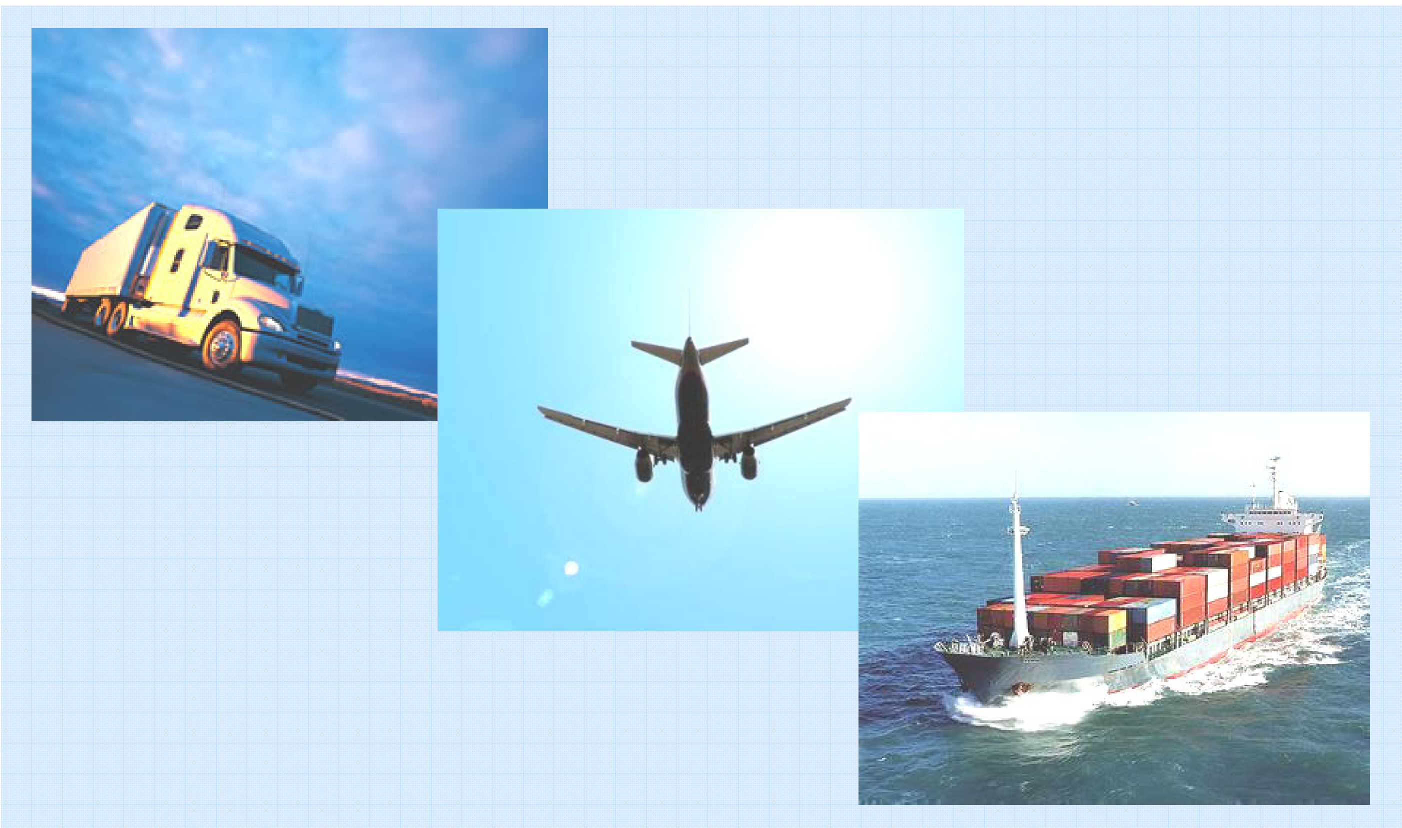
The forgotten sectors.

Alternative drivetrain technologies and fuels to diminish CO_2 emission in the Dutch aviation, the freight road and the maritime sector in 2020 and 2050.



