels will eventually diminish and supply will shift towards aviation. Although this was not explicitly captured in the interviews, it was alluded to on several occasions.

The next group of drivers are technological drivers. The drivers refer to the fact that the aviation industry has very few technological options to de-carbonise.

7.2.3. Technological drivers

Ten respondents acknowledged that the aviation industry has a lack of alternative technologies to de-carbonise. Respondents stated the aviation industry has a serious long term issue in that it does
not have many replacement technologies that offer the same performance as the jet-airliner. It was stressed very clearly by two engine manufacturers and three airframe manufacturers that the industry needs to either diversify its propulsion technology or use a replacement low carbon fuel; with the latter being the indisputably most viable option. Although efficiency improvements are still the research focus for those companies, the long-term future of the industry is looking at radical technologies such as biofuels which offer step changes in emissions. Other respondents expressed the same opinion by comparing the aviation industry to other transport sectors. It was expressed that other sectors such as road and rail have considerably better options for reducing emissions. Academic M stated:

“...if you look at the car industry they have several sources of emission reductions. Aviation does not. They can’t rely on one type of fuel. For this reason biofuels is a potential solution”

Other respondents re-iterated these statements and added that the only cost effective solution for the next 40 years will be to use aviation biofuels. The other technologies which are being looked at such as hydrogen and electric are too far away from feasibility and cost effectiveness. Aviation biofuels were therefore seen as an ‘essential’ measure to take. These technological issues are well documented in the literature and therefore they are fairly established. The scoping study and the survey findings furthermore confirmed these findings showing that the whole aviation industry is clearly in agreement that there are very few options for the aviation industry to reduce emissions. This is also a reflection of the aviation industry’s technological regime which is discussed in chapter 2. Evidence certainly points towards the fact that the technological regime is resistant to radical step changes in technology.

Thus far the section has reviewed the various drivers which were acknowledged by the key stakeholders. However, as mentioned there are numerous issues that are hindering the uptake and development of aviation biofuels. These issues have been referred to as constraints throughout this thesis. Thus far it has been shown that the main constraints associated with aviation biofuels are the high costs associated with development and production and the lack of legislative support to support such development. This stage of research built upon those findings to dig deeper into the complexities of these issues by asking a further 25 industry experts. This stage of research identified a number for new issues which were previously overlooked both in the literature and in the first two stages of data collection. The final group of drivers are environmental issues. These issues act as some of the most important drivers for the emergence, development and uptake of aviation biofuels.
7.2.4. Environmental drivers

Environmental issues featured heavily in the discussions. All 25 respondents stated that environmental issues are a significant driver of the fuels. This aligns with the findings from the scoping study which revealed the EU was facing significant political and industry pressures to reduce aircraft emissions. Although the survey (chapter 6) rated environmental issues as being less important than oil prices, the issue was still observed to be ‘very important’. The findings from this stage of research also showed that the environmental drivers nearly always stemmed from legislation or policy issues such as the EU ETS or the threat of future environmental controls. In other words, the real reason to reduce emissions comes from high level policy and legislative changes. All of the 25 respondents stated that the aviation industry needed to reduce carbon emissions in light of these pressures. Certain airlines respondents did however discuss an additional reason for emissions reductions. They stated that industry wide targets to reduce environmental footprints were vitally important especially for the development of the fuels and the testing of the product. This finding is mentioned briefly in the literature by EU studies such as SAWFEA (2012) but it is not really touched upon in the remainder of the studies. Indeed, it appears there is a gap in the literature specific to industry drivers of aviation biofuels. The scoping study also revealed evidence that industry level targets to reduce emissions an important driver for aviation biofuels are important but crucially, that study was only looking at the EU region. This stage of research incorporated non-EU stakeholders revealing that there were subtle differences between EU and U.S respondents.

EU based respondents; which represented around two thirds of the interviewees, suggested that reducing emissions was motivated by both of these factors, i.e. environmental legislation and voluntary industry targets. In contrast however, U.S aviation respondents only quoted the external pressures that environmental legislation was threatening in the EU regions. Non-EU respondents acknowledged that environmental legislation such as the EU ETS and the threat of a spread of this type of system were the most significant motivation. National environmental legislation within the U.S. deemed insignificant. U.S. respondents were also much more open to talking about the threat that environmental legislation had for ‘raising costs’ rather than achieving a reduction in emissions. In fact, most non-EU respondents quoted that the extra cost associated with carbon reductions was the primary driver for biofuels, not necessarily the emission reductions themselves. Airline G stated:

“Environmental legislation will increase our costs. This is the bottom line when we think about reducing emissions, and I know a lot of other airlines think exactly the same [way]”
This view was shared by the majority of US respondents. This is not to say that EU respondents were unaware of the cost implications associated with reducing emissions. In fact, EU respondents appeared to be consciously factoring this into their future business strategies. The EU airlines were also very aware of the long term implications of carbon pricing on profitability, but many had recognised there was potential to raise valuable revenue by reducing their emissions and selling superfluous permits. According to Airline B, emissions reductions will play a larger role in the EU airline industry’s business strategy in future years:

“Strategically we knew that emissions are a key issue to get right. We are looking therefore for long term solutions. We are not sure that biofuels will be the sole measure used but they will definitely be part of the mix”

In addition to the ETS, voluntary emission targets provide a strong motivation for EU airlines and engine and aircraft manufacturers (but, crucially, not US ones) to reduce their carbon emissions. As mentioned, the voluntary aspect was not picked up from the U.S. Four EU respondents including three airlines spoke in detail about the aviation industry’s own voluntary targets to reduce carbon emissions. One European airframe manufacturer spoke at length about their own industry targets, asserting they are the most important driver for aviation biofuels:

“Aviation is one of the few industries that have clear targets for reducing CO2. [We want] carbon neutral growth by 2020 and 50% CO2 reduction by 2050. That’s a key target that we have all committed to, along with all the other airlines and manufacturers that have signed that piece of paper saying we will do this. So this is the primary driver - number one.”
[Airframe manufacturer A]

The evidence indicates that respondents from the U.S. were driven primarily by the threat of increased costs from the EU ETS, whereas the EU airlines were driven by the combination of strong industry targets and the EU ETS. Respondents from Brazil and Australia shared a similar view to that of the U.S. airlines.

The view of the U.S. government agency respondent however appeared to contradict the US airlines view:

“We [the agency] are driven by an environmental perspective, and I think the US airlines would say the same thing. I think that the environmental benefits are key, and that’s particularly so given that the aviation industry is a global industry and a lot of the flights are going to Europe and other places”
Finally, one aviation industry expert stated that an additional driver for biofuels comes from proposed introduction of particulate emissions legislation around airports. Although it was only mentioned by a single respondent, it is a fact that one key characteristic of certain types of biofuel is a lower particulate emissions profile. If particulate emissions legislation was to be increased, biofuels would be beneficial.

“As engine soot emissions tends to be lower while using biofuels, airline operators might be given preferential treatment for meeting ground emission requirements and local air quality restrictions using biofuels”

In summary, the aviation biofuel stakeholders universally believed that the need to reduce emission is the principle issue driving the development of the biofuel; however, the perceived strength of this driver varies between the EU, U.S and Brazilian stakeholders. Within the EU, the combined forces of voluntary emissions targets and emissions legislation act as a driver. In the U.S and Brazil however, interest is primarily driven by the threat of increased costs from the EU ETS. Here the role of legislation and the pricing mechanism came to the fore in discussion. The proceeding sections of this chapter will now discuss the constraining factors associated with the emergence, development and uptake of aviation biofuels.

7.3. **Constraints**

Respondents acknowledged a number of constraints associated with emergence, development and uptake of aviation biofuels. These constraints were often closely interlinked with one another and at times combined to create an altogether stronger constraint. It will be revealed that constraints can be different depending on the type of biofuel technology being analysed; as well as the region in which the fuel is being produced and the availability of legislative support. The first constraints to be discussed are political and legal constraints.

7.3.1. **Political and legal constraints**

Lack of legislation was a constraint which almost all of the respondents described as being a serious issue. A lack of legislative measures, particularly incentive based economic measures, features as a prominent constraining issue throughout this thesis. These 25 interviews complement those existing findings by allowing for a greater understanding of the difference between regional areas, reflecting varying degrees of competency in aviation biofuels development and geopolitics. This is something which is generally missing from the literature as well. There are several regional studies such as the CCC (2009) report and Dray et al., (2009) however few studies attempt to analyse the difference
between regions. SWAFEA (2011) does attempt to do this however it looks at very high level issues rather than at the stakeholder level. Going back to the data, most respondents described the issue of legislation as a ‘lack of a level playing field’ between road-based biofuels and aviation biofuels. Others discussed a lack of legislation with respect to insufficient funding or supportive measures for the fuels.

The focus of many stakeholders was on the EU which, with the exception of Holland, favoured the use of road based biofuels over aviation biofuels in its use of legislation. Road based biofuels were described as being supported by a plethora of incentives and legislative support measures including: subsidies of feedstocks, mandates of biofuel blending and tax breaks. This was described as being ‘unfair’ towards aviation biofuels.

Another common topic of discussion surrounding legislation was the EU ETS. Almost all of the respondents stated that although the system has a zero carbon accounting procedure for aviation biofuels, this does not create any incentive to use aviation biofuels. This is because the price of carbon is too low. This view is also accepted in the literature in reports such as Dray et al., (2009) however most studies assume a growing carbon price over time. Data from this study revealed that certain authoritative stakeholders, such as petrochemical major A, believed the cost of carbon will remain low for several years despite the literature findings. This issue is due to the fact the aviation industry does not have a closed system of trading. This means that the aviation industry will be allowed to purchase cheap emissions credits from the static industries at prices much lower than that required to create an incentive. Additionally, the EU ETS system was criticised for creating significant accounting issues for non-EU airlines.

An additional issue related to legislation was the level of knowledge flows between legislators and the aviation biofuel community. The main area of focus was on the EU. It was expressed by over half of the EU respondents that there is inadequate knowledge flows between legislators and the industry, and this may be impacting on the industry’s ability to develop. UK airline A described their interaction with legislators as follows:

“We do try to talk a lot to legislators and make recommendation but there are so many issues to resolve. It’s not all that encouraging that they are taking it all in from what we see”

Inadequate knowledge transfer between stakeholders and policy makers was not discussed formally in the scoping study or the survey however, it was fairly clear from the discussions that the level of government engagement in matters relating the aviation biofuels is inadequate. Stakeholders and policy makers were frequently expressed as being disconnected or difficult to work with due to a
lack of understanding surrounding aviation biofuels issues. Within the SNM literature, this can have damaging effects on the development of a niche market though this is not considered in the literature. The CCC (2009) report and the SWAFEA report (2011) do however recommend increasing the level of government incentives and support for aviation biofuels, so it appears that they are aware of the issue.

The constraints which have been presented thus far can be described as being the core constraints. Indeed, they featured as the main issues hindering the development and uptake of aviation biofuels according to the respondents. However, in addition to these core constraints there were other issues which were mentioned by a select few respondents. These include: applying too strict environmental criteria on aviation biofuels and a pipe-line infrastructure certification issue. The first constraint is that of strict environmental hurdles.

The issue of having strict environmental hurdles for aviation biofuels was flagged up as being a potentially overlooked constraint by three respondents. The issue surrounds the idea that legislators and NGO’s are being too strict on setting environmental hurdles for aviation biofuels. Despite the fact that there are no formal environmental guidelines for aviation biofuels as yet, the respondents warned that the initial interest is too focused on overly optimistic technologies. The respondents explained that there may be a tendency to overlook slightly less environmentally beneficial technologies in favour of the ‘Holy Grail’ type technologies which seek to be almost perfect from the outset. The three respondents spoke at length about the fact that this could be counterproductive to the development of the industry as a whole. Two respondents from the petrochemical industry stated that being ‘too’ strict on the technologies in their early stages was detrimental. They stated that the best solution was to develop upon technologies that are proven and over time the sustainability will be improved. One respondent, from a major oil company, justified this suggestion based on experience with palm oil production:

“Biofuel production using Palm oil is the best one because it’s an existing technology that we can scale up now, and we can get the yields up on those, rather than start with new technologies that are no good…the sustainability isn’t as good today but if we put measures in place it can be”

It was explained that over time the sustainability of certain less efficient feedstocks will improve if appropriate legislative measures are put in place. Although this view was shared by three other stakeholders, most respondents warned of a scenario in which the scale up of any unsustainable feedstock production would be catastrophic for the environment. This is an issue which was not
picked up by the scoping study, survey or the literature specific to aviation biofuels. There appears to be a gap in the literature surrounding these issues. SWAFEA (2011) does describe factors that are considered during the development of aviation biofuels policy measures however applying environmental controls which are too strict does not feature. In fact, the main argument for aviation biofuel studies has been to increase the level of regulation on emissions and other environmental issues in light of the uncertainty surrounding the sustainability of aviation biofuels. This is of course in direct conflict with these respondents.

The next political or legal constraint which was expressed by respondents is a ‘lack of supply chain certification’.

Although certification was a minor issue in the interviews, one respondent spoke at length about a potentially overlooked issue surrounding the certification of the supply chains. The respondent, from a certification and testing company, explained that within the EU, aviation biofuel blends cannot be distributed through existing fossil-fuel pipe lines or mixed in standard jet fuel mixing facilities. This is because of a lack of integration of ASTM with the UK’s DEF-STAN and EU’s AFQGS. This means that dedicated systems are still required for the fuel, despite the fuel being fully certified in up to 50% HEFA and FT fuel blends with standard jet fuel. Although the volumes are quite low at present, it was acknowledged by one respondent that this is causing logistical constraints for trials. The next section will discuss the economic constraints, the first being high costs.

7.3.2. Economic constraints

High costs were mentioned by all respondents as a significant constraint to the development and uptake of aviation biofuels. All respondents acknowledged that the purchase price of aviation biofuels given current technology will be higher than the price of standard jet fuel. Biofuel producer S stated:

“The price of bio-kerosene is at least twice the price of fossil jet fuel alone. And the price is really a challenge. We are working hard to get the costs down but this is a major issue for everybody”

Estimates for price parity were given reluctantly, but most estimates were between the years of 2015 and 2030. This large variation may be explained, in part, by the complexity of the cost issue. When respondents elaborated on the cost issue it was apparent that estimating the final cost of aviation biofuels can be difficult. This is because the final price of the fuel is influenced by various factors such as: the production process, feedstock costs, the costs of infrastructure and legislative
support. Each of these components will vary depending on the technology being used, the region, and the level of infrastructure available and legislative support. One engine manufacturer, which had direct involvement with the production of aviation biofuels, discussed in detail how costs associated with different aviation biofuel technologies would vary considerably. The respondent used two contrasting aviation biofuel production paths to illustrate this difference. The respondent discussed Biomass to Liquid (BtL) technology and Hydroprocessed Esters and Fatty Acids (HEFA) technology. Firstly, BtL technologies; which can convert numerous cheap feedstocks such as municipal waste into biofuel, are associated with considerable capital costs. Indeed, half of the respondents were quoted as saying that BtL technologies in particular are being constrained by high capital costs. In contrast to BtL however, HEFA fuel; which uses a simpler production process of converting vegetable oils into biofuels through hydrotreating, is much cheaper to put into operation because it can be produced using existing technologies or from adapted facilities that already exist. The capital cost constraint for HEFA facilities is therefore much smaller than for the BtL facilities. However, HEFA fuel production may be more costly in the long run due to higher feedstock prices. Compared with BtL technology; which can utilise a much cheaper feedstock base; HEFA fuels can only use oils which are in short supply and are relatively expensive. Furthermore, the price of oily feedstocks has become increasingly correlated with the price of crude oil in recent years; this may mean that volatility in the prices of crude oil may not feature as a significant driver for this technology.

In this section costs were analysed and acknowledged as a significant constraint to the development of aviation biofuels. The next constraint to be discussed is closely linked to costs. It was explained in this section that a major factor of cost is associated with the investment into the construction of a biofuel plant. However, obtaining investment in itself is a fundamental constraint to the entire technology. Indeed, almost all of the respondents acknowledged that there is a lack of investment for aviation biofuel technologies.

80% of the respondents acknowledged that insufficient investment was reaching aviation biofuel technologies. Most of these respondents believed that the main factors hindering the level of investment were: uncertainty about the technologies, uncertainty about legislative support and an inability to obtain credit because of the global economic downturn. Further factors included an inability to de-risk investments and a lack of government investment. The situation was expressed as being better in the US, but still inadequate.

Uncertainty was a common issue associated with a lack of investment. Investors were acknowledged as being cautious about the technology because of insufficient understanding about the
technologies. This makes the investment decision more difficult because risks cannot be accurately assessed. Furthermore, uncertainty about the level of legislative support and the duration of the support makes the risk calculation even worse. Airline B described its own difficulty in obtaining investment as follows:

“We had a hard time getting finance. Banks don’t want to take risk on a ‘first of a kind technology’. Apart from the US, the UK hasn’t got their heads around how they will de-risk these investments. The US on the other hand is doing much more than the EU”

When the airline mentioned de-risking, they were referring to the presence of government backed loans or guarantees that can be offered to insure against losses on the technology. Indeed, with the exception of the U.S, there are very few regions where ‘de-risking’ is occurring according to the respondents.

The other constraint related to investment was acknowledged as a lack of government grant funds for new biofuel technologies. As well as having insufficient quantities of funding in most regions, the other issue related to the way government funds were administered. Four respondents mentioned that the way grant funding is administered may be suppressing promising technologies before they have a chance to show their potential. The main issue is that funding is not being given out quick enough. One NGO respondent spoke passionately about the fact that very often in Australia and Europe the time required to administer funds could be up to a year. According to the respondent, in that time the company can easily go bankrupt. The respondent went further in saying that because of political agendas, the structure of funding and the rules and guidelines that are in place lead to slow decision making. Referring to the Australian funding system specifically, NGO respondent A stated:

“In almost all cases, the political nature of the funding means that the time frames to allocate the funding are way too long, if you have a start-up company that needs cash, 18 months is a ludicrous amount of time to wait - and it happens elsewhere. There is a need for quicker discussion making”

The next constraint to be discussed is related to feedstocks or more specifically a lack of ‘sustainable’ feedstock. There are considerable constraints associated with the development of the industry because of a lack of feedstock supply. The constraint has already been briefly mentioned as a reason why the price of aviation biofuels is so high however; there are other effects that a lack of feedstock supply creates as well. The next section will review these issues in more detail under the theme of environmental constraints.
7.3.3. Environmental constraints

A lack of sustainable feedstock supply was an important constraint according to all of the respondents. Respondents commonly described the aviation biofuel industry as being ‘lacking in sufficient feedstocks to make existing technologies economically viable and sustainable’. The emphasis moreover was on a lack of ‘sustainable feedstocks’ which meet both economic and environmental criteria. The main reasons for a lack of sustainable feedstock supply that were acknowledged included: a lack of supply chain, a lack of feedstock research and a lack of clear sustainability criteria. These issues will now be discussed.