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Summary

There is a growing awareness that CO_2 emissions may lead to climate change. To avert this threat, measures to reduce CO_2 emission are investigated. Up till now, an overview of the CO_2 emission reduction that can be achieved in the aviation, maritime or road freight segments is missing. Such an overview is important because these sectors together emit a significant amount of CO_2 and increasing emissions are expected in the future. This report provides an overview of the CO_2 reduction potential from new drivetrains and fuels in the three sectors. These potentials are based on estimates of the technical potential, the cost-effectiveness and the Innovation System Performance.

As a start, CO_2 emission projections for the three sectors toward 2050 were made. By combining these projections with CO_2 emission reduction possibilities of drivetrain technologies and alternative fuels, a technical CO_2 emission reduction potential is arrived at. The cost-effectiveness of drivetrain technologies and fuels values are calculated and compared with cost estimates for CO_2 in 2020 and 2050 to provide insight from an economical point of view.

It is assumed that the performance and development of a Technology Specific Innovation System influences the chance that a large share of the potentials (by drivetrain technologies and fuels) may actually be exploited in 2020 and 2050. The CO2 emission reductions that can maximally be achieved in 2020 and 2050 are estimated by considering an average diffusion time based on historical technologies. We assume that the build-up of a Technology Specific Innovation System is linked to the diffusion along an S-curve. Four Technology Specific Innovation Systems are analyzed on their Innovation System Performance to reveal the current weak spots that need to be improved in order to achieve the estimated CO_2 emission reductions.

The research indicates that the drivetrain technologies and alternative fuels are currently in the pre-development phase. The analysis of the four Innovation Systems pointed out that the quality and/or quantity of these Innovation Systems and the extent to which the Innovation System functions are served currently falls short to start diffusion among society. Significant improvements have to occur in these Innovation Systems to achieve the potential CO_2 emission reductions of drivetrain technologies and alternative fuels.

The results show that significant (Innovation System and Innovation System Function) improvements have to occur to lower the cost-effectiveness of the technological options towards 2020 and 2050.

Both industry and government should act and invest in diminishing CO_2 emissions by improving the current Innovation System's quality and quantity and Innovation System Functions, otherwise the aviation, freight road and maritime sector will indeed become the forgotten sectors.

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1. Introduction

The world-wide interest in sustainable energy sources as alternative to the current fossil energy sources emerged from the energy crises in the 1970s (Chau & Wong, 2002; Negro et al., 2007). The search for alternative energy sources was further strengthened by increasing concerns about societal problems. Examples are the risk of climate change due to human related CO_2 emissions which is considered to be very likely (IPCC, 2007), the dependence of oil imports given the localized nature in instable countries (Nichols, 2003; House of Lords, 2006), the extensive use of fossil fuels that may lead to the depletion of these finite resources (Conte et al., 2001; Chau & Wong, 2002; Bradley & Frank, 2007). The likelihood of climate change due to human related activities forms the main rationale to conduct this research.

To counteract climate change, ambitious goals for greenhouse gas emission reduction are set for the mid- and long-term by both the national government and international organizations. The target years for these goals are 2020 and 2050. It is the Dutch government's target to reduce the greenhouse gas emission in 2020 with 30% relative to the 1990 levels. Stern (2006) states that industrialized countries, like the Netherlands, need to reduce their emissions by 60 – 80% of the 1990 levels in the year 2050 to prevent disproportionate climate change. In the fourth assessment report of the IPCC (2007) even higher percentages (85 – 95) are mentioned.

Accordingly, these targets have implications for the transport sector. For the transport sector, it holds that according to the Dutch government *Clean and Efficient programme* an emission reduction should be achieved of 13 – 17 Mton in 2020 (ECN/MNP, 2007; VROM, 2007). The Dutch transport sector is the second largest emitter of greenhouse gases with approximately 20% of the total carbon dioxide (CO_2) emission (Emissieregistratie, 2008). In the long run it is expected that the transport sector's CO_2 emission will increase from 20% to 30% while other sectors remain more or less constant (Hoen et al., 2006; Milieu & NatuurCompendium, 2008).

The understanding of the likelihood that CO_2 emissions, including those of the transport sector, lead to climate change resulted in the need for measures to reduce CO_2 emissions (Lugar & Woolsey, 1999; Jacobsson & Johnson, 2000; Office of Policy, Planning and Evaluation, 2002). This emerged in studies that describe and analyze alternative drivetrain technologies and fuels for (primarily) light duty vehicles because approximately 70% of the emissions in the transport sector can be contributed to light duty vehicles (King, 2007) (for example Poulton (1994); Sandén & Jonasson (2005); Bomb et al. (2006); Demirbas (2007); Keles et al. (2008); Hoekman (2009)). An overview of the reduction that can be achieved in the aviation, maritime or road freight segments is currently missing. Such an overview is crucial because these together emit a significant amount of CO_2 and an increase is expected in the future (van Thuijl, 2002; Hoen et al., 2006; Boer den et al., 2009).

The aim of this research is to fill the knowledge gap by providing insights in the emission reduction potential of maritime, aviation and freight transport by road with a focus on:

- drivetrain technologies
- alternative fuels

For specific drivetrains and alternative fuels maximum CO_2 emission reductions can be estimated. The maximum amount of emission reduction, expressed in CO_2, when considered from an isolated technical point of view is regarded as the technical potential. The emissions of conventional and alternative drivetrain technologies and fuels may differ in life cycle steps like production, distribution, storage, conversion and usage. Therefore, it is important to include the whole well-to-wheel (WTW) cycle of the drivetrain technologies and alternative fuels in the analysis.

In many cases, measures to reduce emissions lead to extra costs. By including the extra costs to prevent an amount of CO_2, a so-called cost-effectiveness may be arrived at. Including the cost-effectiveness in the analysis, provides information about the additional cost levels to reduce an amount of CO_2 with a drivetrain technology or alternative fuel. Furthermore, including cost-effectiveness leads to additional insights of the drivetrain technologies and alternative fuels from an economic point of view.

It must be noticed that new technologies cannot be taken from the shelf when they are needed but that it comprises heavy involvement of actors, knowledge development and improvement. In order to capture a high reduction potential in the (near) future attention has to be put on alternatives at this moment in terms of investments, research and development. The 'innovation system' approach takes into account that actors do not innovate in isolation (Edquist, 2005). Actors interact with other actors to gain, develop and exchange knowledge and other resources (Negro, 2007). To achieve a large share of the technical potential and improving cost-effectiveness, sufficient actors have to be involved. Besides the presence of sufficient actors in an Innovation System also activities that determine the development, diffusion, and implementation of these drivetrains and alternative fuels are crucial. Such activities have been referred to as the Functions of Innovation Systems (Johnson, 1998; Jacobsson & Johnson, 2000; Liu & White, 2001; Rickne, 2001). It is assumed that the more actors become involved in the Innovation System and the more and the better functions are served, the better the innovation system of a drivetrain or alternative fuel is performing which increases the chance of achieving a better CO_2 emission reduction.

By identifying the (missing) actors and activities of an Innovation System, the strong and weak spots will be discovered. Insights in the strong and weak spots reveal where in the Innovation System intervention may be needed to achieve a higher actual CO_2 emission reduction, as a share of the technical CO_2 emission reduction potential, in the target years 2020 and 2050. The performance of the Innovation System in developing and deploying new technologies is in this study measured on the basis of the Innovation System structure and the fulfillment of Innovation System Functions[1].

For providing an overview of the CO_2 emission reduction potential of drivetrain technologies and alternative fuels in the maritime, aviation and freight transport by road segments this research will make a distinction between the:

- Technical potential
- Cost-effectiveness
- Innovation System Performance

This research provides a scientific contribution since it will fill the knowledge gap of the CO_2 emission reduction potential in the maritime transport, aviation transport and freight transport by road. An overview of the current Innovation System Performance of drivetrain technologies and alternative fuels will be provided to reveal where intervention can take place to achieve a higher CO_2 emission reduction in the years 2020 and 2050. The research is of

[1] Innovation Systems and Functions of Innovation Systems will be elaborated on in the theory section.

societal interest because it provides insights in the extent to which drivetrain technologies and alternative fuels can diminish the risk of climate change.