A lack of supply chain was mentioned by ten respondents from mixed sectors. Five respondents from the CAAFI initiative called this the ‘agricultural vertical’. Respondents stated that at current levels, the agricultural vertical for sustainable feedstocks is almost non-existent in most regions. This means that the physical and monetary effort to obtain sustainable feedstocks is excessive. Respondents that had been involved in creating a supply chain for aviation biofuels in Brazil described the work required to source relatively small amounts of sustainable Jatropha feedstock as ‘excessive and ‘non-economical’. The respondents described a situation in which the final feedstock delivery for a particular trial was amalgamated from numerous geographically scattered batches.

“...for one of the trials we sourced the Jatropha nuts ourselves. It was a big challenge because we had to squeeze every little bit we could find from all over the country just to get enough. And there was no supply chain yet so the logistics were also a challenge” [Biofuel supply chain expert]

The second issue acknowledged was a lack of feedstock research. Although major breakthroughs have been made surrounding new feedstocks and production methods, there is still a considerable amount of research work required. One NGO respondent stated that all too often attention is wrongfully focused on the production side of the business i.e. on the processing technology, rather than on the feedstock bases. This was described by the NGO as being highly counterproductive. The respondent elaborated on the views of other respondents in saying that more research effort and funding is required on the feedstock side to ensure that the processing technologies have sufficient raw materials to produce fuel. NGO respondent B stated:

“There’s a tendency we focus on the production side of things because that is the attractive and interesting side of the business, whereas in relativity there is so much work to be done on the feedstock side. The reality is that the plant you build once and the biomass will be used for 30 or 40 years. [sic]”
Related to a lack of feedstock research is a lack of sustainability criteria for aviation biofuel feedstocks. This was expressed by the same ten respondents from mixed sectors. Although there are various projects which are underway to tackle this issue, at present it is hindering the development of the industry. As well as creating uncertainty for investors, one respondent talked about how farmers are not getting sufficient information about sustainability criteria. One US airline respondent described this sentiment for some U.S farmers. Related to sustainability of feedstocks are the environmental effects of land use change and pressure on the food supply among other things. These issues were carried over from the conventional biofuel debate where they are major topics of discussion. The majority of respondents said that the industry is taking the issues very seriously indeed.

Thus far this constraints section has shown that there are a number of significant issues associated with aviation biofuels. The core constraints acknowledged in the 25 interviews were: high costs, a lack of investment, a lack of sustainable feedstocks and a lack of legislative support. It was revealed over the course of this section that these core constraints are closely interlinked with one another. Indeed, one constraint can very often lead to a series of other constraints. For example: a lack of sustainable feedstocks leads to higher feedstock prices; this leads to higher aviation biofuel price projections. Higher biofuel price projections make the business model for aviation biofuels risky to investors. A lack of de-risking however means that investors do not invest. This vicious cycle is all too familiar in emerging technologies. It is what a few respondents in this series of interviews called ‘a chicken and egg scenario’.

There are however possible ways of breaking this chain of constraints. Strategies can be used to support the development of emerging technologies in such a way that increases investments. This could be by nurturing a technology from an early stage through the various stages of technological development. Or perhaps using government incentives that are applied to an entire industry; such as a tax break or mandate. Whatever the means, there are several ways in which a technology can be supported. Aviation biofuels are being supported by certain industry and government strategies that hope to incentivise the uptake of the fuel. However, there are several issues associated with the support packages that are currently in place.

7.4. Existing Strategies

Support strategies are defined in this section as initiatives or measures that are used to support the development and uptake of aviation biofuels. They differ from drivers because they are artificially created to aid the development and commercialisation of sustainable aviation biofuels. A number of
strategies are currently being implemented; some of which that are very effective at supporting the aviation biofuels and others which are in need of changes. Political and legal strategies will be discussed first.

7.4.1. Political and legislative incentives

Around half of the respondents mentioned some form of legislative measure that was being used to positively influence the development of aviation biofuels. The most frequently acknowledged measure was the U.S RINS system and Holland’s use of subsidies. Both of these measures have been put in place to attempt to draw equivalence to road based biofuel incentives. The U.S has done this by allowing aviation biofuels producers to qualify for the Renewable Identification Numbers (RINS) thus making their biofuels part of the nationwide Renewable Fuels Standard (RFS). Biofuel producer B stated that this is positive step towards creating a wider incentive, but not enough to create complete equivalence between the fuels:

“Yes they have made a level playing field for the RINS and that was a very positive move forward for the development of the fuels. I think it certainly helps level the playing field between road based biofuels”

However, respondents acknowledged that although the RIN system has begun the process of levelling legislative measures, a bias towards road based biofuels remains. This is because it is much cheaper to produce road based biofuels due to cheaper production processes and more established supply chains. Furthermore, the production yields for producing road based biofuels using first generation crops is comparatively higher. So for every tonne of feedstock the producer will make more money.

In the Netherlands, extra subsidies for aviation biofuels have been introduced in an attempt to create equal incentives. One EU biofuel producer called this: “an aggressive move to encourage aviation biofuel; it is a great opportunity that the Dutch government is seeing in the fuels”. Furthermore, an EU consultant was quoted as saying that the Dutch are trying to become the EU biofuel leaders. Other EU respondents including two petrochemical majors mentioned that the nation’s efforts were generally very positive for the industry, but again, the measures were described as merely the starting point for drawing complete equivalence between road-biofuels and aviation biofuels.

The next political or legislative strategy being currently utilised is public-private partnerships. In several cases, governments are actively working with the private sector to assist in the development
and emergence of aviation biofuels. Almost all of the respondents mentioned some form of partnership whilst discussing strategies. There were two main types of partnerships discussed; public-private partnerships, airline-producer partnerships

**Public-private Partnerships**

Public-private partnerships were mentioned by almost all of the respondents. The main public-private partnerships that were discussed were: the ‘Farm to Fly’ initiatives based in the U.S and the EC Flight Path Initiatives in the EU. A minority mentioned some South American and Chinese governmental-industry initiatives as well. This section will review the main public-private partnerships starting with the US based partnerships.

Around a quarter of the respondents acknowledged the U.S. ‘Farm to fly’ initiative. Respondents described it as being a focused strategy for supporting the development of U.S aviation biofuels. The ‘Farm to Fly’ initiative incorporates a wide variety of partnerships including: the US Air Force, the Department for Energy (DOE), the U.S Department for agriculture and a number of producers and airlines within the US. Regionally focused partnerships have also emerged such as the Midwest Aviation Sustainable Biofuels Initiative. The U.S government was recognised for making a ‘significant effort’ to work with stakeholders and develop partnerships, though with additional help from CAAFI members. According to one government official, the US government is engaged in a wide range of activities:

“The US government do a lot of work. We have built a lot of partnerships with people we don’t usefully do business with. We have worked a lot with the US Air force, worked a lot with NASA; we have also worked with the US Department of Energy and the U.S Department of Agriculture. Most of the initial work was done through CAAFI”

The Department of Energy (DOE) was also acknowledged as having a number of programs that were being used to demonstrate newer technologies and pilot scale demonstration plants. According to the US government official, the U.S government were providing loan grantees and grant funding for programs to help build infrastructure. Furthermore, it was explained that the loan guarantees, once they are administered, would be fixed regardless of a change in administration. The US government had recently provided funding for a company called Shappire Energy to construct a one million gallon integrated production facility. The company were given a series of government backed loans. This type of funding model will likely be applied to other projects according to the US Government Official.
Another route of funding was in the form of U.S military purchasing agreements of biofuel. Although it was alluded to in the interviews that this may be reduced eventually, the volumes which were being purchased had a dramatic effect on some businesses as well as on the public attention on the fuels. The military were purchasing the fuels at many times the price of standard jet fuel for the test.

The U.S. is indeed carrying out a lot of work in creating public-private partnerships. Almost all of the respondents were knowledgeable of the work that the U.S was doing and praise was given to the level of organisation and alignment that the U.S. government had achieved in a very short space of time. In fact, four non-U.S. respondents suggested that emulating the region elsewhere may be necessary. One petrochemical respondent described the efforts as being ‘excellent’; while a U.S engine manufacturer called their achievements ‘a fantastic start’. Most stakeholders however acknowledged that there is still a real need for more government funding and greater alignment of the various government departments. Public-private partnerships are also occurring in the EU region however, the way the partnerships were formed was expressed to be different.

EU partnerships were mentioned by around a quarter of the respondents. Although much of the effort to bring together partnerships was described as being ‘industry-led’ in the EU, public-private partnerships have nevertheless begun to emerge in certain EU member states and each of these are communicating with the European Commission (EC). Around a quarter of the respondents referred to the ‘EC Flight Path’ at some point in their discussions. The main countries that were discussed were: Spain, Germany, Holland, France and the UK, as well as a future partnership between Romanian airline TAROMM and the Romania government to develop a Camellia supply chain.

Most respondents stated that partnerships were important for the initial stages of development of aviation biofuels however; in most of the existing cases within the EU funding and co-ordination were clear issues that needed to be resolved. In relation to the UK, one airline described the level of organisation in the UK as being poor in relation to the U.S. The respondent compared the alignment of the UK system with that of the U.S:

“If you look at the U.S., different departments are strategically working together; they have a perfectly co-ordinated system. If you look at the agricultural department; it’s sitting next to the department for energy and next to the FAA and next to the airlines and producers. The UK works differently, I can be in a meeting with the Department for Energy and Climate Change (DECC), and the commonwealth office and DEFRA and they all have different agendas.... so there isn’t a huge amount of alignment at this level. This is a problem” [Airline A]
Indeed, the lack of alignment described above is also visible in other EU countries within the EC Flight Path initiative. A lack of alignment was mentioned by two EU respondents regarding the EU in general. However, the coordination of EU member states was acknowledged as being inherently difficult due to the varied nature of legislation and policy measures offered between nation states. Holland for instance was described as being the most aggressive country within the EU region because it had already begun to create equal legislative incentives for aviation biofuels in relation to road based biofuels. None of the other EU countries have started this yet. This lack of alignment is creating distortion in the EU region.

As yet, the U.S and the EU are the only regions which have been discussed in this section. However, as previously mentioned there are other initiatives that are taking place elsewhere in the world.

Other public-private partnerships

Around one quarter of respondents mentioned other regions in their responses with Brazil in particular being identified as a region that had successfully set up aviation biofuel alliances between industry and government. Two Brazilian respondents stated that the level of government support was growing, though still limited and in need of improvement. The other regions that were discussed were China and Africa. China was mentioned by five respondents as being a region that had been aggressively pursuing aviation biofuels with collaboration between government and industry. The Chinese developments are occurring at an extremely fast pace, much faster than the U.S and the E.U. One academic respondent stated that that nation’s speed of development with respect to biofuels was ‘astonishing’. The academic gave an example of an aviation biofuel production facility that was planned, funded and constructed within a few months. The respondents stated that: “China want to be the leaders in producing biofuels”. Four other respondents mentioned that China’s rapidly developing biofuel initiatives were mainly due to the countries communistic system. The aviation academic described that the Chinese government are likely to have taken a much larger leadership role in the development of the initiatives. However, the five respondents warned that the Chinese may attempt to convert coal to Jet fuel as well, thus off-setting the environmental benefits of using biofuels. The other regions that were acknowledged were Africa and Australasia. Only two respondents mentioned efforts in these regions. The Australian public-private partnerships were acknowledged as being perhaps lacking at this stage. African partnerships were briefly mentioned but not elaborated on in any way.

The remainder of existing strategies which were discussed by the respondents cannot be easily categorised into the PESTLE framework because they involve private partnerships and industry
initiatives to streamline the development of aviation biofuels. The first type of strategy to be discussed is an ‘industry initiative’. This was by far the most commonly cited existing strategy discussed by the stakeholders.

7.4.2. Industry initiatives

Industry initiatives were acknowledged as being a vital supporting mechanism for the development and uptake of aviation biofuels. These initiatives seek to speed up the development and uptake of aviation biofuels by encouraging dialogue amongst stakeholders and providing a single voice for lobbying towards legislative support. They also provide a forum for communicating concepts and guidance about aviation biofuel developments to stakeholders outside of the aviation industry. The initiatives were viewed positively by the majority of interviewees, though respondents did state that each initiative had relative strengths and weaknesses. There are a growing number of industry initiatives which are being formed. However, the majority of discussion surrounded the following four industry initiatives: the Commercial Alternative Aviation Fuels Initiative (CAAFI), the Sustainable Alternative Fuels User Group (SUFUG); the Brazilian Alliance for Aviation Biofuels (ABRABA) and the ‘Six Step Strategy’ from the International Airlines Transport Association (IATA).

The most deliberated initiative was CAAFI. CAAFI was described as a U.S focused program that has been very active in encouraging the certification, testing and the commercialisation of aviation biofuel technologies. Around four fifths of the respondents stated that CAAFI was a key player in facilitating the ASTM certification of HEFA and FT aviation biofuels, and will continue to be a key figure in the future development of the fuels. In fact, around half of all the respondents interviewed were members of CAAFI. The majority of these respondents believed that CAAFI will feature as a central platform for supporting the development of aviation biofuels well into the future. The success of the CAAFI initiative is the result of good organisation, clear plans for supporting each stage of the aviation biofuel supply chain and an aggressive entrepreneurial attitude from its members. Furthermore, it was also mentioned that CAAFI is likely to increase its scope of influence to beyond the U.S. CAAFI was acknowledged as one of the facilitators for public private partnerships in the U.S, such as the Midwest Sustainable Biofuels Initiative and the Farm to Fly initiative. These public private schemes were described as being important for the commercialisation of aviation biofuel within the U.S – they will also be analysed in more detail later in this section.

Despite the acknowledgements of success of the CAAFI initiative, three airline respondents warned that there was perhaps a lack of work on environmental issues in relation to its efforts to support the business and commercialisation. U.S engine manufacture A stated:
“CAAFI could be a little more effective in looking at sustainability issues I think. But all of the work at the moment is being done is on a voluntary basis. CAAFI only really have a couple of people directly involved in the day to day activities.”

The second most discussed initiative was SAFUG; 20 respondents described SAFUG as an important initiative; the other five did not mention SAFUG in their responses. SAFUG was described as an EU focused initiative that was highly competent in creating dialogue amongst policy makers and NGO’s, and discussing issues of legislation and sustainability. The initiative was however criticised for a less effective strategies for commercialising the aviation biofuels. A core aspect of SAFUG is to identify and assess sustainable aviation biofuels and to develop processes for assessing the sustainability of new biofuel technologies. The initiative has ‘Roundtable on Sustainable Biofuels’ (RSB) as a founding member and members are required to make an environmental pledge to support sustainable aviation biofuels.

“… SAFUG members have all signed a sustainability pledge that has put down some of the principles that we think are key for sustainability. This puts out the message that the aviation industry takes sustainability of the fuels very seriously in terms of signalling that the aviation industry will not go down a road of unsustainable biofuel development”

One airframe manufacturer however stated that SAFUG was also an important initiative for inducing investment within the EU region because of the trusted signals about sustainability that the initiative sends to investors. The respondent stated that it is important that investors understand the genuine intentions of the aviation industry to support ‘sustainable’ fuels.

However, two other respondents from outside of the EU stated that SUFUG appeared to be focusing too hard on the EU region, when the sustainability issue is in fact world-wide. This contradicted the initiative’s own objectives to look at world-wide strategies and ignored the members from outside the EU. These two respondents were not members of SAFUG themselves.

The third industry initiative discussed by respondents was ABRABA. ABRABA was described as being a similar model to that of CAAFI; with a strong focus on acquiring certification of the fuels and streamlining the commercialisation stages of the fuels. Five respondents acknowledged that the initiative will be important for the commercialisation of Brazilian aviation biofuels. Like CAAFI, ABRABA is beginning to develop public private initiatives in an attempt to establish funding arrangements. However, two Brazilian respondents voiced concerns about an insufficient level of government backing for aviation biofuels in general. The respondents also stated that strategies
should be run by the government and not the aviation or biofuels industry. They justified these views based on the country’s prior successes with the ethanol industry.

Finally, the fourth industry strategy that was mentioned was that of IATA’s ‘Six Step Strategy’. This is a roadmap for development and uptake of the fuels featuring six recommendations for encouraging uptake. Four respondents, each from the EU region, mentioned the six step strategy in their responses. Although it does not involve any physical initiatives as such, it does act as guide for many of the respondent’s recommendations. The next section describes the airline and producer partnerships. They differ from public-private partnerships in the fact that the airline is actually investing its own money in the production plant, without government assistance.

Airline and producer partnerships

Airline and producer partnerships were recognised by around a quarter of respondents from a mixture of sectors and locations. All of the respondents mentioned the collaboration between British Airways and Solena Group and Virgin Atlantic and Solena Group. The BA and Solena partnership however was the only project which was described at length, perhaps indicating that there are actually very few significant airline and producer partnerships in existence. This project was commended for the sustainability of the fuel due to the fact it will be using municipal solid waste as a feedstock. However, one negative issue which was highlighted out of the project was a lack of government funding. Indeed, it was mentioned by around five respondents that to the best of their knowledge, no UK government funding had been made available for the project. The respondents were from the EU region and stated that this was a serious issue hindering further plants. Overall, although there were very few negative issues associated with the project, the airline-producer partnership was seen a positive strategy to facilitate the development of the fuels. It also allows airlines to guarantee a supply of fuel, and have some degree of control on price. It furthermore appears strange that more initiatives such as these have not been set up.

Thus far industry initiatives, public private-partnerships and producer-airline partnerships have been described and analysed. It has been revealed that there has been significant collaboration between industry stakeholders in the U.S and EU. The rest of the world is somewhat lagging in relation to these two regions, though regions such as Brazil and China are quickly catching up. Some of the initiatives have proven to be very effective at creating dialogue with governments and in some cases have encouraged considerable government funding. In conjunction to the industry initiatives and public-private partnerships however, there have been a number of legislative measures that have
been used to help influence the development and uptake of aviation biofuel. These include renewable energy credits and subsidies.

In summary, this section has revealed that there are a number of different types of strategy which are being implemented to encourage the uptake of aviation biofuel. As mentioned, the U.S and EU are leading the way in terms of the number of types of initiatives and public-private programs that have been created. The U.S. efforts appear to be the most aggressive, as well as the best aligned with industry. It appears that the various government offices within the U.S. are working very closely with one another. In the EU it was acknowledged that the alignment is lacking. China has emerged quickly as a major player in the development of aviation biofuels through its use of aggressive government funded programs. Other emerging regions such as Africa, South America, Asia and Australia are developing their own initiatives’ and strategies and it appears that those regions will develop a larger role in coming years. However, as mentioned throughout this section. Respondents acknowledged that much more can be done to support the development of aviation biofuels. Indeed, the respondents acknowledged a number of recommended changes to existing strategies or proposals for new strategies. The next section therefore analyses these recommendations as future strategies.

7.5. Future strategies

Respondents were asked to make recommendations for existing strategies and future proposals for new approaches. Although numerous different recommendations were made, clear common themes could be discerned. Sometimes the recommendations were applicable to a number of different regions and technologies. In other cases, very specific recommendations were made in relation to specific technologies and regions. Indeed, it was expressed that in certain instances tailor making strategies to fit within the specific needs of the technology and the region is the best solution. Every recommendation however was acknowledged as being important and each will be analysed in this section. Recommendations were often described as an objective; such as to increase investment. The first section discusses political and legal strategies, starting with increasing government funding.

7.5.1. Political and legal

All of the respondents recommended increasing government funding in some way. Respondents usually described a specific type of funding arrangement that was appropriate for their region. Respondents were predominantly interested in obtaining funding for plant construction and infrastructure i.e. for technologies that were proven and ready to be scaled up. The common types
included: government backed loan guarantees, low interest rate loan facilities and shared risk financing schemes.

Government backed loan guarantees were the most frequently mentioned. Respondents from the U.S, E.U, Australia and Brazil all recommended the use of loan guarantees for the development of aviation biofuels in their regions. The main rationale was to allow funding to flow towards start-up companies that had low creditworthiness. Around three quarters of the respondents stated that loan guarantees would be beneficial provided that ‘promising companies’ were chosen to receive the funds. However, respondents warned that an overuse of government backed loans can be detrimental for an emerging technology because it may falsely over value it. One government official gave an example of how this had happened in the U.S. A Solar Energy company that had been heavily financed by the U.S government recently went bankrupt because of a miss calculation of the future value of the technology. As a result, the government lost a considerable amount of money and developed a poor public image locally. These concerns are acknowledged as being serious constraints to the use of government loans, on top of the fact that government budgets are extremely limited at the time of writing.

The second most discussed funding mechanism was a low interest rate loan facility. Ten respondents from mixed sectors mentioned low interest rate loan facilities in their responses; either refereeing to them as ‘soft-loans’, ‘soft-financing agreements’ or ‘low interest rate loans’. The rationale for providing these loans was to ensure that additional streams of financing were available for start-up companies. One NGO stated that the administration of soft loans would also need to be hurried to reap the full benefits of the loans. Speeding up the process would allow start-up companies to obtain funding quickly enough to ensure that their development is not halted. A select few respondents however warned that any increase in the use of what they called ‘soft financing’ needs to be carefully managed. The respondents stated that the main constraint to offering more soft loans is caused by assessing the companies and making the right decisions. However, this topic was not discussed in much detail by the respondents. Indeed, there appeared to be a general lack of understanding around the risks associated with soft financing or the administration of such soft financing loans.

The last government funding facility mentioned was a ‘shared risk financing scheme’. Three respondents from the EU including one airline and one consultant mentioned the possibility of using a shared risk financing mechanism to ‘de-risk’ investments attached to aviation biofuels. Respondents were referring to an innovative investment facility developed by the European Investment Bank called ‘Risk Sharing Finance Facilities’ (RSFF). The use of such facilities was
described as being quite versatile because it can be applied to almost every stage of the development process i.e. from research and development projects to the construction of plants. However, none of the respondents had a thorough knowledge of this facility at the time and unfortunately no one could elaborate on the strengths and weakness of this strategy.

The second recommendation that emerged from the interviews was for increased government incentives. Increasing government incentives can be achieved in several ways.

Almost all of the respondents recommended more government incentives for aviation biofuels. Most respondents referred to the issue of unequal incentives directed to road biofuels. Suggestions for equating the incentives included: better accounting of renewable energy credits, global emission trading systems, mandates, subsidies and free-trade agreements. A running theme throughout the respondents recommendations however, was to prevent discrimination towards any particular technology. It was agreed by almost all respondents that measures should be applied fairly across all technologies at this stage. The first way to increase government incentives is to use renewable energy credits or change the way the existence renewable credits are accounted for.

Ten respondents from mixed sectors recommended that changes were required in the way that renewable energy credits were accounted for. All of the ten respondents referred to the EU region in their responses. Indeed, five respondents referred exclusively to the UK region in their recommendations, stating that the Renewable Energy Directive (RED) needed to be changed in order to incorporate aviation biofuels in a ‘fair’ and ‘easily understood’ manner. One UK NGO stated that a solution may be to include aviation biofuels under the Renewable Transport Fuels Obligation (RTFO). It was postulated that this would equate to a noticeable incentive towards aviation biofuels. However, there was a huge amount of uncertainty surrounding the UK’s RED system. Some respondents said that the fuels were included in the RED already whereas others said the RED did not include aviation biofuels. Although almost half of the respondents recommended some form of change to the renewable energy credit system, there was also uncertainty in the existing accounting procedures of the RED in the UK and the RIN in the U.S. No one elaborated on the accounting methods that are used for the RED and the RIN system in the U.S.

Eight respondents from mixed sectors recommended a global emissions trading system mimicking that of the EU ETS. One U.S airline stated that a system like this would be: “a clear international signal to airlines and investors is needed to induce these large emissions reductions”. Five respondents from the U.S and three from the E.U stated that an un-biased and easily understood incentive is vital. Indeed, it would be the most significant support measure for the development and
uptake of aviation biofuels according to the respondents. However, most of the eight respondents which mentioned global schemes also warned that the idea is many years away from actually happening. Indeed, one UK academic stated that this is a measure which needs to be addressed by ICAO, and as yet, ICAO is only just beginning to take environmental matters seriously.

The next recommendation was related to a mandate on the production of aviation biofuel. This measure was however contested; with two respondents recommending its use and four respondents that recommended against its use. The recommendations were made by two petrochemical companies. The respondents explained that a mandate is the only real solution for balancing the incentives between road biofuels and aviation, aside from removing the mandate of road biofuels altogether. It was explained that the level of mandates applied to road biofuels are too large for other incentives to have a major effect. The four respondents who recommended against mandates were from the aviation industry. They stated that the incentives could be equated by removing the mandates for road biofuel all together. It was acknowledged that mandates are detrimental to sustainability and economic viability of the industry according to airframe manufacturer A:

“Mandates worry me. Mandates don’t work! You are told to do something so it affects quality and price, it also affects sustainability issues. It [aviation biofuel] can’t be purely mandated.”

The final recommendation for incentives was made in reaction to the EU ETS. It was acknowledged by three respondents including one airline, a consultant and an airframe manufacturer that the revenues generated from the scheme should be re-invested back into the aviation industry in order to fund emissions reductions. The respondents said that at present there is no plan to use EU ETS funding for aviation related projects. Instead, the revenues will be spread across national governments. This was expressed as a serious issue according to these three respondents.

An additional legal recommendation related to certification. It was mentioned by ten stakeholders that continued certification of new production pathways remains an important strategy for the uptake of aviation biofuels. An anomalous recommendation was also made with regards to the integration of the ASTM certification into EU fossil-fuel pipe-line supply infrastructure certification.

Continued certification of new production pathways was recommended by ten respondents. The two main recommendations were: to continually certify new production pathways through ASTM and to ensure that all supply chain infrastructure is also certified. It was championed heavily by two airframe manufacturers that the certification of the new production pathways is essential.
Certification of new fuels creates positive signals to airlines, investors and producers about the possibilities of using aviation biofuels. Commonly, respondents would say that the more certified fuels the better because this opens up the possibility to produce aviation biofuels in different parts of the world using different feedstocks.

The other recommendation referred to an issue of obtaining certification for supply chain infrastructure in the EU. It was acknowledged that within the EU there is no certification granted for the use of aviation biofuels in existing fossil-fuel pipelines and mixing terminals. This means that biofuels must use separated supply chains. One respondent, from a fuels testing company, recommended extension of the UK’s DEF-STAN and EU’s AFQGS guidelines to include aviation biofuels.

Thus far it has been revealed that respondents are recommending increased government funding and incentives. The increased funding is mainly to finance infrastructure and continued research. However, private investment, as shown in previous sections of this chapter, is also vitally important for financing these things. Indeed, increasing private investment was discussed by many respondents. This section is categorised as economic using the PESTLE framework

7.5.2. Economic

Increasing private investment was mentioned by almost all of the respondents. The rationale for more investment was the same as government funding, though the ways that the industry could achieve greater private investment is slightly different. Central to the idea of increasing private investment is lowering perceived risk. The main recommendations therefore were for: partnerships, off-take agreements, more stable legislation and the encouragement of large petrochemical investment.

Twelve respondents acknowledged that partnerships, either in the form of public-private or industry partnerships are beneficial for encouraging investment. It was acknowledged that private investors have so far used partnerships originated from initiatives such as CAAFI and SAFUG to learn more about technologies and engage into dialogue with legislators. Partnerships that incorporate a wide variety of stakeholders appear to be the most attractive to investors according to the respondents. This is because they offer better platforms for spreading knowledge about risks and they typically have closer connections with legislators.

Linked to partnerships is the idea of creating off-take agreements between airlines and producers. Off-take agreements are contracted agreements to purchase the fuel when production commences.
These are attractive to private investors because they lower the perceivable risk attached to their investments. Almost half of the respondents, from a mix of sectors, indicated that investors were looking towards partnerships that have robust off-take agreements when making investments. The recommendation therefore was to encourage more off-take agreements.

The third recommendation for increasing private investment was to create more stable legislative measures. Seven respondents acknowledged that investors were worried about legislative support that makes the investment attractive today being changed over time. This leads to inherent uncertainties surrounding costs and risks. The recommendation was therefore to increase government dialogue with investors to help them understand more about legislation, as well as to lobby towards longer-term legislative measures which allow investors to make decisions about the technology.

The last recommendation that was made in relation to private investment was to increase airline funding schemes for supply chains. One engine manufacturer spoke at length about how this model could be extremely successful, especially for supplementing government funding within larger public-private partnerships. Engine manufacturer A stated:

“Getting the airlines to maybe do some investment of their own, and maybe invest deeper into their supply chain is good strategy. I think there are a lot of things that can and need to be done in this area that can help with those larger strategies”.

Thus far it has been shown that there are numerous recommendations for how aviation biofuel technologies should be supported. However, a running theme throughout people’s recommendations is the idea that different regions often need different approaches depending on their own circumstances. Indeed, a number of respondents proposed that nations and even regional areas should have their own focused strategies. The next recommendation which emerged in the interviews surrounded the issues of sustainability criteria. The main recommendations were with regard to the lack of understanding and lack of international alignment of sustainability criteria. There were several recommendations for introducing robust sustainability criteria for aviation biofuels. This section discusses environmental strategies.

### 7.5.3. Environmental

Recommendations related to sustainability criteria were mentioned by the majority of the respondents. The main recommendations were: creating clear accounting procedures, creating more dialogue with NGOs and avoiding too strict control on initial sustainability of technologies.
Creating clear accounting procedures for life-cycle emissions was recommended by nineteen respondents. At present there is no agreed procedure for accounting for the life-cycle emission savings attributed to aviation biofuels. Airlines, engine manufacturers, academics, NGOs and government respondents each stated that accounting procedures are therefore vital. A further key factor is to ensure that the accounting procedures are uniform across all regions. At present there is no way of comparing different biofuels accurately because the accounting methods vary from region to region. This in turn makes accounting for things like the EU ETS and renewable energy credits inherently difficult when feedstocks or biofuels are imported. Potential recommendations included: setting up dedicated accounting bodies to calculate the life-cycle emission attributed to the fuels or to work with trusted institutions to aid in the development of a uniform methodology for quantifying life cycle emissions.

Linked to the issue of accounting procedures was creating more dialogue with NGOs. It was acknowledged by two respondents that gaining credibility surrounding sustainability is essential. As already mentioned, stakeholders are worried about the image that biofuels creates and they are not prepared to support unsustainable technologies. The recommendation was to continue to use existing platforms such as SAFUG and CAFFI, but also to encourage greater dialogue with governments surrounding sustainability.

Lastly, two respondents made a somewhat contradictory recommendation about calling for a reduction in the desired environmental performance of technologies in the short-term. This was mentioned in previous sections as being a constraint to the development of the industry. Indeed, one of the respondents stated a recommendation would be to support moderately good biofuels today which over time will become more efficient though learning mechanisms and experience. These efficiency savings will translate into increases in the life-cycle emission savings.

Thus far the main recommendations have focused on biofuels which are nearing the commercial stage i.e. which require funding for plant construction and infrastructure. However, there are several aviation biofuel technologies that are still in their research and development and certification stages. In order to ensure that these technologies are commercialised, research, development and certification must be continued. This was a clear message from a number of respondents in the interviews. There are also certain areas within research and design that should be changed. The next section will outline these issues.
Research and Development

Eight respondents recommended that increased research and development is essential for the development and uptake of aviation biofuel. Recommendations about research and development included: more attention to the technical production issues, more attention to future feedstocks, and continued research into new pathways.

Six respondents recommended that more attention needs to be directed to technical issues. The respondents were referring to chemical and biological engineering issues and research into enzymes and catalysts. The six respondents acknowledged that there are potentially large advances that can be made in the way we convert feedstocks into fuels. The recommendation was to encourage more collaboration with universities and chemical engineering companies in this sphere. One respondent stated that the industry initiatives such as CAAFI may offer a good platform for university collaboration.

The second recommendation was for more feedstock research; three respondents acknowledged that there should be more effective research into feedstocks. It was mentioned in the constraints section that one NGO respondent acknowledged that the industry is focusing too hard on the production pathways rather than looking at the feedstock bases. However, according to five other respondents, continued research and design efforts need to be carefully spread across all newer production pathways such as algae, cellulosic and alcohol-to-jet. It was acknowledged that these future pathways offer the best economic and environmental benefits in the long-term. As a final condition, a number of stakeholders stated that strategies such as policy incentives and public private partnerships may be better served if they were tightly geographically focused. This is due to the variability in feedstocks between differently regions, as well as the varied political landscapes between nations.

Twenty respondents suggested that strategies should differ depending on location because of feedstock availability. Ten respondents, from mixed sectors, explained that locally focused strategies were the best solution for their countries. This is because the nature of feedstocks available to dissimilar locations is inherently different depending on the physical geography of the region and its climate. It was acknowledged therefore that regions should tailor make strategies to optimise their resources. Recommendations included the development and nurturing of specified niche markets similar to the efforts being done in the Netherlands, while others recommended the development of further regional public-private partnerships programs that are focused on their geographical locale.
However, the same respondent identified an area of conflict between regional schemes and larger scale national or international schemes. It was acknowledged that regionally focused strategies will inevitably be influenced by wider scale governmental incentives or policies. It is important that the regional schemes are well aligned with the national schemes. A U.S. airline elaborated on this matter by saying that, although regional strategies are the best option national policies will inevitably become involved and perhaps hinder the wider development of the technology:

“Part of me says that strategies should be addressed in a slightly different way in each region but I think we know how pragmatically that that is never the case. When politics are involved, various things happened to change local policies etc.”

7.6. Summary

This chapter has added to the evidence that there are a number of complex and interlinked drivers and constraints associated with aviation biofuels. All respondents from the three stages of data collection stated that the aviation industry needs to reduce emissions and avoid oil price rises. These findings more or less align with the literature, scoping study and survey. However; this chapter also provided a number of deeper insights into the drivers and constraints of aviation biofuel. It can be said therefore with confidence that system level drivers are vitally important for the emergence, development and uptake of aviation biofuels. The interviews revealed that sub-system drivers (i.e. airline producer partnerships, investor awareness, business opportunities and development consortia) are much more important for the successful emergence of aviation biofuels than first thought. It appears, for instance, that the aviation industry will play a larger role in encouraging the development of aviation biofuels. This basically suggests that, although the underlying rationale for aviation biofuel may be rooted in the known system level changes, there are several interesting sub-system issues which make the technology a compelling case for the aviation industry. Certain aviation industry players are seeing aviation biofuels as a long-term strategy. The case is so convincing in fact that the aviation industry is willing to invest financially in streamlining the emergence, development and uptake of the fuel in light of the economic and environmental gains which may be achieved. This is a significant finding which may have implications for providing supporting strategies and/or policy frameworks for aviation biofuel. More discussion around this topic is provided in chapter 8.

As well as driving issues, the interviews also identified issues acting to constraint the development of aviation biofuels. Some of these issues were seen before in the scoping study, survey and the literature. Known constraints were mainly system level issues such as lack of policy support, the
relatively low price of oil and the low price of carbon. These system level constraints are discussed extensively SWAFEA (2011), as well as in the scoping study and survey, though earlier aviation biofuels studies such as Marsh (2008) and Dray et al., (2009) fail to discuss the issue of ‘lack of policy support’. This chapter also revealed the importance of sub-system level issues such as low feedstock supply, inefficient production, lack of private/public funding and a lack of supply chain. With the exception of lack of feedstock supply, these constraints were not well reported in the literature. Furthermore, this chapter highlighted the interactions between constraints which create a vicious cycle of issues. It appears that the key issue is obtaining adequate finance to develop the technology, the feedstock and supply chain. Without policy support and public/private investment the technology will develop slowly or not at all.

The vicious cycle of issues can nevertheless be broken through the use of supportive strategies such as government funding schemes, environmental policies and subsidy schemes. Indeed, it was revealed that there are a number of strategies which currently exist that seek to aid the development of aviation biofuels, though with the exception of industry initiatives, most of these strategies are ineffective. Respondents made recommendations to obtain more funding, publically and privately, to support the development of the technology, particularly surrounding the development of production plants for newer aviation biofuel technologies. It was revealed that the greatest issue is a lack of real financing and a lack of environmental sustainability for aviation biofuels. These are areas that future strategies should address.

As mentioned of the start of this chapter, the latter section of this chapter will provide a case-study of the UK’s first aviation biofuel trial using aviation biofuels on a commercial flight. Test flights have been discussed throughout this thesis; some stakeholders have acknowledged that test flights which incorporate development of a supply chain for the fuel are important drivers of the fuel. However, stakeholders were unable to elaborate on why test flights were effective as a driver. Stakeholders were also unable to elaborate on the finer details of a test flight in terms of the issues which were faced and how the issues may have been overcome. This information may be vital for the development of aviation biofuels. It may provide insight into the issues of developing a supply chain for the fuels, storing the fuels and administrating the fuels at the airport.

7.7. UK’s First Commercial Aviation Biofuel Trial – Overcoming the challenges of technology readiness

Although flight trials of aviation biofuels occurred in 2006, it is only very recently that they could be used on commercial revenue generating passenger flights. In June 2011, HEFA type biofuels were
granted ASTM certification for blends of up to 50% in standard jet fuel. This allowed airlines to begin testing aviation biofuels on scheduled flights with paying customers. To date there have been more than fifteen commercial trials in four continents; each showing no adverse performance issues or malfunctions on the engines (enviro.aero, 2009). Although the test flights themselves were invariably well documented in the popular press, there has been a lack of empirical research into the planning and logistical stages of these trials. This is unusual given the fact that much of the work involved in facilitating an aviation biofuel trial occurs in the planning and logistical stages. On the 6th of October 2011, the UK’s first commercial aviation biofuel flight trial with paying customers occurred. This section comprises a case-study of this trial; involving collaboration between the stakeholders involved.