The aim of the research is to create insight in the CO_2 emission reduction potential of alternative drivetrain technologies and fuels for the freight transport by road, maritime transport and aviation transport for the years 2020 and 2050. An overview of the reduction potential by these drivetrains and fuels will be provided by considering the technical potential, the cost-effectiveness and the Innovation System Performance.

This yields the main research question:
"To what extent are drivetrain technologies and alternative fuels capable of reducing CO_2 emission in freight transport by road, maritime transport and aviation transport in the years 2020 and 2050?"

This research question will be answered by answering the following sub questions for each of the three transport segments:
"What is the technical potential of the drivetrain technologies and alternative fuels?"

"What is the cost-effectiveness of the drivetrain technologies and alternative fuels?"

"What is the Innovation System Performance of the drivetrain technologies and alternative fuels?"

The outline of the report is as follow. Section 2 comprises a demarcation of alternative drivetrains and fuels that this research will consider. In section 3 the used theory is set out and will end in a conceptual model. Then the used method is elaborated on in section 4. Then the results are presented starting with the aviation sector in section 5, the freight road sector in section 6 and the maritime sector in section 7. All three sections begin with a description of the sector towards 2050. Then the most feasible drivetrain and fuel alternatives are selected. The technical potential, cost-effectiveness and innovation system performance of the selected alternatives will then be elaborated on. Section 8 comprises the conclusion, section 9 comprises the recommendations and the report ends with section 10, the discussion.

2. Demarcation of drivetrain technologies and alternative fuels

There are several ways of reducing CO_2 emissions in the transport sector. King (2007) indicates cleaner fuels (I), more efficient vehicles (II), and smart driver choices (III) as paths of opportunity for reducing CO_2 emissions. The smart driver choices path tries to influence and change an individual's behavior. The other options are emission reduction possibilities which do not have the intention to change people's behavior. This research only considers the technological options, given that behavior of people is complex and hard to change. Some scholars also state that a transition towards cleaner and sustainable alternatives is inevitable (Hekkert & van den Hoed, 2004).

With regard to light duty vehicles, three drivetrain technologies are widely considered as most promising, namely the (plug-in) hybrid electric vehicle (HEV), the battery electric vehicle (BEV), and the fuel cell vehicle (FCV). A study by Frenken et al. (2003) indicated that these drivetrain technologies received an increasing attention over time. Although this research does not focus on light duty vehicles it will consider the drivetrains applied in light duty vehicles for their possible implementation in aircraft, ships and heavy duty vehicles. Some heavy duty vehicle manufactures, Volvo and DAF, already produce and test hybrids. With regard to fuels, a lot of attention goes to biofuels in both scientific articles as well as newspapers and magazines. The Süddeutsche Zeitung (2009) published an article on the possibility and effects of biofuels in aviation transport. A news website published an article about the implementation of biofuels in the aviation sector (Nu.nl; 2009). Currently bio-ethanol and biodiesel are the most produced and used biofuels in the world (Fulton et al., 2004; Murray, 2005; Koh & Ghazoul, 2008). Hydrogen is also seen as a fuel, an energy carrier, for the use in fuel cell drive trains (Hamelinck & Faaij, 2005). A study by Smokers et al. (1997) investigated the hybrid, battery electric, and the fuel cell drivetrain and a set of fuels, including hydrogen and biofuels, as options for a wide variety of modalities including freight transport by road and shipping. A study by Kampman et al. (2006) proposed a list of new technologies that are expected to have the highest potential to reduce CO_2 for, among other modalities, heavy duty road vehicles, aircrafts and ships. The list of technologies includes hydrogen, biofuels and hybrid drivetrains.

This research considers the hybrid electric, the battery electric, and the fuel cell drivetrain, biofuels and hydrogen as possible drivetrain technologies and fuels to diminish CO_2 emission because these are well-documented in scientific journals, grey literature and newspapers.