The case study is based on a mixture of semi-structured interviews with four of the key authorities involved in the trial and documentation collected at the end of the first stage of the trial in October 2011. The case study builds a detailed picture of the procedures and challenges that took place during the preparation and execution of the trial, as well as the main outcomes and recommendations. The case study will be arranged into five sections: planning and motivation, sourcing and mixing, airport administration, outcomes and recommendations. A copy of the interview schedule is in appendix D. The study will show that although the flight tests themselves were met with very few technical or operational issues, at various stages of the trials development there were significant challenges to overcome. A more detailed explanation of the methodological approach was discussed in the methods chapter 5 (Section 5.8). The first section of the study describes the planning and motivation stage of the trial and the challenges that were faced.

**Planning and motivation**

Respondents were each asked about their company’s motivations for undertaking the UK’s first aviation biofuel trial. They were then asked about what role they played in the planning and development stage of the trial. The participants did not want to be formally identified in the case-study therefore they will be referred to by their company description. The planning of the trial was initiated in 2009 when the major UK airline began collaborating with a Dutch aviation biofuel specialist. At this time aviation biofuels were a relatively unknown concept to the airline and seeking senior level approval for the trial was challenging. The main issues surrounded uncertainty about the safety of the fuels, concerns about sustainability and costs. Although some effort was made by the airline to obtain extra investment, it became clear that there would be no allocated funding from government sources. After careful consideration of the issues, the airline agreed to provide funding for a three year investment project. The project had five objectives:
(1) Demonstrate an airline market demand for aviation biofuels

(2) Facilitate daily flight trials using an aviation biofuel blend

(3) Quantify any difference in performance using the biofuel

(4) Work with industry partners to encourage an increase in production of aviation biofuel

(5) Engage with the UK government and EU institutions regarding the development of a policy framework to support the development of the fuels

The airline also acknowledged that the trial would be a beneficial public display of the company’s effort to manage carbon emissions. Indeed, the airline was active in carbon management in various other projects related to the company. The airline representative stated:

“We looked at all the issues and thought biofuel meets all our sustainability criteria.”

At this point, the airframe manufacturer became involved as an advisor. The airframe manufacturer offered advice on matters surrounding the certification of the fuel, operational aspects and potential issues concerning the Rolls-Royce RB211 powered B757-200 aircraft. The airframe manufacturer had already facilitated a number of aviation biofuel trials in other countries and had developed experience with the fuels. There was no funding allocated by the airframe manufacturer to aid in the trial. No modifications were made to the aircraft or its engines.

After the funding had been confirmed, the aviation biofuel specialist began sourcing a sustainable aviation biofuel for the trial. ASTM certification was not yet granted but it was expected that the fuel would be certified before the trial was ready. The sourcing stage involved many difficulties. These included obtaining a producer, issues surrounding the traceability of the fuel and challenges with mixing the fuel. These challenges are discussed in the next section.

Sourcing and mixing the fuel

The biofuel specialist began sourcing a suitable biofuel in May 2010. Due to a lack of European producers, the fuel needed to be sourced from overseas. A 100% blend of Hydroprocessed Esters and Fatty Acids (HEFA) was purchased from a U.S. biofuel producer. The feedstock used was waste cooking oil. The conversion was carried out using a process of filtration and specialist hydrotreating.

It was an active decision to choose a producer which converted waste cooking oils; this was because waste oils were assessed as being one of most sustainable feedstock sources available at the time. According to biofuel specialist and the airline it was of paramount importance that the highest level
of sustainability would be adhered to throughout the trial. Additional advice was provided by the Roundtable on Sustainable Biofuels and members of the Sustainable Aviation Fuels User Group.

When the HEFA fuel had been produced, it was shipped immediately to biofuel producers mixing facilities in Holland. Shipping the fuel created several logistical challenges. The first involved maintaining a chain of custody for the fuel to ensure that it did not contain contaminants such as water or fungi. Although this was a standard procedure in the transportation of aviation fuels, the HEFA fuel was not technically an aviation fuel yet because it still needed to be mixed with 50% jet-A. This issue was overcome by carrying out rigorous testing of the HEFA fuel at every stage of transportation. The aviation biofuel specialist stated that:

“The traceability of the fuel was enormously checked at every stage, and for the right reasons! We were very confident in this area but it was a challenge.”

Although traceability issues were resolved, another logistical challenge manifested itself at Dutch customs. The representative from the biofuel specialist reported that customs had experienced difficulty recognising the fuel as either a ‘jet fuel’ or a ‘biofuel’ because there was confusion about the fuels origins and end use. The company worked with the authorities to inform them about the nature of the fuels and assist them in making amendments to the way imported HEFA fuel would be classified.

When the fuel reached aviation biofuel specialists mixing facilities, it underwent further testing to ensure it was free from contaminants. The next stage was to mix the 100% HEFA fuel with Jet-A. This process caused a number of technical issues which the representative chose not to discuss, the issues were however apparently resolved quickly. The resultant mixture was a 50% HEFA and 50% Jet-A blend which then securely stored at the facility.

Although the fuel was now ready to be transported to and used in an aircraft, there were still a number of challenges to overcome. These challenges related to the airport administration stage. The main challenges centred around providing a separated fuelling system for the biofuel and gaining CAA approval to use the fuel at the airport. These will be discussed now.

Administration and trial flight

In June 2011 the airline approached one of the UKs largest airports based in the West Midlands about facilitating the biofuel trial. It was required that the aviation biofuel mixture needed to remain separate from all other sources of jet fuel under DEF-STAN ruling. DEF-STAN is the UK equivalent to ASTM certification. However, under the DEF-STAN ruling aviation biofuel is not currently able to
enter the UK pipe line system, despite being certified for use in aircraft. The airport assessed these requirements and was satisfied that it could facilitate the trial by using a small in-house fuel operator which could easily separate the fuelling systems by using a dedicated fuel bowser. The original plan was to carry out the trial in July 2011 however; the trial was pushed back until October due to unforeseen issues with the Civil Aviation Authority (CAA). The CAA was still uncertain about the compatibility of the ASTM certification within existing DEF-STAN fuel standards. The authority therefore wanted to verify the fuels production themselves (Flight Global, 2011). However, because the biofuel had not been shipped from Holland yet, the test could not be carried out immediately. This led to delays and the flight had to be pushed back until October. After the biofuel reached the UK, the fuel was certified for use. The aviation biofuel specialist, airline and airport then worked with CAA to make amendments to the ASTM certification. After these issues were resolved the fuel was sent through a dedicated pumping and filtration system and fed into a 36,000 litre fuelling bowser based at the airport.

The airline then arranged a flight date – the 6th of October 2011. The airline personally contacted every passenger that had bought a ticket informing them that they would be traveling on the first commercial UK aviation biofuel flight. The airline ensured that they had a positive response from every passenger before giving the final go ahead for the trial. The representative stated that the flight would not have taken place or at least shifted to another flight if any passenger had issues with the concept. According to the airline however there were no issues reported by any passengers. On the day of departure, the passengers were greeted with a champagne reception and several press reporters and journalists joined the reception to witness the flight’s departure. The Boeing 757-200 was fuelled so that one wing and engine was supplied with a 50% blend of HEFA fuel. The only fuelling issue concerned reported changes in fuel flow characteristics, although these were within predetermined and tolerated levels.

Before take-off, three naked environmentalists from the Plane Stupid anti-aviation expansion campaign group protested at the airport with banners of ‘green wash’ and ‘a bare faced cheek’. The protestors argued that the scale up of aviation biofuels would lead to the destruction of rainforests (Airport Watch, 2012). The naked protesters were however quickly arrested and taken off the premises. The activists were later charged with contravening an airport by law and pleaded guilty; they were each fined £150 (Birmingham Post, 2011). The first flight took off and completed its journey without any technical problems.
Outcomes

All parties involved stated that the trial was a success. The main positive outcomes included: gaining detailed knowledge about supply chain issues, certification issues, customs and excise issues, airport infrastructure requirements and ASTM, CAA and DEF-STAN certification requirements. The number of actual flights which took place using the fuel was not divulged by the airline, though the airline had plans to carry out daily flights for six weeks in early 2012. The engine data did not show any performance issues and the data was shared with the engine manufacturer.

The trial was well documented internationally via industry journals and newspapers articles including Flight Global (2011), Airport Watch (2012), Friends of the Earth (2011) and BBC (2011). Environmental groups such as Friends of the Earth reacted to the trial negatively. The group made a statement on their website saying the trial was a: ‘hollow PR stunt that would pave the way for deforestation’ (Friends of the Earth, 2011). The group criticised the trial as being a catalyst for the use of first generation biofuels that have been linked to food price issues and rainforest destruction in the past. However, the airline dismissed the allegation that the trial was merely a PR stunt and reiterated that sustainability was taken extremely carefully. Both the airline and aviation biofuel specialist acknowledged that the trials were being used to support the development of ‘sustainable’ feedstocks and aviation fuels for the future. The aviation biofuel specialist acknowledged their disappointment at the response of UK environmental groups, describing the UK as:

“the toughest climate in terms of NGOs. It was very frustrating, because we are really trying to have the highest sustainability criteria and people are saying it’s wrong.”

Although the stakeholders thought the trial was an overall a success. Several recommendations were made with regard to future trials and the development of the aviation biofuel industry. The next section will discuss these recommendations.

Recommendations

The stakeholders that were involved stated that they learned a lot about aviation biofuels over the course of the trial. Some stakeholders made recommendations about the way future trials should take place within the UK.

The airline called for greater collaboration with the UK government and legislators. This may help other airlines with their ability to do their own trials; further increasing the visibility of the fuels and perhaps increasing investment. Ideas for funding included using Air Passenger Duty revenues for biofuel trials or perhaps taking EU ETS revenues and distributing them for biofuel trials. The other
recommendation was to address the policy incentives given to road based biofuels. As mentioned throughout this thesis, this issue increases the price of aviation biofuel drastically. The view was shared by the other stakeholders involved. The airline and aviation biofuel specialist called for a global framework for biofuels such as a crediting system, though the issue was not discussed in much detail. Other recommendations were to stop any action of creating a mandate because this, although being hugely beneficial for the UK, would distort the market and create unfair advantages to others regions. The aviation biofuel specialist added that to overcome these issues you need “leadership and advice from government”.

The airport involved in the trial made recommendations about allowing the fuel to be mixed with their existing fuel lines and storage tanks. This would greatly lower the airport side challenges according to the airport. The airport also made recommendations about the involvement of the CAA. It was acknowledged that he CAA are not fuel experts since they deal with many aviation issues, but it was expressed that knowledge and work within this area should be increased. However, the CAA is beginning to make airports have greater oversight of their fuelling operations; which was previously managed by the oil companies. This was seen as a positive step by the airport.

The next section offers a discussion of the findings with the respect to the theoretical underpinning of strategic niche management (SNM).

Summary

The first UK commercial aviation biofuel trial was considered a success by all parties in that the commercial aviation flight took place with revenue passengers on board without any significant issues. The pre-operational and logistical stages of the trial were however inherently challenging; mostly due to the fact that the stakeholders involved were embarking on a first of a kind procedure. Most of the issues surrounded certification of the fuels use from all parties involved. All stakeholders acknowledged that they learned a huge deal of information about aviation biofuels over the course of the trial and that future trials were being organised. Although issues were raised by environmentalists, the stakeholders supported the trial and maintained that it was sustainable. The trial generated a significant amount of press and attention for aviation biofuels and is thought to have positively influenced the development of aviation biofuels.
Chapter 8

Discussion of findings

8.1. Introduction

This chapter will draw together the findings from the four stages of data collection by comparing and contrasting the principal issues with the extant literature and Strategic Niche Management (SNM) theory. The discussion will be used to formulate recommendations to support the development of aviation biofuels within the SNM phase of development. It will discuss the fact that more support may be needed after the SNM development stages i.e. the pervasive diffusion phase (Chapter 2). Given that the aim of this thesis is to investigate the factors affecting the emergence, development and uptake of aviation biofuels with the intention to make recommendations about its development, this chapter will be organised into two sections. The first section will discuss the contemporary driving and constraining issues influencing the emergence, development and uptake of aviation biofuels; including a contextualisation of aviation biofuel within SNM theory and the framework proposed at the end of chapter 4. The second will critically examine the future perspectives and recommendations offered by the aviation biofuel stakeholders surrounding the uptake and future development of aviation biofuels. This section will identify parallels between SNM theory and the extant literature as well as the suggestions offered by stakeholders in order to establish areas for further research and to make recommendations about the future of aviation biofuels.

The first section will discuss the contemporary issues facing aviation biofuel development and uptake based on the combined data from this thesis. The findings from the four stages of data will be compared and contrasted with the existing biofuel literature as well as that of the SNM theory.

8.2. Contemporary issues

The combined data reveals current stakeholder perceptions regarding the contemporary driving and constraining factors associated with the emergence, development and uptake of aviation biofuels. The central findings from the data show that there are a complex set of interrelated issues influencing the development, testing and uptake of aviation biofuels. Although the core drivers of aviation biofuel are focused around the ‘need’ to reduce emissions and avoid rising oil prices, there are different types of drivers at work. System-level drivers such as rising global oil prices and increasing environmental legislation acts on the entire aviation industry; while sub-system drivers
such as economic profit; company targets and new business opportunities, drive individual companies to pursue aviation biofuels. The data revealed that the system level drivers are certainly the strongest drivers while the sub-system level drivers have created a sense of urgency within the industry. In other words, it appears that the sub-system level drivers may be acting to increase awareness in aviation biofuels for the whole industry, while system-level drivers are creating the stronger and more long-term demand for the fuels. In the literature the sub-system drivers are not adequately appreciated. This may have implications in terms of developing supportive strategies for aviation biofuels. This thesis also revealed other complexities arise from the policy environment for aviation. The international nature of aviation creates uncertainty surrounding policy changes, particularly surrounding the use of carbon pricing like the EU ETS. This uncertainty is a strong incentive for the aviation industry to take precautionary action in terms of setting up emission reduction technologies. The findings from this thesis do however confirm that the overarching driver of aviation biofuels is rooted in the fact that the aviation industry has very few technological options to reduce emissions and to avoid high oil prices. The next section will discuss the contemporary drivers.

8.2.1. Contemporary drivers

As mentioned, the data reveals that there are a complex set of driving factors influencing the development and uptake of aviation biofuel. Although the findings of the stages of data generally concur with one another, there are some minor contradictions in terms of the views of certain stakeholders. These differences are mainly the result of varying market conditions and geopolitical factors. The main driving issues associated with aviation biofuels are: rising oil prices, a need to reduce emissions because of existing or expected environmental policy, business opportunities for airlines and biofuels companies, and to a lesser extent; concerns regarding oil supply and a lack of viable low-carbon alternatives to jet air travel. These issues concur with the major aviation biofuels studies including the CCC report (2009), the Omega study (2009) and the most recent report – SWAFEA (2011). However; although the main findings concur with these studies, there are nuances in the data which highlight several interesting inconsistencies in the other extant literature. The data from this thesis revealed that the U.S. stakeholders are predominantly concerned with fuel security and oil price because the need to reduce emissions is much less important. This is despite the fact that all of the U.S. respondents are fully aware of the negative effects of aircraft emissions and the potential future implications of environmental policy. Only the EU ETS was mentioned as a significant environmental driver of aviation biofuels. Conversely, in U.S. papers including Daggett et al., (2008) and Hendriks et al., (2009), the U.S. is portrayed as having a strong environmental drive
for pursing aviation biofuels. Similarly, the U.S. orientated biofuel initiative CAFFI cites emissions reductions and environmental degradation as key drivers for the development of aviation biofuels. There are only a few studies which analyse how environmental policy will affect the development and uptake of aviation biofuel within the U.S. Daggett et al., (2006); Marsh (2008) and Bomani et al., (2009) focus on fuel security and oil prices as major drivers for aviation biofuel uptake mainly due to the fact that the political framework in the U.S. is ordinated toward energy security. Instead, the U.S. stakeholders from this study, including a U.S. legislator, emphasised that the environmental driver for aviation biofuels is fundamentally a long-term driver. The main discussions surrounded the threat of future environmental policies within the U.S.A and/or international aviation policies affecting U.S flights in coming years. These findings, in conjunction with the sparse policy literature in the aviation biofuel field, are strong indicators of a general lack of understanding regarding the present day and future policy environment within the U.S. It is clear that U.S. stakeholders are very knowledgeable of the issues of environmental sustainability, biofuel technology and development; however the current policy environment is distinctly uncertain.

In contrast to the U.S, stakeholders from Europe and elsewhere emphasised that a bigger driver of the fuels comes from the environmental benefits of aviation biofuels. Almost all of the EU respondents stated that the environmental benefits may be greater than the economic benefits of the fuel, especially considering that the price of aviation biofuel is likely to remain uncompetitive for at least a decade. These respondents also acknowledge that the EU ETS and other environmental policy measures within the EU, with the exception of the Netherlands, are not sufficient to incentivise development and uptake of the biofuels. Non U.S Stakeholders and those from outside of the EU also emphasised that the environmental benefits of the fuel were greater than the supply security benefits or economic benefits, but the EU respondents clearly stated that a vitally important driver is reducing emissions. Interestingly, both the EU and U.S. respondents stated that the EU ETS is inadequate as a driver for aviation biofuels. This fact is mentioned in most EU ordinated studies such as the CCC (2009) and SWAFEA (2011) however non-EU studies such as Dagget et al., (2008) do not cite this fact. It appears then that the EU ETS works merely to raise awareness about reducing emissions within the commercial aviation industry. The long-term sentiments towards the EU ETS are very different. The EU ETS will act as a driver for the fuels in the long-term when relative prices of carbon, standard jet fuel and aviation biofuel reach a break-even point. Stakeholders were reluctant to estimate a date for this however. These findings suggest that the aviation industry is generally quite uncertain about the policy environment.
The findings from this study are in contrast to some academic reports such as the Omega Report (2009) and CCC report (2009). The Omega Report showed that the effect of the EU ETS on the uptake of aviation biofuel would be apparent from 2015. Almost all of the stakeholders from this study were highly sceptical of sufficient rises in carbon prices even after that date however; they did suggest that the price of aviation biofuel may reduce faster than the estimates in the literature. Stakeholders were furthermore reluctant to estimate price rises in the carbon markets and could not predict a break even date for the price of aviation biofuel and carbon. This finding concurs with the CCC Report which used a larger degree of variance in their modelling of carbon prices and biofuel uptake. The study showed that the uptake of aviation biofuel could arrive as late as 2025. The findings from this thesis indicated that despite significant developments in the aviation biofuel field, the general understanding surrounding costs and projections for supply growth are vague.

Thus far this chapter has discussed aviation biofuel in terms of how system-level factors are impacting on the development of the technology. It has been shown that there are several issues which can be described as being drivers of aviation biofuels including oil price, environmental policy and fuel security. However, as yet there has been little discussion surrounding how these drivers influence the development of a niche market based on principles from the SNM literature. A key objective of this thesis was to make recommendations for strategies that will support the continued emergence, development and uptake of aviation biofuel based on principles from SNM. It was therefore essential to obtain data that could establish whether aviation biofuels had developed into a niche market and whether the technology was suitable to be supported using strategic niche management concepts. The subsequent sections will therefore begin to describe the role of different drivers within the technical regime on the development of a niche market.

8.2.2. The development of a niche market

Evidence obtained from the four stages of data collection suggests that the aviation biofuel technologies may indeed be developing into a technological niche; and therefore strategies within the SNM literature may be suitable in order to make recommendations about its development through to a market niche and mass market. The interviews revealed that there are no single driving factors which could be described as being the main driving force behind the recent developments into aviation biofuels. The various driving factors instead work together to encourage stakeholder interest in aviation biofuels. Furthermore, different regions have unique drivers due to geopolitical differences. This suggests that a localised solution, such as strategic management of niches, is required.
In relation to the SNM literature, the drivers that have been identified can be interpreted as resulting in large scale destabilisation of the technical regime for commercial aviation (Raven, 2005; Weber et al., 2009). It is possible to interpret the driving issues such as oil price rises, carbon pricing, fuel supply concerns, corporate social responsibility issues and lack of alternative technologies as being destabilising issues for commercial aviation. These destabilising issues are shifting commercial aviation’s demand for standard jet fuel towards a technology which may be cheaper and more environmentally friendly, though still compatible with conventional fuels. The aviation industry is actively pursuing aviation biofuels as a means of avoiding these issues by carrying out testing programs and funding demonstration plants and networking with other stakeholders in the field. These actions are clear signals that the industry is attempting to develop a niche market for the fuels, or indeed develop a commercially viable mass market for the fuels. However, as well as these factors, there are other features obtained from ‘contemporary driving issues’ which suggest that there are preconditions necessary to develop a niche. For instance, certain stakeholders are taking a leading role in encouraging the development of aviation biofuels. The particular actions of these companies within the aviation industry can be interpreted as being the first evolutionary steps towards the development of a technological niche for aviation biofuels. These companies can be referred to as change agents according to the SNM literature (Weber et al., (2009).

The second important factor is that the technology in question is compatible with technology within the existing regime. Although this is an area which is contestable, aviation biofuels are technically viable (not economically at the present time) and have been granted full ASTM certification for blends up to 50% on commercial flights. According to Weber et al., (2009) this is a key pre-condition of a technology developing into a niche. However; there are issues which were highlighted in this thesis which suggest that the fuels are not fully compatible with the existing regime. The main issue surrounds pipeline certification. At present, certification for blending aviation biofuel in pipeline infrastructure is not present. This means that the fuels must be transported by truck and mixed at the airport. Although these issues where not expressed by all respondents, they do affect the compatibility of the fuels with the existing regime. Nonetheless, despite the pipeline certification issue, the aviation biofuel technology is relatively well matched with the technical regime.

Other factors required for successful niche development include ‘incremental development’ factors (Weber et al., 2009; Raven, 2006). These are related to whether the technology in question can benefit from incremental increases in efficiency and cost reductions, as well as spin-off technologies. Evidence from the data and the literature review suggest that the aviation biofuel technologies are indeed developing incrementally and that, given the incremental improvements in conventional
biofuel technologies, will benefit from early support in the form of financial incentives. The price reduction models of the existing biofuels industry have shown clear incremental increases in efficiency and cost savings through learning by doing and economies of scale.

Another factor is the ‘condition’ of the research environment surrounding aviation biofuels i.e. how many research projects are currently on-going in the field, how many are planned for the future. Mourik and Raven (2008) acknowledge that a healthy research and design environment is a prerequisite for niche development. The research environment should be looking into several possible streams and variations of the same technology. There is strong evidence to suggest that the research environment surrounding aviation biofuels is developing quickly. There are several companies globally that are researching variants of the same technology as well as numerous spin-off innovations that can be developed from existing viable technologies such as bio-plastics, substitute fuels, food proteins and electricity production. Raven (2005) suggests that a successful niche will form when such parallel ‘product definitions’ (i.e. subtly different technologies) exist. Aviation biofuel technologies appear to be developing in an almost parallel fashion. Similarities can be made between concepts within TRLs here. Gove et al., (2007) proposed that TRLs be combined with the newly developed integration readiness level measurement (IRL). This provided a metric to determine the ability for a technology to integrate into a system of complementary technologies. The three main technologies are HEFA fuel, gasification and lingo-cellulosic and alcohol-to-jet fuels, although they are not strictly complimentary technologies within the context of TRLs, the principal advantage of having parallel development is to allow for back up options i.e. if one technology fails, there is a second one to fall back on. Raven (2005) calls this a ‘back-up strategy’. The more variations there are of a certain technology, the better chance the niche market will develop.

There are also a number of long established research institutes that are involved in aviation biofuel development. The stakeholders interviewed for this thesis expressed their opinion that there is a very good level of communication and data sharing within the aviation biofuel research field. The data from the case study of an aviation biofuel flight trial showed that re-evaluation of the developments in the field, including sharing of data between test flights, is occurring regularly. All the respondents however stated that more and better communication is needed. In strategic niche management theory, these findings suggest that the technical developments within the aviation biofuels field are being well evaluated and communicated; which Caniëls and Romijn (2006) state are beneficial factors for the development of a niche.

Additional factors that are conducive of forming a technical niche are present including anecdotal evidence suggesting considerable cost reductions and incremental production yield improvements
are occurring. Evidence relating to these incremental improvements was acknowledged in the interviews of almost all of the stakeholders; which suggest that the aviation biofuels technologies are experiencing learning economies through learning by doing, the development of demonstration plants and communication of the developments. This is another pre-condition for the development a niche market according to Caniëls and Romijn (2006).

Astley (1985) showed that a technological niche can only develop when the ‘selection criteria’ (i.e. the demand for certain products and services) changes significantly enough for a new product to ‘break through’. Astley (1985) specifically discusses the need for the selection criteria to become ‘less severe’ i.e. the market must be willing to tolerate a less profitable innovation. The development of testing programs such as those used by Lufthansa and Thomson Airways are potential examples of an increased willingness to pursue unprofitable fuels. Contradictory evidence from the scoping study interviews and the third stage interviews does however suggest that for long term commercial operations, aviation biofuels will not be adopted unless they are at an equal price to that of standard jet fuel. Only one airline was quoted as saying that they would be prepared to pay a premium.

Another key issue which influenced the development of a niche is the availability of sheltered spaces for the nurturing of the technology. These sheltered spaces might be demonstration plants, or testing environments in which the technology can be developed away from a competitive market. Evidence from this thesis and the literature review indicates that there is a relative abundance of nurtured testing spaces for aviation biofuels. There have been some 25 separate testing programmes for aviation biofuels spanning almost every continent and a growing number for commercial flight tests (enviro.area.com, 2012). The evidence presented thus far suggests that the development of niche markets for aviation biofuels may already be well underway. The only issues are the ability for test projects and programme to communicate the developments and share information, as well as a lack of government funding and policy provision. The use of SAFUG and CAFFI, which have a goal of communication and organisation of the testing projects, suggests that this will improve, certainly within the U.S and Europe. Within Brazil and Australia there are similar programs being established however, the evidence from this thesis suggests communication is not as streamlined as CAFFI and SAFUG.

Another interesting factor is the influence of policy. Policy is shown to be a key feature in developing a niche market because it can destabilise the technical regime creating changes in demand for innovations as well as creating nurtured spaces for a technology to mature. However, given that the commercial aviation industry is a global industry which is governed by global regulatory policies, the policy effect is likely to be localised. This will of course impact on the development of niche markets.
The evidence from the interviews suggests that the U.S. policy frameworks for aviation biofuels is much more attractive and has received higher levels of funding from the FAA and government and military; suggesting that the development of niche markets in those regions is more likely. A similar situation is present in the Netherlands; which is actively supporting aviation biofuel development using extra subsidises and policy measures. Niche markets for aviation biofuel may well develop in these two regions first. However, British Airways, which currently has comparatively less policy support in the form of subsidies, renewable energy credits and government grants, is still developing an aviation biofuel plant. The interview data reveals that this is based on the expectation that policies will become more favourable for aviation biofuels in the future. British Airways and other airlines are lobbying towards greater support for aviation biofuel.

An additional stakeholder factor expressed in the SNM literature is the ability for policy makers and niche managers to be neutral towards the technology options i.e. there should not be considerable bias towards one technology. Indeed, Mourik and Raven (2008) state that it is not the task of policy makers to choose the best technology, this should be achieved through market forces. Four stakeholders from this study stated that the industry should avoid picking winners during the developmental stages of the technology. The literature generally concurs with this view. For instance, the CCC (2009) report states that incentives should be developed which do not bias a particular technology. To do so would be unfair and potentially unsustainable.

Finally, according to Caniëls and Romijn (2006), to achieve a successful niche market the technology in question must have a tangible advantage in relation to the incumbent technology. Indeed, aviation biofuel has several advantages over standard jet fuel. These are expressed in the literature and were the focus of several stakeholder discussions surrounding drivers. The advantages of the technology are centred on mitigating rising oil prices and environmental regulation of aviation. Aviation biofuel is also renewable and thus is appealing to countries that are net importers of oil. However, Caniëls and Romijn (2006) make it clear in their study that the niche market will only form if the advantages of the technology far outweigh the disadvantages. The disadvantages of aviation biofuel have not yet been discussed in this chapter. However, before discussing the constraints of aviation biofuel, the perspectives of the aviation biofuel stakeholders should be discussed in terms of the strategic niche management literature. The findings from this thesis suggest that certain aviation biofuel stakeholders may be considered as change agents for the technology and therefore will be more influential in the development of a technical niche.
8.2.3. Stakeholders

There is evidence that the technical regime for commercial aviation has become destabilised by fuels price, fuel security and environmental regulation, and that a technical niche may be forming for aviation biofuels. The findings also suggest that due to the destabilisation of the technical regime; two types of aviation biofuel stakeholder have emerged: those that are aware of the changing market conditions that are affecting the aviation industry but are unwilling to pro-actively pursue biofuels and those who are taking pro-active steps to tackle those issues. The majority of aviation biofuel stakeholders are aware of the changing market conditions such as rising oil prices and environmental policy; however these stakeholders are making no clear actions to respond to these changes. These aviation biofuel stakeholders are relatively cautious and are waiting for the fuels to be developed by other companies. They may well eventually purchase the fuel when the price is competitive but they have no direct involvement in its current development.

On the other hand, there are a number of aviation biofuel stakeholders that are extremely pro-active. Indeed, these stakeholders are what could be described as being extra aware of the benefits of aviation biofuels with respect to the changing market conditions and thus more willing to take financial risks on the part of the various technologies development. Furthermore, these stakeholders are actively encouraging the uptake of the fuel by supporting the development and testing of the fuels; as well as the formation of initiatives and government lobbying. These stakeholders are called change agents within the SNM and diffusion literature. According to Kempt et al., (1998) change agents are very important for the development of an innovation and a technical niche. Change agents provide early support for the technology to push the innovation through the most difficult stages between research and development and niche market. Change agents are also important for the development of demonstration projects; which will be discussed in more detail in the future perspectives section later in this chapter. The rest of the aviation industry was not accounted for in this study however, based on the literature search and stakeholder identification process, the majority of the commercial aviation industry is not directly involved in the development of the fuels.

The data from this thesis also revealed that the airlines which have shown the most interest in the fuels are large and established international carriers. There are few examples of low cost carriers or smaller domestic carriers investing in aviation biofuel testing or development. In terms of strategic niche management, it is apparent then that there are certain sections of the aviation industry which are unaware and or resistant to aviation biofuels. This is probably a reflection of the technical regime. The technical regime for aviation, as mentioned, has been resistant to radical changes in
technology. It would stand to reason then that the majority of the other stakeholders in the commercial aviation industry are not considering the fuels yet.

The extant literature makes little mention of the potential differences between stakeholders in the aviation biofuel field, or of the importance of particular stakeholders which are leading the way in aviation biofuel development. However, studies such as Marsh (2008) and Omega (2009) and CCC (2009) acknowledge clear differences in investment and resources that have been put into the technology thus far. Five large companies have invested heavily in the testing and certification of aviation biofuels for a number of years. Furthermore, they have made much of the preliminary work in forming the alliances between airlines and biofuel producers in a bid to create testing programmes. These are clear signs that the technology was aided by the action of these change agents.

Thus far the drivers have been discussed in terms of strategic niche management theory; showing that several preconditions for the development of a niche market are present. In fact, there is evidence that niche formation is already occurring; such as in the various demonstration projects which are taking place in several locations around the world. However, although there are several drivers of the fuels, there are also barriers for the development and uptake of the fuels according to the strategic niche management concept. The next section will discuss the contemporary constraints associated with aviation biofuel; discussing how these issues are affected by the technical regime.

8.3. Contemporary constraints

The findings from the four stages can be triangulated very easily. The main constraints are: high costs, lack of feedstock supply and insufficient policy measures, as well as an overall lack of investment. Other constraints which were highlighted by a minority of stakeholders included infrastructure compatibility issues, fuel consistency concerns and overly strict environmental hurdles for emerging biofuel technologies. Although the extant literature mentioned the constraints of aviation biofuel, few go into detail regarding the impact on the stakeholders. Furthermore, very few academic papers acknowledge the constraints of infrastructure compatibility, fuel consistency and overly strict environmental policy. In the literature, more emphasis is placed on high costs of aviation biofuel in relation to the cost of oil. There are several studies that attempt to establish why the fuel is more expensive however most focus on higher feedstock prices and higher conversion costs. They fail to emphasise the importance of competitive policy support for aviation biofuels in comparison to road based biofuels as well as the learning effect and economies of scale which will
influence the price of the product. Issues surrounding environmental policy were a frequently recurring problem acknowledged by the respondents in this study. Road based biofuels have a significant policy advantage in comparison to aviation biofuels. Most respondents mentioned the EU region, with the exception of the Netherlands, will need to address these concerns if it is to see any significant aviation biofuel production. The perceived bias towards road based biofuels is a serious issue according to the stakeholders; indeed it was described as being a significant barrier to investment and thus perhaps a larger influence on the cost of the final fuel than portrayed in the literature.

In terms of strategic niche management, there are several insights that can be discussed. As mentioned previously, aviation biofuels can be considered a radical technology in relation to the dominant technical regime in the commercial aviation industry. This means that the technology will most likely face barriers to its diffusion. Indeed, evidence from the literature and this thesis reveal that aviation biofuels do not currently fit into the existing regime. In fact, almost all of the constraints acknowledged by the stakeholders can be related back to the technical regime and SNM theory. The following sections will discuss the various constraints in terms of SNM.

Following Kemp et al., (1998), the first factors that can be discussed are technological factors. Most technical issues, such as production capability and compatibility with commercial jet engines, are almost completely resolved however; the findings from this thesis suggest that there are still some technical issues which need to be determined. In terms of SNM theory, this leads to what is known as technical instability. This is created by a number of issues. The first issue which creates instability is the 50% blend limit; there are uncertain infrastructural issues associated with mass blending and storage of aviation biofuels. Although new technologies are being developed to allow for 100% aviation biofuel blends, stakeholders are uncertain about the outcome of these developments. The second issue is due to the fact that there are several possible production routes available for aviation biofuel thus there are no clear indications of which technologies will prevail. Although this is also a positive factor for niche development, it can also create uncertainty within the technical regime.

The second expected barrier for radical technologies identified from the data which can be related to the SNM theory is government policy. SNM theory reveals that new technologies do not tend to have an adequate policy framework available to support their development. This may be due to a lack of awareness or uncertainty surrounding the benefits of the technology. With the case of commercial aviation and aviation biofuel, the policy frameworks and government support are not properly aligned and have not been assessed properly to benefit the industry. This was expressed by
most of the stakeholders from the four stages of data. The issue of policy is a complex and interesting topic. For instance, the EU region is perceived as having the strictest environmental targets for aviation. However, developments in the field of aviation biofuels have not always necessarily reacted to these policies. This is because there are actually fewer incentives specifically to produce aviation biofuel within the E.U. The U.S., Netherlands and Brazil on the other hand have aligned their biofuel policy to include aviation biofuels. This means biofuel producers can begin planning to enter the market. According to the data from this thesis, the U.S. has become aligned in terms of environmental policy directed towards aviation biofuel. The U.S. has aligned its existing road biofuel policies with those of aviation biofuel. The Netherlands have also aligned their policy support, in an effort to create a niche market. In fact, one stakeholder made a reference to nurturing the technology within the Netherlands in a bid to create a niche market within Europe. For these reasons, the U.S. and the Netherlands may well develop a niche market for aviation biofuels before other regions. As mentioned throughout this chapter, the use of government policy is an area which is not addressed properly in the aviation biofuel literature.

The policy issue is also more complex than simply directing policy support towards aviation biofuel. Aviation biofuels stakeholders indicated that if the environmental controls on new biofuel technologies are too severe i.e. if governments block biofuels that are assessed as being less environmentally friendly today but may reap benefits in the future, biofuels producers will move away from the industry and back into road based biofuels. These complexities create uncertainty amongst the aviation biofuel stakeholders. Indeed, stakeholders expressed this uncertainty regarding the path of contemporary and future environmental policy measures globally.

Another key constraint associated with aviation biofuel is the effect of societal factors. Mourik and Raven (2006) state that societal and psychological factors can affect an innovation’s ability to diffuse into a technical regime. With respect to aviation biofuels, numerous stakeholders acknowledged that they have come across NGO’s and environmental groups which are against the use of aviation biofuels. The NGO concern for aviation biofuel regards the potential impact on global food supply and price, as well as uncertainty surrounding the environmental benefits of the fuel. In the case study undertaken in this thesis; the biofuel specialist stated that NGO interference was a significant issue during the trial. The stakeholder acknowledged that the UK is the most challenging market in terms of NGO interference and prevention of aviation biofuel. However, there was no evidence that the airline customers were against the use of aviation biofuels considering that the airline stated that they had no complaints about using the fuel. Nonetheless, these NGO issues are evidence of social and cultural barriers to the development of aviation biofuels. These barriers have been shown
to be significant constraints to the introduction of certain innovations in the SNM literature, as well as the wider diffusion literature. Furthermore, given the high visibility of aviation, societal factors may be particularly important for the industry to resolve.

The fourth factor which relates to SNM theory is a demand factor i.e. innovation does not fit with the existing demands of the regime. This is however an interesting factor because the aviation industry is shown to have a strong demand for the fuel, though the price of the fuels in order of magnitude more expensive than the standard jet fuel. This has created a significant demand constraint for the fuel. Furthermore, certain stakeholders in this study clearly stated that there will be no demand for a fuel which is more expensive than standard jet fuel. However, as mentioned throughout this thesis, the cost factor is a complex issue. Several of the other constraints such as policy support and supply and production capability of the plants will impact upon cost. Linked to the issue of demand, is the issue of investment. In the SNM literature it is shown that the existing regime will be resistant to investing in the new technology if it is a direct substitute to its main business. New innovations may compete with the firms existing products thus companies will divert investment away from such technologies. Drawing upon evidence from the interview data and the case study material, it appears that these issues may have already been happening. Only one petrochemical company clearly stated that aviation biofuel was a strategic area of development. In fact, one petrochemical company clearly stated that they were not prepared to divert resources to the industry. Two oil majors did however express their interest in the fuels though they were reluctant to mention their involvement. It is reasonable to assume that petrochemical companies are more involved than they stated in the interviews and are waiting for economies of scale to make the fuel more competitive.

The final constraining factor relates to infrastructure and maintenance. SNM shows that a lack of support infrastructure and issues related to new maintenance schedules within the existing regime will impact on the ability for new innovations to be adopted. Aviation biofuels are described as being drop-in alternatives to existing jet fuel however, as mentioned there is a 50% blend limit with standard fuel which may impact on storage and transportation of the fuel. The stakeholders did not believe that this issue was significant, with the exception of one; however it may have played a significant role in the early stages of the technologies development. The issues of maintenance were mentioned by several stakeholders but evidence from the Lufthansa trial indicates negligible difference in the maintenance of the engine (Lufthansa, 2012). Testing is however on-going.

Thus far this chapter has examined the contemporary issues facing aviation biofuel. It has been seen that there are a number of issues facing aviation biofuels which can be related specifically to
strategic niche management theory. These issues also suggest that the technology may indeed be developing into a niche market and therefore would be a suitable technology to aid. However, additional data in the form of stakeholder recommendations will be beneficial to discuss aviation biofuel in relation to the strategic niche management concept. The next section will therefore discuss the future perspectives surrounding aviation biofuel.

8.4. Future direction and recommendations from stakeholders

Stakeholders were asked to make recommendations about the future of aviation biofuel. In most cases, when stakeholders made recommendations they alluded to the development process between a niche type market and a mass market. The stakeholders suggested that there needed to be changes to the current provision of government policy, investment and stakeholder networking in order to build the technology into a competitive industry. These provisions, in their opinion, would benefit the technology by protecting it in its early stages in order to reap the benefits of economies of scale. Although the stakeholders did not mention strategic niche management, the recommendations which were made were strikingly similar to principles of SNM theory.

The primary recommendations that stakeholders made related to the provision of extra policy support and/or specific policy frameworks directed toward aviation biofuel. These included: increasing public funding for demonstration projects using soft loans, risk sharing schemes amongst stakeholders, better leadership from governments as well as better accountability for the fuels sustainability. The former would allow the construction of the initial biofuels plants and infrastructure which is required to initiate the supply chain. This was expressed as being very important. The latter recommendation of increasing networking and knowledge sharing was hoped to speed up the development process. Stakeholders also suggested that there needed to be geographically focused national policies and leadership schemes where aviation biofuel projects are managed and executed. Two UK based aviation biofuel stakeholders stated that the UK should take a leading role in developing the technology by adopting such policies. Stakeholders from the U.S, Brazil, the Netherlands and Ukraine stated that other nations are pursuing similar strategies. As well as being a key recommendation of the SNM literature, this also follows from the actions of the road based biofuel industry which benefited significantly from early policy incentives. They also recommended more international legislative incentives such as emissions regulations for aviation biofuel; this would provide a better trading environment for the fuels and better accountability of the fuels sustainability.
As well as a policy framework designed for aviation biofuel, the stakeholders predicted that continued testing and the development of strategic partnerships between biofuel companies, airlines and airports, will facilitate development of the technology into a mass market. They suggested that the continued use of the aviation biofuels stakeholder initiatives such as CAFFI and SAFUG were essential to the development of a competitive aviation biofuel market because they provided a single voice for the aviation industry to lobby towards government for policy changes. Clear parallels can be made between these stakeholder recommendations and the SNM literature. The following sections will discuss the main stakeholder recommendations in relation to the existing literature and the SNM theory.

Although only two stakeholders explicitly discussed the idea of developing the niche market specifically, one of the overriding messages from data was the need to address the level of government policy support for aviation biofuels. The existing literature does not report significantly on the need for greater policy support, especially within the EU, though strategic niche management theory suggests that policy measures are fundamental features of a successful niche market. The stakeholders clearly stated that equal incentives are needed for road based biofuels and aviation biofuel in order to provide a level playing field for both fuels within the EU. There were furthermore recommendations for specific policy measures to be directed towards nation states and even particular locations where biofuel is an economic venture. These ideas are strikingly similar to those within SNM literature. For instance, within SNM theory, creating local demonstration projects and protected spaces using policy incentives is a key strategy for developing a technology. Raven (2005) shows that policy makers can create niches in three ways.

The first option is to use a formal policy instrument such as mandates which are arranged via central planning. This type of policy measure was mentioned by half of the respondents. This would include national laws and regulations. The second option is to create an incentive based scheme in which economic incentives such as tax exceptions and subsides are used to make the technology temporarily economically viable. The hope is that the technology will then benefit from economies of scale, efficiency increases and cost reductions through learning by doing; this is referred to as a bottom-up market model as it attempts to guide the market into producing the technology. This type of policy was expressed by all of the stakeholders. Indeed, it appeared that the main overriding goal of the stakeholders was to allow the technology to become economically competitive with standard fuel. The stakeholders appeared to understand the importance of early nurturing of technologies. Geels and Kemp (2000) advise that policy makers should use generic measures that do not support a single technology. This also related to the recommendation of a level playing field for
road based biofuels and aviation biofuels. Currently, the policy framework for biofuel is biased towards a particular set of technologies. The final option offered by Raven (2005) is to aid in the creation of networking and initiatives to bring together stakeholders to develop projects, seminars and workshops. This strategy is identical to the action of the aviation biofuel development initiatives which are being formed. Indeed, there is a great deal of evidence that suggests that the aviation industry is actively pursuing these ideas as a means of streamlining the development of the fuels into a niche market.

There are a number of strategic alliances that have been formed in an attempt to test the fuels, encourage networking between stakeholders, provide seminars and workshops for aviation and biofuel stakeholders, and lobby towards policy measures as a single voice for the entire industry. The stakeholders in this study mentioned that the Sustainable Aviation Fuels User Group (SAFUG) and the Commercial Aviation Alternative Fuels Initiative (CAFFI), as well as the Brazilian ABRABA intuitive. These programmes were quoted as being very important for the future development of aviation biofuels; which corresponds with the SNM theory recommendations. It was also mentioned by several of the members of the initiatives that local projects and local supply chains may be suitable means of developing the industry. The SNM theory suggests that local demonstration projects can develop and merge together forming a larger niche market and eventually a mass market. The data from this thesis suggested that this may be possible. According to one of the biofuel producers, learning is occurring rapidly between the projects, though there are instances were communication is definitely not occurring; such as where commercial sensitivity does not allow it. This is an issue which is very difficult to overcome unless the projects are entirely state managed. Weber et al., (1999) state that it is beneficial to have simultaneously occurring projects which are linked together so that the projects can learn from one another. However, there was no evidence that stakeholders had looked into this strategy of merging projects.

Additional recommendations, such as the design of more accurate accountability procedures for aviation biofuel sustainability can be related to the idea of reducing technical uncertainty in the technology, as well as reducing the negative societal and psychological factors associated with the fuels. There are indeed a larger number of parallels that can be made between the stakeholder recommendations and the SNM literature.

8.5. Summary

This is the first time SNM theory has been used to discuss the aviation biofuels industry. This chapter has revealed that aviation biofuels may be interpreted as being a radical-sustainable technology that
can benefit from concepts and recommendations that have been formed in the SNM literature. The discussion has revealed that aviation biofuels do not fit within the existing technical regime and that this has created a number of barriers to the emergence, development and uptake of the technology. The chapter has also revealed that nurturing the technology using strategic niche management may therefore be valuable for the development of a sustainable aviation biofuels industry. However, the chapter also reveals that the preconditions for a niche market are already in place and that the aviation biofuel developments have, in part, been guided by a number of change agents such as Boeing and Airbus. These change agents will continue to act as important catalysts for the development and uptake of the fuels and therefore more attention should be given in helping these change agents continue their good work.

This chapter reveals several unique perspectives to discuss the development and uptake of aviation biofuel. However, it does not offer any unique recommendations with respect to supporting the development of aviation biofuels. Objective 5 of this thesis is to ‘make recommendations to support the emergence, development and uptake of aviation biofuels’. In the next chapter, conclusions and recommendations of the thesis will be offered.
Chapter 9

Conclusions and recommendations

9.1. Introduction

This chapter combines the research findings to discuss key conclusions in relation to the thesis aim, objectives and research questions. The chapter will outline how the findings have contributed to addressing the aim of the thesis and how they can be used to make recommendations about the future of biofuel within the commercial aviation industry. The first section will summarise the findings from each stage of data collection.

9.2. Summary of the findings

The aim of this thesis was to investigate the factors affecting the emergence, development and uptake of aviation biofuel. This was achieved using five objectives and a series of individual research questions.

Objective 1 – Situate the emergence, development and uptake of aviation biofuel within existing theoretical literatures on technological change.

Objective one was addressed via a comprehensive review of extant academic and practitioner literature on biofuels (Chapter 3). The literature review found that although there was a dearth of aviation biofuel studies, the emergence, development and uptake of aviation biofuel was perceived to have been influenced by a number of driving and constraining issues. The main driving issues were thought to be high oil prices, a need to reduce aircraft emissions and environmental policy. The main constraining issues were perceived as being the difficulties in producing advanced biofuels that are suitable for jet aircraft, certification, and the low availability of feedstocks, environmental sustainability concerns and high costs of production. Crucially, the literature review revealed that peer reviewed research surrounding stakeholder issues and supportive measures for the emergence, development and uptake of the fuels was limited and outdated.

Due to the limitations of the extant literature, a scoping study was undertaken to better understand the factors affecting the emergence, development and uptake of aviation biofuels.
Objective 2 - Identify the political, economic, social, technological, legal and environmental factors affecting the emergence, development and uptake of aviation biofuel.

Research question 1 - What are the key stakeholder issues associated with the emergence, development and uptake of aviation biofuels?

The scoping study expanded on the literature review to provide a better understanding of the issues affecting emergence, development and uptake. The scoping study helped to understand issues unclear in the literature such as constraints associated with policy support and funding. It also revealed unreported issues such as the inadequacy of the EU ETS as a policy driver for aviation biofuels. It was revealed that the main driving issues for emergence, development and uptake stem from a combination of environmental policy, energy security and a lack of low-carbon alternative technologies. Some of these driving factors are demand side drivers (i.e. from airlines) while others are from the supply side (i.e. biofuel producers). EU airlines were predominantly motivated by the threat of carbon pricing mechanisms such as the EU ETS while non-EU airlines may have been driven by an energy security threat. In combination with the carbon pricing and energy security issues, the aviation industry was motivated to develop aviation biofuels because it was heavily constrained by its dominate propulsion technology i.e. the jet engine. Alternative low-carbon propulsion technologies such as hydrogen and electric were consistently labelled as being unfeasible; even in the long-term. Low-carbon technologies which can use existing aircraft and engines were therefore deemed highly attractive. It is concluded that these factors combine to create a strong demand for biofuel. According to a majority of respondents, the aviation industry has a considerable growth opportunity for both start-up biofuel companies and established biofuel producers. One petrochemical major however expressed serious concerns regarding the ability to expand the already constrained road based biofuel production volume. Additional drivers identified included green public relations for airlines, though this was actually described as being a weak driver for aviation biofuels by some stakeholders.

The main constraints associated with emergence, development and uptake were: feedstock supply, high costs, lack of policy support, environmental sustainability concerns and fuel consistency. Although feedstock supply, high costs and environmental sustainability were documented in the literature, lack of policy support and fuel consistency did not feature heavily. Indeed, the lack of policy support for aviation biofuels was expressed by all the respondents as being an area of major
concern for the emergence, development and uptake of aviation biofuels. At the time of writing, the road based biofuels markets have comparatively much better support for the emergence, development and uptake of biofuels. The policy support offered to road biofuels currently includes higher subsidies, tax breaks and mandated production volumes in the EU, Brazil and U.S. These supporting mechanisms do not currently exist for the aviation biofuels. Although the EU ETS does acknowledge the use of aviation biofuel, it will not act as a major driver of the fuel until the price of carbon rises to around $100. At the time of writing the carbon price was around $7.5 (Economist, 2013). An additional key finding was that concern regarding fuel consistency may have been being overlooked. This issue was suggested to be a significant issue for infrastructure and the long-term maintenance of jet engines.

Research question 2 – What is the state of stakeholder knowledge surrounding aviation biofuel issues?

Some stakeholders appeared to have a considerable amount of knowledge surrounding the aviation biofuel issues while others had quite limited knowledge. There appeared to be a large difference in the knowledge between those which were active in the field and those which were non-active. Due to the contrast in knowledge between stakeholders, it was concluded that there are two types of stakeholder; ‘change agents’ who have a considerable amount of expertise in the area, and ‘non-proactive stakeholders’ who have an energetic interest in the fuels but not physical involvement in any of the development of the technology. Stakeholders that were active in the aviation biofuel field were more willing to promote the use of aviation biofuels and emphasised the benefits of the fuel more freely than the non-active stakeholders. Some of the scepticism towards aviation biofuel, particularly surrounding the sustainability of the fuels or issues related to production was mainly acknowledged by non-active stakeholders. This may suggest that non-active stakeholders are considerably less knowledgeable about the emergence, development and uptake of aviation biofuels.

Objective 3 - Investigate the relative importance of these factors for the continued emergence, development and uptake of aviation biofuel.

The scoping study showed that there were certain issues which were acting as barriers to the emergence, development and uptake of aviation biofuels and certain issues which were drivers. It was concluded that the barriers need to be addressed if the technology is to be commercialised and successfully taken up by the aviation industry. However, the drivers were also important to understand in order to recommend support measures which will work. However, the scoping study
did not attempt to test the relative importance of the issues. This led to research questions 3, 4 and 5.

**Research question 3** - What drivers, if any, are the most important factors motivating the development and uptake of aviation biofuels?

The survey concluded that it was possible to rank the driving factors in terms of importance based on Likert scale data. The survey found that the five most important drivers were either policy or economic factors; these were access to public funding, incentive schemes, the rising jet prices and commercial opportunities for airlines and biofuel companies and compatibility with existing engines and infrastructure. The survey also revealed new driving factors which were not picked up by the scoping study or literature review; these included the importance of the military sector for the development of the fuels, and the importance of information gathering and dissemination between stakeholders.

**Research question 4** - What constraints, if any, are the most significant barriers to the development and uptake of aviation biofuels?

The survey also found that the five key constraining factors were either policy or economic factors, the factors were: a lack of policy incentives for aviation biofuel, a lack of feedstock supply, (in)stability of feedstock supply, high production costs and lack of government funding. The survey also identified two additional constraints including: uncertainty surrounding the carbon calculation of aviation biofuels within the carbon pricing schemes. In addition to analysing the importance of the driving and constraining issues, the survey wanted to ascertain the importance of different support measures for aviation biofuels.

**Research question 5** - What support measures are the most important for the development and uptake of aviation biofuels?

The most important support measures for aviation biofuel, which are currently being used, were revealed as: fostering research into the quality and quantity of feedstocks, fostering research into improving the production process, lowering the risk of public investment in aviation biofuel and encouraging stakeholders to commit to robust international sustainability. Additional support measures included the establishment of coalitions to support the development of supply chains.
With the relative importance of the issues identified, objective four was designed to investigate the supportive measures further using in-depth interviews and a case-study.

**Objective 4 – Analyse the support measures currently available for the development of aviation biofuel**

Objective four was fulfilled using a combination of two methods. The first was in-depth interview data obtained from 25 stakeholders. The second was by using a case-study of the UK’s first commercial aviation biofuel flight test. The case-study was used to build an in-depth understanding of a single aviation biofuels flight test case.

**Research question 6 -** What support strategies are currently in place to support the commercialisation of aviation biofuels?

The interview data revealed that there were a number of support strategies influencing the uptake and development of aviation biofuels. The most important however were: commercial aviation led strategies such as CAFFI and SAFUG, ICAO and IATA backing of biofuel projects, partnerships and national government incentives. The commercial aviation industry was portrayed as taking a leading role in the development and uptake of aviation biofuels. Indeed, the presence of change agents within the commercial aviation led initiatives was seen as being a key supporting measure for the future of the technology. Partnerships between biofuel companies and airlines were also seen as being important but only if national government incentives were provided towards the funding of demonstration plants and supply chains.

**Research question 7 –** What support measures can be used to influence the development and uptake of aviation biofuels?

It was revealed that support measures can indeed be used to influence the development and uptake of aviation biofuels. It was shown in the literature review that the conventional biofuels markets have been heavily influenced by support measures in the form of mandates, subsidies, tax breaks and research findings. Aviation biofuels stakeholders acknowledged that they believed support strategies similar to the conventional biofuels industry would be affective at supporting the development of aviation biofuels as well. Indeed, many stakeholders stated aviation biofuel will not commercialise unless the support measures are equated in some way with conventional biofuels. The main support measures that were recommended however were: to increase government funding; to provide legislative incentives such as a global carbon price mechanism, to create better environmental sustainability criteria and to continue to research new production pathways. The
stakeholders also stated that continued test flights and certification of newer aviation biofuels is needed.

**Research questions 8** - What role can strategic niche management (SNM) play in the development and uptake of aviation biofuels?

In chapter 8 the strategic niche management concept was discussed in relation to the findings from all the stages of data collection. Aviation biofuels was interpreted as being a radical-sustainable technology which does not fit well with the existing technical regime. This means that recommendations for the nurturing of strategic niche management may be valuable for the development of a sustainable industry. SNM can therefore play an important role in the development and uptake of aviation biofuels. The aviation biofuel technology may be susceptible to nurturing using technology push mechanisms created by the industry stakeholders and governments. This could be achieved by nurturing the technology in strategic niches and inducing the development and uptake of the fuels using incentives and policy measures.

**9.3. Recommendations**

The aim of this thesis was to investigate the factors affecting the emergence, development and uptake of aviation biofuel. In the previous sections it was shown that the literature review, scoping study, survey and interviews and case-study fulfil objectives 1-4. However, they only partially fulfil the research aim. The final objective of the thesis was to make recommendations to support the future emergence, development and uptake of aviation biofuels.

**Objective 5 – Make recommendations for strategies that will support the development and uptake of aviation biofuel.**

This thesis has obtained unique insights into the development of aviation biofuels; revealing that aviation biofuels could provide many benefits to the aviation industry. However, the technology is not yet fully commercialised. This is because there are several barriers (summarised in the previous sections) which are acting to prevent the wide-spread commercialisation and uptake of the technology. These barriers are common to technologies which are emerging from the research and development stages. The main recommendations for supporting aviation biofuels focus therefore on addressing these constraints.

The most common concerns were issues of funding or the perceived lack of economic incentives that could be used either for the construction of biofuel plants or to reduce the final price of aviation
biofuels for the consumer. Within the UK there are no formal policy incentives or grant allocations available for aviation biofuels. This is severally hindering the development of strategic demonstration projects. An obvious recommendation is therefore to address the level of government support offered to aviation biofuels by introducing government backed bank-loans and an industry wide subsidy for the production of sustainable aviation biofuel. The growth of the road biofuel market clearly shows that policies such as subsidies, tax breaks and mandates are affective at supporting the emergence, development and uptake of the technology. Indeed, almost all of the respondents stated that without a similar incentive system, the emergence, development and uptake of aviation biofuel will be limited. However, this thesis does not support the use of national or regional mandates for aviation biofuel. Although a mandate was recommended by three stakeholders, a mandate should not be used until the environmental sustainability of aviation biofuels is proven. Instead, an intelligent use of government funding and incentives is required. This thesis recommends that aviation biofuels should use government funding and incentives to nurture the development of demonstration projects. The next section will describe those recommendations in more detail.

_Nurtured demonstration projects:_

Based on evidence from SNM theory, a protected space for aviation biofuels may be highly beneficial for the long-term development of the technology. The preliminary stages of niche market development are already being set up by organisations such as CAFFI and SAFUG, as well as by private partnerships such as those involving Virgin Atlantic, Lufthansa and British Airways. One key barrier however is the development of demonstration plants. The UK government should consider offering more loan guarantees for the construction of demonstration plants. Grants should only be offered to the companies that have a proven technology. This will increase the likelihood of pilot plant production and in turn lead to the development of small supply chains involving multiple stakeholders. Crucially, the funding should be allocated much faster than it currently is in order to ensure that companies do not become bankrupt and/or discouraged before a working demonstration plant is constructed. In terms of sustainability, the technologies should be assessed in terms of their expected life-cycle emission savings by an independent body though this thesis is reluctant to create a strict sustainability criterion for aviation biofuels. Although ensuring sustainability of the aviation biofuels is paramount, evidence from this thesis shows that enforcing sustainability criteria which is too strict will ultimately hinder the emergence, development and uptake of the entire industry. This in turn may lead to less aviation biofuel technologies being taken-
up by the aviation industry and lower overall emissions reductions across the entire commercial aviation sector.

In conjunction with the plant funding, a crucial factor is to ensure that demonstration projects work towards establishing off-take agreements with airlines once production commences. Evidence suggested that private investors want to see this happening more. To incentivise off-take agreements, a UK ‘early entry’ subsidy should be provided to remove the price differential between the price of standard jet A/A1 and aviation biofuel. In return for government subsidy, the stakeholders must be encouraged to work as ‘change agents’ for the on-going emergence, development and uptake of aviation biofuels. Evidence from the SNM and innovation literature suggests that change agents are highly beneficial for supporting the development of technologies by communicating the benefits of the technology to the rest of the industry. However, although a subsidy is suggested, this thesis does not recommend increasing existing subsidies for biofuel feedstocks; this may lead to over production of feedstocks in spite of a lack of aviation biofuel production capacity. The ‘early entry’ subsidy should also only be given to producers which agree to the SNM recommendations. The subsidy will allow the participating stakeholders to use the fuels commercially and become accustomed to the issues of fuel administration, policy and issues associated with developing a sustainable supply chain. In the initial stages the total subsidy expenditure will be small because the production volumes of aviation biofuel within the UK are so limited. The system should of course be reviewed over time and adjusted. When production facilities become commercially viable, the subsidies should be altered to reflect the sustainability of the product.

The demonstration projects should be assessed in terms of their environmental sustainability and encouraged to increase the GHG emission savings over time. Economic incentives should eventually be reduced to reflect the environmental benefits of the fuels so as to avoid the sustainability issues associated with the development of the conventional biofuels technologies. However, as mentioned, contrary to placing stricter emissions reductions criteria on aviation biofuel production in the short term, aviation biofuel technologies should be allowed some leniency in terms of emission reductions in their early stages. Setting emissions reductions criteria which are too severe may discourage projects from forming. However, notwithstanding these issues, a key recommendation linked to sustainability is the need for more robust and comparable sustainability criteria. Detailed recommendations for creating robust sustainability criteria go beyond the scope of this thesis however this is an issue which is on-going within the conventional biofuel industry as well.
Other recommendations are to encourage greater dialogue between industry and government organisations. At present, the level of communication between the aviation biofuel industry and governing bodies is lacking. Although CAFFI and SAFUG are very effective at bringing private stakeholders together, there is a lack of government involvement in these discussions according to most respondents. This is significantly hindering the progress of development, especially within the UK where there is no central government body for biofuel related issues. From a UK perspective, it would be highly beneficial to set up a government development team to focuses on bringing together the relevant government bodies to discuss aviation biofuel issues.

Another recommendation is to geographically target areas that are suitable to support supply chains and/or that can benefit from local economic development. Although the idea of nurtured demonstration projects was not explicitly recommended by stakeholders, over half of the respondents stated that support for aviation biofuel should have a regional focus, for example; exploiting areas that have abundant feedstock resources. Airframe Manufacturer A and the aviation biofuel specialist representative stated that geographically focused policy strategies would be the most effective solutions. The aviation biofuel specialist also stated that national policies for aviation biofuels in the Netherlands offered a “great opportunity” for the Dutch biofuels industry to allow early emergence, development and uptake of aviation biofuels. The U.S. has also begun to alter their national policies to support aviation biofuels with a similar objective, although no studies have been undertaken to measure the effect of this change.

Within the UK, nurtured projects or similar supply chain experiments are already being formed. British Airways and Solena have created a biofuel supply chain project working with the London councils to utilise municipal wastes to create aviation biofuel (BA, 2011). There is evidence in the SNM literature to suggest that when the projects are run by a single private company the advances in cost reductions and efficiency improvements are faster (Weber et al., 1999). This thesis recommends that these UK projects should be overseen by an independent central body, perhaps the same development team that will bring together the relevant government bodies for aviation biofuels. This also links back to the recommendation that governments need to increase dialogue with individual stakeholders in the development of demonstration projects.

Addressing sustainability methodology:

As mentioned, there is a global need to develop a uniform methodology for calculating the GHG emission savings attributed to aviation biofuels. This is an issue which applies to conventional biofuels as well. A key issue with current methods of calculating the sustainability of a biofuel is that
they are un-transferable and non-standardised. This makes cross examination of biofuels by academics and independent bodies either impossible or extremely expensive and time consuming. Furthermore, because of the non-uniform methodologies, there is a great deal of uncertainty in the literature and among stakeholders about the true environmental benefits of the fuels. This is limiting investment and generally damaging the reputation of the technology. Continued work should be carried out by NGO’s such as the Roundtable on Sustainable Biofuels and the World Wildlife Fund to create a transferrable system which will generate greater confidence in the long-term sustainability of the technology.

Finally, the last recommendation is to provide continued research and development into advancing aviation biofuel technology.

Continued research and development:

Although the HEFA fuels and F-T fuels could be considered almost commercial technologies, the advanced aviation biofuel technologies such as alcohol to jet, methanol to jet and the algae biofuels may offer considerable efficiency and sustainability gains over the HEFA and F-T biofuels. Research and development into these novel aviation biofuel technologies is therefore likely to be highly beneficial for their longer term development and uptake. Again, demonstration projects may be considered to provide the advanced technologies with a stable environment of funding and knowledge transfer between multiple projects. The demonstration projects may also provide a much easier route to testing as well as a platform for knowledge of the technologies to be spread to investors and the general public. This may encourage a change in social norms and pre-conceptions about the technologies which in turn may lead to a faster diffusion of knowledge, investment and uptake of aviation biofuels.

9.4. Contributions to knowledge

The aim of this research was to investigate the factors affecting the emergence, development and uptake of aviation biofuel. In fulfilling the aim, this thesis has contributed to knowledge in the following ways.

Understanding the stakeholder issues associated with the emergence, development and uptake of aviation biofuel

This thesis has offered insights into the issues associated with the emergence, development and uptake of aviation biofuels. It has provided a comprehensive review of the aviation biofuel literature
offering new insights into the issues related to policy support and stakeholder issues. It has captured a significant amount of empirical data from a scoping study, online survey, in-depth interviews and case-study. This data has provided a way to rank the relative importance of issues associated with the emergence, development and uptake of aviation biofuels. The data has revealed that fuel costs, fuel supply and aircraft emissions are perceived as the most serious stakeholder issues facing the commercial aviation industry. Furthermore, it has revealed that the most important perceived technologies and procedures available to alleviate these issues are biofuels, enhanced ATM and new engine and aircraft.

A number of previously unreported issues associated with the emergence, development and uptake of aviation biofuels were revealed including: the need for greater public funding and the need for continued partnerships with airlines and biofuel companies. The data revealed that commercial opportunities for airlines and biofuel companies are an important driver for the fuels emergence, development and uptake. This thesis has revealed that airline corporate social responsibility, or green PR, is much less important for motivating development and uptake than the extant literature suggested.

**Understanding the importance of policy support**

This thesis has obtained primary stakeholder data to show that aviation biofuel is likely to be heavily reliant on policies to support its emergence, development and uptake. The data has revealed that stakeholders are well aware of the fact that aviation biofuel has significantly less support in terms of government grants, subsidies, mandates and tax rebates compared to road based biofuel. Furthermore, this thesis has shown that there is a considerable amount of uncertainty surrounding the long-term policy outlook for aviation biofuels. This uncertainty is restricting the emergence, development and uptake of biofuels. Additionally, contrary to the extant literature, the EU ETS will not act as a significant driver for the development and uptake of aviation biofuels - the price of carbon is currently too low. Evidence from this thesis suggests that the low price of carbon may be a result of the aviation industry’s ability to trade freely with the static industries such as electricity production. The thesis has also revealed that airline stakeholders are sceptical of carbon price rises and that more policy support is required.

**The importance of partnerships, supply chains and biofuel stakeholder initiatives**

The thesis has revealed for the first time that partnerships between airlines and biofuels companies are vitally important for the emergence, development and uptake of aviation biofuel. They will aid in the development of supply chains and help to lobby towards policy changes that favour aviation
biofuel. Biofuels initiatives such as SAFUG and CAFFI are also effective at bringing together stakeholders and guiding the emergence, development and uptake of the fuels. However, combined with the principal recommendations of this thesis, biofuel initiatives could work a lot harder to bring the technology to the commercial scale. This thesis has offered specific recommendations for supporting the development a UK aviation biofuel industry using a unique set of supportive policies and government backing.

Theoretical contributions

This thesis has made a number of theoretical contributions. The first contribution is in the form of empirical data which supports the principles of SNM theory for emerging sustainable technologies. To date, SNM theory has suffered from a lack of real world empirical examples pertaining to nurtured spaces for emerging sustainable technologies. This thesis has shown that the development of aviation biofuels exhibits striking similarities to the concepts within SNM. Aviation biofuels is developing within small scale demonstration projects involving the development of stakeholder led supply chains and minor niche markets for the fuel. Furthermore, the technological regime for aviation (being particularly stubborn to radical technological change) aligns perfectly within the theoretical framework of SNM. These findings provided up to date evidence to suggest that ‘SNM like’ behaviour is an essential route of development within industries which are constrained by stubborn technological regimes.

This thesis has also provided unique modifications to SNM. It was revealed that SNM may not be adequately equipped to address the multitude of issues influencing the development of aviation biofuels. Firstly, SNM does not adequately consider the differences between system and sub-system drivers and constraints in the same way, for example, that technology readiness levels (TRL) does. SNM also takes a narrower view of the development process because it focuses essentially on a short period of ‘niche market development’. SNM therefore does not fully take into account the processes before or after a strategic niche market. This thesis developed a new model which combines aspects of SNM theory with the IEA model of biofuel development (IEA, 2009), diffusion theory and insights from technology readiness levels (TRL). The model considered the development of aviation biofuel technologies over five distinct phases, similar to the IEA model discussed in the literature review (Chapter 3, Figure 3.8). However, the third phase of development in the IEA model, which previously was a stage involving ‘policy and protection provision’, focused exclusively on recommendations from Strategic Niche Management (SNM). The model also considered the emergence, development and uptake of aviation biofuels from an evolutionary economic perspective where the development and diffusion of the technology is expected to be non-linear.
Based on evidence from previous biofuel studies, as well as empirical findings from this thesis, it is anticipated that aviation biofuels would follow an iterative path of development. This is furthermore typical of emerging sustainable technologies, especially those which encounter a large number of driving and constraining issues such as biofuels (IEA, 2009). Finally, the model considered that aviation biofuels will be driven and constrained by a series of factors working at different system levels. For instance, changes in environmental government policy may create a demand for aviation biofuels at the system-level however; sub-system drivers such as agricultural development or the development of local supply-chains will also be vitally important for the emergence, development and uptake as well. This was certainly confirmed by the empirical findings from this thesis. Indeed, it was revealed that the drivers and constraints are inherently interlinked which impacts on the provision of support for aviation biofuels.

To the best of the author’s knowledge, this modification has not been done before and it represents an important progression from the existing SNM theory. This thesis has also shown that SNM is versatile in the respect that it can complement and strengthen existing frameworks of innovation.

9.5. Limitations of the research

Although the findings from this research were detailed and have contributed significantly to knowledge surrounding the emergence, development and uptake of aviation biofuels, there were naturally some limitations that were related to the methods used and data obtained.

Availability of stakeholders

The thesis was limited by the availability of stakeholders in the aviation biofuel field. Although the scoping study and in-depth interview stages obtained an adequate number of stakeholders, the survey obtained a lower number than expected. This may have been a result of distributing the survey via a web portal. Indeed, Dillman (2000) states that respondents of a web-based survey will often make the decision to ‘not respond’ much more quickly than a paper based survey. However, up to four reminder emails were sent to non-responsive respondents. Alternatively, the length of the survey or the complexity of the questions may have been daunting to the stakeholders due to their busy schedules. However, the survey did have a facility built into the system to allow the respondents to partially complete the survey and return to it later. Other possible explanations may be related to the sensitively of the topic area and confusion regarding the confidentiality agreements between the research and the stakeholder. Indeed, the confidentiality agreement may have been misunderstood by a minority of respondents because it limited other parts of the research as well.
Confidentiality

Due to corporate sensitivity of the subject area, the questioning of the four stages of primary data was limited to non-financial information. This limited the amount of information relating to the price of aviation biofuels, the current investment in the technologies and the company’s future involvement with the fuels. Although it was universally agreed by stakeholders that the price of aviation biofuel was in order of magnitude higher than the price of fossil fuel, having accurate cost estimates would have been useful for assessing the economic viability of the fuel.

With respect to the online survey, around half of the stakeholders that completed the survey decided to remain anonymous after making their responses. This limited the level of sector based and geographic analysis that could be carried out. Furthermore, the case study encountered minor issues related to obtaining confidentiality agreements between all parties. The case study questions needed to be modified and accepted by all parties before the study could be carried out. Crucially, confidentiality limited the number of questions that could have been asked that relate to issues such as the manufacturing of the fuel, the mixing of the fuel and financial and infrastructural investments in the trial. There were also limitations of the methods used.

Methods

Due in part to the unit of analysis, compromises in the methods were made. Firstly, the scoping study and in-depth interviews obtained mainly qualitative data. Although this provided a detailed understanding of the stakeholder issues, quantification of the issues, particularly surrounding the costs of the fuels and investments in the field was limited. On the other hand, the online survey did obtain quantitative data in the form of Likert scale questioning. However, due to the unexpectedly small sample size, quantitative analysis in the form of ANOVA testing or probabilistic analysis was not possible. The survey was thus limited mainly to descriptive statistics. Finally, time and financial constraints limited the ability to undertake follow up research to investigate the long-term outcomes of aviation biofuel trials and the plans for future trails.

9.6. Further research

Although this thesis had provided several important contributions to knowledge, it did also open up several areas of further research.

More longitudinal research is required to understand the policy influence over time
This thesis revealed that policy support is likely to affect the emergence, development and uptake of aviation biofuels. Stakeholders perceived policy incentives to be a necessary precondition for emergence, development and uptake. It was also revealed that the policy support was perceived to be seriously lacking; which is hindering the current emergence, development and uptake for the fuels. However, due to the fact that research drew upon interviews and personal perceptions that were made over a three month period, no longitudinal effects of actual policy changes could be measured. Indeed, because policy changes are expected over the coming years, further research is needed to track the development of these changes and their effect on emergence, development and uptake. It is essential to know how effective these policies are in practice.

Further research surrounding demonstration projects

Further research is also required to investigate the effect of SNM like demonstration projects for the development of supply chains and niche markets. This thesis made recommendations to transform the current aviation biofuels testing programmes into nurtured niche markets following principles from SNM theory. However, this strategy needs to be tested with further research, possibly by using a case-study approach that follows the development and outcomes of one experiment. This research is essential because the key issues from trials must be passed on to further trails in order to maximise learning-by-doing and thereby speed up niche market development. Indeed, as described earlier, information sharing is a key factor in the successful development of a niche.

More empirical data surrounding aviation biofuel demand and supply

Finally, although econometric modelling of aviation biofuel demand and supply exists, the models do not appear to be accurate enough according to the perspectives of the aviation biofuels stakeholder’s interviewed in this thesis. A key issue is however that the models do not use high quality empirical data. More data is needed therefore to establish the production volume capabilities of the current aviation biofuel technologies. Furthermore, the policy environment for aviation biofuel is likely to change. These changes need to be considered in future econometric modelling scenarios. Furthermore, based on the evidence from the literature review and the stakeholder interviews, it appears that there is still scope for further research to assess the likely impact of different policy measures and interventions for the future emergence, development and uptake and sustainability of aviation biofuels.
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Appendix A

Scoping study questions

1) Please describe a little about yourself and your field of expertise.
2) How did you first become interested in biofuels, or biofuels research, and why?

*Questions 3 – 7 relate to commercial liquid biofuels (i.e. liquid biofuels which are available for purchase on the open market today).*

3) What have been the main commercial applications of liquid biofuels to date and why?
4) What have been the main factors driving:
   a. Market uptake?
   b. Market growth?
5) From your experience, have these factors changed over time and how?
6) What have been the main constraints or challenges associated with:
   a. Market uptake?
   b. Market growth?
7) From your experience, have these constraints or challenges changed over time and how?

*Questions 10 - 15 still relate to existing liquid biofuels however, this section seeks to establish your perspectives concerning the future of liquid biofuels.*

8) Looking into the future, what factors are most likely to positively influence:
   a. Research and development?
   b. Market growth?
9) Looking into the future, what constraints are most likely to negatively affect:
   a. Research and development?
   b. Market growth?
10) What will the role of legislation and regulation play for:
    a. Research and development into new biofuel technologies
    b. Market growth of existing biofuel technologies?
11) How likely is it that the main application of existing biofuels will change in the future, and if so how?
Questions 12 – 16 relate to the use of liquid biofuels for commercial aviation. This section seeks to identify your perspectives regarding the current situation of aviation biofuel.

12) When did you first become interested in the potential of liquid biofuels for commercial aviation?
13) What are the main factors driving the research and development into aviation biofuels?
14) How do these factors differ from those already experienced with existing liquid biofuels and why?
15) What are the main challenges associated with aviation biofuels?
16) Will these challenges differ from those already experienced with existing liquid biofuels and why?
17) Questions 17 – 22 relate to your perspectives for the future of aviation biofuels.

18) What will be the most influential factors driving the commercialisation and market uptake of aviation biofuel and why?
19) What role will legislation play in facilitating commercialisation and market uptake?
20) What time-frame, if any, do you foresee aviation biofuels becoming commercially viable?
21) Will the commercialisation of aviation biofuel have any effect on the existing biofuels markets and how?
22) What areas of research relating to aviation biofuels do you feel are yet to be explored, or worthy of further investigation?
23) Finally, are there any further issues related to aviation biofuel which you would like to talk about?
Appendix B Screenshots of aviation biofuels stakeholder survey

The Aviation Biofuel Survey 2011

Welcome to the Aviation Biofuel Survey

This survey is split into three sections:
Section 1: Introduction
Section 2: The development of aviation biofuel
Section 3: Future scenarios for aviation biofuel

Section 1: Introduction

1. How serious do you consider the following issues to be for commercial aviation?

<table>
<thead>
<tr>
<th>Issue</th>
<th>Not at all serious</th>
<th>Not very serious</th>
<th>Fairly serious</th>
<th>Serious</th>
<th>Very serious</th>
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<tbody>
<tr>
<td>a. Future fuel supply / security</td>
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<td>b. Fuel costs</td>
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<td>c. Aircraft emissions</td>
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<td>d. Air quality around airports</td>
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<td>e. Global demand in economic activity</td>
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<td>f. Financing new aircraft</td>
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<td>g. Profitability</td>
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<td>h. Airport capacity</td>
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Section 2: In your opinion how important are the following technologies and procedures for commercial aviation?

<table>
<thead>
<tr>
<th>Technology</th>
<th>Very unimportant</th>
<th>Unimportant</th>
<th>Neither unimportant or important</th>
<th>Important</th>
<th>Very important</th>
</tr>
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<tbody>
<tr>
<td>a. Synthetic jet-fuels (from coal, shale, gas)</td>
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<td>b. Biofuels</td>
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<td>c. Enhanced air traffic management procedures</td>
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<td>d. Electric powered aircraft</td>
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<td>e. Hydrogen powered aircraft</td>
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<td>f. New engine design</td>
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<td>g. Reduced take-off weight design</td>
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<td>h. Exhausted technologies (such as using-lox)</td>
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Section 3: In your opinion how important are the following issues for the development of aviation biofuels?

<table>
<thead>
<tr>
<th>Issue</th>
<th>Very unimportant</th>
<th>Unimportant</th>
<th>Neither unimportant or important</th>
<th>Important</th>
<th>Very important</th>
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</thead>
<tbody>
<tr>
<td>a. Air passenger awareness of environmental issues</td>
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<td>b. Airline and engine manufacturers awareness of environmental issues</td>
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<td>c. Government or legislators awareness of environmental issues</td>
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<td>d. Cost of awareness of environmental issues</td>
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<td>e. Rising jet-fuel prices</td>
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<td>f. Rising oil prices</td>
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<td>g. Volatility of jet fuel price</td>
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<td>h. Carbon content of jet fuel</td>
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<tr>
<td>i. Fuel security concerns</td>
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<td>j. Emission reduction legislation</td>
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<td>k. Commercial opportunities for biofuel companies</td>
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<tr>
<td>l. Commercial opportunities for all companies</td>
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<td>m. Commercial opportunities for airlines</td>
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<tr>
<td>n. Compatibility with existing engines and infrastructure</td>
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<tr>
<td>o. Corporate social responsibility</td>
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<td>p. Job creation</td>
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<td>q. Rural economic development</td>
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<tr>
<td>r. Energy density of the fuel</td>
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<tr>
<td>s. Inclusion of aviation within emissions trading schemes</td>
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</tbody>
</table>
4. Are there any other issues in terms of the development of aviation biofuel? (not mentioned in question 3.) Please state and rate their importance. (Optional)

5. In your opinion how important are the following factors with respect to the production of aviation biofuel?

<table>
<thead>
<tr>
<th>Factor</th>
<th>Very unimportant</th>
<th>Unimportant</th>
<th>Neither unimportant or important</th>
<th>Important</th>
<th>Very important</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Access to private funding</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
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<tr>
<td>b. Access to public funding</td>
<td>Ø</td>
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<tr>
<td>c. Availability of fertilizers</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
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<td>Ø</td>
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<tr>
<td>d. Experience with existing biofuels</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
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<tr>
<td>e. Experience with oil production</td>
<td>Ø</td>
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<tr>
<td>f. Incentive schemes</td>
<td>Ø</td>
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<tr>
<td>g. Land availability for feedstock</td>
<td>Ø</td>
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<td>h. Low labour costs</td>
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<td>Ø</td>
<td>Ø</td>
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<tr>
<td>i. Low land prices</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
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<tr>
<td>j. Productive soils</td>
<td>Ø</td>
<td>Ø</td>
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<td>Ø</td>
<td>Ø</td>
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<tr>
<td>k. Public Private co-operation</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
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<tr>
<td>l. Strong government targets for emission reduction</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
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<tr>
<td>m. Climate for growing feedstock</td>
<td>Ø</td>
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<tr>
<td>n. Well defined environmental policies</td>
<td>Ø</td>
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</table>

6. Are there any other factors (not mentioned in question 5) that are important for the production of aviation biofuel? Please state and rate their importance. (Optional)

7. The following issues are potential challenges to the adoption of aviation biofuel. How serious do you perceive these challenges to be?

<table>
<thead>
<tr>
<th>Challenge</th>
<th>Not at all serious</th>
<th>Not very serious</th>
<th>Fairly serious</th>
<th>Serious</th>
<th>Very serious</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Competition with food production</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
</tr>
<tr>
<td>b. Stability of biodiesel supply</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
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<tr>
<td>c. Molecular consistency of different biofuels</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
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<tr>
<td>d. Contamination concern (TAME)</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
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<tr>
<td>e. Freezing point of aviation biofuel</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
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<tr>
<td>f. Relatively high production costs</td>
<td>Ø</td>
<td>Ø</td>
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<tr>
<td>g. Relatively high capital costs</td>
<td>Ø</td>
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<tr>
<td>h. Lack of an aviation fuel tax</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
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<tr>
<td>i. Potential modification of infrastructure</td>
<td>Ø</td>
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<tr>
<td>j. Lack of 100% blend certification</td>
<td>Ø</td>
<td>Ø</td>
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<tr>
<td>k. Lack of access to credit</td>
<td>Ø</td>
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<tr>
<td>l. Lack of feedstock supply</td>
<td>Ø</td>
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<tr>
<td>m. Lack of financial resources</td>
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<tr>
<td>n. Lack of financial support from governments</td>
<td>Ø</td>
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<tr>
<td>o. Lack of investor support</td>
<td>Ø</td>
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<tr>
<td>p. Lack of policy incentives for aviation biofuel</td>
<td>Ø</td>
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<tr>
<td>q. Low carbon price</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
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<tr>
<td>r. Relatively low jet-fuel price</td>
<td>Ø</td>
<td>Ø</td>
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<tr>
<td>s. Potential negative environmental image of biofuel</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
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<tr>
<td>t. Protection of oil market by major oil companies</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
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</tr>
<tr>
<td>u. Securing sufficient investment</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
<td>Ø</td>
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<tr>
<td>v. Uncertain carbon price</td>
<td>Ø</td>
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<tr>
<td>w. Uncertain production costs</td>
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<tr>
<td>x. Uncertain legislative control on airline emissions</td>
<td>Ø</td>
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<tr>
<td>y. Uncertainty surrounding the EU Emissions Trading Scheme</td>
<td>Ø</td>
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</tbody>
</table>

8. Are there any other challenges to the adoption of aviation biofuel? (not mentioned in question 7) Please state and rate their importance. (Optional)
### Section 4: Future scenarios for aviation biofuel

#### 9. In your opinion how likely is it that the following scenarios will occur in the next 10 years?

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Very unlikely</th>
<th>Unlikely</th>
<th>Neither unlikely or likely</th>
<th>Likely</th>
<th>Very likely</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Decreased risk of ORC supply interruptions</td>
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<tr>
<td>b. Decreased volatility in oil prices</td>
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<tr>
<td>c. Biofuel demand exceeding supply</td>
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<td>d. Discovery of significant new oil reserves</td>
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<tr>
<td>e. Global economic recession</td>
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<tr>
<td>f. Higher jet fuel prices</td>
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<tr>
<td>g. Higher oil prices</td>
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<td>h. Higher prices of biofuel feedstock</td>
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<tr>
<td>i. Increased volatility in oil prices</td>
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<tr>
<td>j. Increased volatility in biofuel feedstock</td>
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<tr>
<td>k. Insufficient government financing</td>
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<tr>
<td>l. Insufficient private financing</td>
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<td>m. Insufficient volumes of suitable feedstock</td>
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<tr>
<td>n. Lower carbon price</td>
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<tr>
<td>o. Lower oil price</td>
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<tr>
<td>p. Lower jet fuel price</td>
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<tr>
<td>q. More investment in aviation biofuel than road sector biofuel</td>
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<tr>
<td>r. Negative image of aviation biofuel from environmental groups</td>
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<tr>
<td>s. No change in food price as a result of aviation biofuel</td>
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<tr>
<td>t. No change in the carbon price</td>
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<tr>
<td>u. No change in the cost of producing aviation biofuel</td>
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<tr>
<td>v. No 'real' rise in biofuel feedstock prices</td>
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<tr>
<td>w. No 'real' rise in oil prices</td>
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</tbody>
</table>

#### 10. To what extent do you agree with the following statements?

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly disagree</th>
<th>Disagree</th>
<th>Neither disagree or agree</th>
<th>Agree</th>
<th>Strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. There will be insufficient feedstocks available to produce aviation biofuel</td>
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<tr>
<td>b. There are too few policy incentives available for aviation biofuel</td>
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<tr>
<td>c. There is insufficient private investment in aviation biofuel</td>
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<tr>
<td>d. The technology to produce aviation biofuel will never be commercially viable</td>
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<tr>
<td>e. There is a lack of government support for aviation biofuel</td>
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<tr>
<td>f. The cost to produce aviation biofuel is too high at present</td>
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<tr>
<td>g. Fuel consistency will prevent the fuels being used commercially</td>
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<tr>
<td>h. Biofuel has a negative environmental image</td>
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<tr>
<td>i. The price of oil will stay below the price of aviation fuel</td>
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<tr>
<td>j. The road transport biofuel market will stifle the development of aviation biofuel</td>
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</tbody>
</table>
11. How important are the following strategies for facilitating the future adoption of aviation biofuel?

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Very unimportant</th>
<th>Unimportant</th>
<th>Neither unimportant or important</th>
<th>Important</th>
<th>Very important</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Maintaining research into improving the quality and quantity of feedstocks</td>
<td></td>
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<tr>
<td>b. Fast-tracking research into improving the production process</td>
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<tr>
<td>c. Lowering the risk of public investment in aviation biofuel</td>
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<tr>
<td>d. Lowering the risk of private investment in aviation biofuel</td>
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<tr>
<td>e. Using subsidies to reduce the initial price of aviation biofuel</td>
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<tr>
<td>f. Using Government-backed loans for plant construction</td>
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<tr>
<td>g. Enforcing a global carbon pricing policy</td>
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<tr>
<td>h. Encouraging funding for research into aviation biofuel</td>
<td></td>
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<tr>
<td>i. Well-defined government objectives</td>
<td></td>
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<td></td>
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<tr>
<td>j. Tax rebates for aviation biofuel feedstocks</td>
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</tbody>
</table>

12. Are there any other strategies for facilitating the future adoption of aviation biofuel which are not mentioned in question 11? Please state and rate their importance. (Optional)

13. Within what time frame do you think that aviation biofuels will be adopted?
   - Less than a year
   - 1-2 years
   - 2-5 years
   - 5-10 years
   - Over ten years
   - Never

14. How long have you been aware of the potential of aviation biofuels?
   - Less than a year
   - 1-2 years
   - 2-5 years
   - 5-10 years
   - Over ten years

15. Please state your company name and job title.

Thank you very much for your cooperation, it is much appreciated.

16. Would you be willing to be interviewed as part of follow-on research some time in the near future?
   - Yes
   - No
   (If so please state your email, or other contact details. (Optional)
Appendix C

Semi-structured interview questions

1. When did your organisation first become aware of aviation biofuels?

2. When did your organisation become aware of the feasibility of aviation biofuels?

3. How did your organisation become involved with aviation biofuels?
   a. Please describe the nature of your company’s involvement with aviation biofuels?

4. From your organisation’s perspective, what is currently driving the development and commercialisation of aviation biofuels?

5. From your organisation’s perspective, what challenges are currently facing the commercialisation and uptake of aviation biofuels?

6. What strategies are your organisation aware of that are being used to support the commercialisation and uptake of aviation biofuels?
   a. Are these strategies sufficient?
   b. Do the strategies need to be changed?
   c. What issues are associated with using strategies to influence the commercialisation and uptake of aviation biofuels?

7. Are there any strategies that your organisation would like to see implemented to influence the development and commercialisation of aviation biofuel?
   a. Should these strategies differ depending on which types of biofuel are being produced?

Networks and communication in the aviation biofuel community:

8. Is your organisation communicating with legislators about issues relating to the development and commercialisation of aviation biofuels?
   a. If so, what legislators are you currently communicating with and what are the nature of the issues that are currently being discussed?
   b. Do you feel that legislators have an adequate understanding of the issues relating to aviation biofuel?

9. Is your organisation communicating with the commercial aviation sector regarding the development and commercialisation of aviation biofuels?
   a. If so, what are the nature of the issues that are currently being discussed?
b. Do you feel that the aviation sector has an adequate understanding of the issues associated with aviation biofuel?

10. Is your organisation communicating with the biofuel sector regarding the development and commercialisation of aviation biofuels?
   a. If so, what are the nature of the issues that are currently being discussed?
   b. Do you feel that the biofuel sector has an adequate understanding of the issues associated with aviation biofuel?

11. Is your organisation a member of any aviation biofuel development initiatives, such as the Sustainable Aviation Fuels User Group (SAFUG) or CAAFI?
   a. If no, why is your company not part of one of these initiatives? If yes, why did your company join the initiative?
   b. What role do initiatives such as these play in terms of the development of aviation biofuels?
   c. What benefits do these organisations offer?
   d. Would your company like to see any changes to the way the market of aviation biofuel is developing?

12. Is your organisation actively cooperating with other stakeholders in the aviation biofuel field?
   a. If so, what are your company’s objectives for cooperation?

Optional questions (only relevant if you have been involved with aviation biofuel trials):

13. Has your organisation been involved with aviation biofuel trials?
   a. If so, please describe the nature of the trial(s) and your involvement in the trial(s)?
   b. Were there any challenges that you faced during the preparation of the trial(s)?
   c. Where there any challenges that you faced during the operation of the trial(s)?
   d. How will the data be used?
   e. Will the data be shared among the aviation biofuel community?
   f. Was there any form of support available to your company to facilitate the trial i.e. financial or legislative support etc?
      i. If so, please describe the nature of support and how it was used?
      ii. How effective was the support that was offered?
   g. Have the trials been successful and why?
Appendix D

Case-study questions:

Opening questions:

1. When did your company first become aware of aviation biofuels and their feasibility?
2. How did your company become involved with aviation biofuels?
3. From your company’s perspective, what is currently driving the development and commercialisation of aviation biofuels?
4. From your company’s perspective, what challenges are currently facing the commercialisation and uptake of aviation biofuels?
5. What strategies are your company aware of that are being used to support the commercialisation and uptake of aviation biofuels?
   a. Are these strategies sufficient?
   b. Do the strategies need to be changed?
6. Are there any strategies that your company would like to see implemented to influence the development and commercialisation of aviation biofuel?
   a. Should these strategies differ depending on which types of biofuel are being produced?

Development and planning of the aviation biofuel trial:

7. How did your company become involved in the aviation biofuel trial?
8. What role did your company play in initiating and planning the aviation biofuel trial?
9. What was your company’s motivation for facilitating the first UK commercial biofuel trial?
10. What were the objectives of the aviation biofuel trial?
11. What time scale was involved in planning the trial?
12. Were there any challenges during the planning stage of the trial?
   a. If so, how did you overcome these challenges?
   b. Were the challenges expected?
13. Was there any form of support available to your company to facilitate the trial i.e. financial or legislative support etc?
    a. If so, please describe the nature of support and how it was used?
    b. How effective was the support that was offered?
    c. Is there sufficient support for the trial of aviation biofuels?
14. How important are aviation biofuel trials for incentivising the commercialisation and uptake of aviation biofuels?

**Operation of the trial:**

15. What role is your company playing in the actual operation of the trial?

16. Were there any challenges that your company faced in undertaking the trial?
   a. If so, how did you overcome these issues?

17. What does your company hope to learn from this trial?
   a. How will the data be used?
   b. Who owns the data that will be produced from the trial?
   c. Will the data be shared among the aviation biofuel community?
   d. To what extent does this trial differ from commercial aviation biofuel trials that are currently being carried out with other airlines such as Lufthansa, KLM, Finnair and Continental?

18. Has the trial been successful and why?

**Networks and communication in the aviation biofuel community:**

19. Is your company communicating with legislators about issues relating to the development and commercialisation of aviation biofuels?
   a. If so, what legislators are you currently communicating with and what are the nature of the issues that are currently being discussed?
   b. Do you feel that legislators have an adequate understanding of the issues relating to aviation biofuel?

20. Is your company communicating with the commercial aviation sector regarding the development and commercialisation of aviation biofuels?
   a. If so, what are the nature of the issues that are currently being discussed?
   b. Do you feel that the aviation sector has an adequate understanding of the issues associated with aviation biofuel?

21. Is your company communicating with the biofuel sector regarding the development and commercialisation of aviation biofuels?
   a. If so, what are the nature of the issues that are currently being discussed?
   b. Do you feel that the biofuel sector has an adequate understanding of the issues associated with aviation biofuel?

22. Is your company a member of any aviation biofuel development initiatives, such as the Sustainable Aviation Fuels User Group (SAFUG) or CAAFI?
a. If no, why is your company not part of one of these initiatives?  
If yes, why did your company join the initiative?

b. What role do initiatives such as these play in terms of the development of aviation biofuels?

c. What benefits do these organisations offer?

d. Would your company like to see any changes to the way the market of aviation biofuel is developing?

23. Apart from those involved in the trial, is your company actively cooperating with other stakeholders in the aviation biofuel field?

   a. If so, what are your company’s objectives for cooperation?

Closing questions:

24. Does your company have any plans for further trials with aviation biofuels?

25. Is your company aware of any other trials of aviation biofuels that are taking place?

   a. Do these trials differ from the trial with Thomson Airways?

26. Apart from for trial purposes, within what time frame would your company predict that aviation biofuels will be adopted commercially?

27. Is price competitiveness with JET-A/A1 important for the initial adoption of the fuels?

   a. What other factors will be important for the initial adoption of aviation biofuels?

Thank you for your time