2.1 Biofuels

In the directive 2003/30/EC (European Parliament, 2003 p.3) biofuels are regarded as "liquid or gaseous fuels for transport produced from biomass" in which biomass means the "biodegradable fraction of products, waste and residues from agriculture (including vegetal and animal substances), forestry and related industries, as well as the biodegradable fraction of industrial and municipal waste".
Biofuels have positive environmental properties which result in no or low net release of CO_2 (Gregory & Rogner, 1998), because the CO_2 that is emitted during combustion of biofuels were absorbed during growth (Thuijl et al., 2003). Despite, this closed carbon cycle biofuels are not carbon neutral, because during production of biofuels CO_2 is emitted during e.g. cultivation, harvest, transport, and conversion of the biomass (Uyterlinde et al., 2008).

Several biomass feedstocks for the production of biofuels can be distinguished. Roughly three basic inputs can be classified for the production of biofuels: oil plants/animal fats (I), sugar/starch crops (II) and lignocellulosic biomass (III) (Hamelinck & Faaij, 2005). The sort of feedstock and the conversion route determine the biofuel produced. This is depicted in figure 2.1.

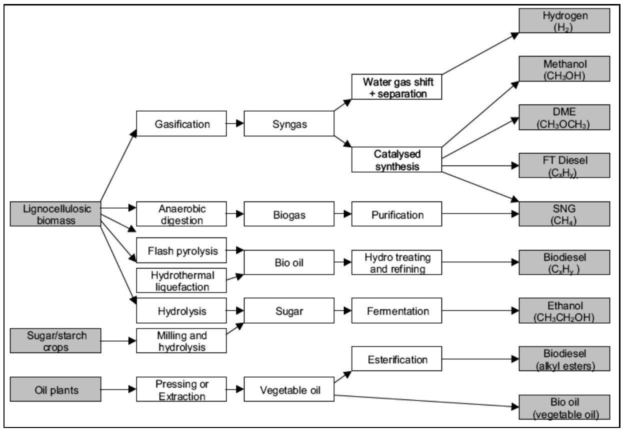


Figure 2.1: Overview of conversion paths from type of feedstock to type of biofuel (Hammelinck & Faaij, 2005 p.19).

The directive 2003/30/EC (European Parliament, 2003) acknowledges the following biofuels:

- Bio-ethanol
- Biodiesel
- Biogas
- Biomethanol
- Biodimethylether
- Bio-ETBE
- Bio-MTBE
- Synthetic biofuels
- Biohydrogen
- Pure vegetable oil

Three technology generations can be distinguished for biofuels based on the feedstock used. The first generation of biofuels is based on conventional technologies in which agricultural crops are used to produce biofuels (Agarwal, 2007). The second generation is produced by a more advanced technology in which lignocellulosic biomass from non-food crops and agricultural and forest residues such as wood or stalks of corn and wheat are converted to biofuels (Hamelinck & Faaij, 2005; UN, 2007). The so called third generation of biofuels is based upon producing biofuels from algae (Carere et al., 2008). In the remainder of the research 1^{st}, 2^{nd} and 3^{rd} generation biofuels are considered.

2.2 Hybrid electric drive train

The innovative aspect of the hybrid electric drivetrain is that, for its propulsion, it combines an internal combustion engine (ICE) with an electric motor that is powered by a battery pack. Hybrid electric drivetrains are the passenger cars Toyota Prius and Honda Civic. The electric motor and ICE configuration determine whether it is a serial or a parallel hybrid electric drivetrain (Friedman, 2003). This is depicted in figure 6.2.

The serial configuration is less complicated than a parallel configuration given that it is the electric motor alone that drives the vehicle directly (Friedman, 2003). The electric motor receives its electricity from a battery pack or indirectly from an internal combustion engine. The internal combustion engine is connected to a generator in which mechanical power is converted into electric power. A controller in the system determines whether the engine and generator, the battery pack or both provide the needed power (Friedman, 2003).

Contrary to the serial drivetrain, a parallel configuration directly links the electromotor and ICE with the powertrain (Friedman, 2003). The ICE in a parallel hybrid is larger than the engine in a series hybrid but it is still smaller than the internal combustion engine in conventional cars (Friedman, 2003).

A whole new hybrid concept is born in the light duty vehicle sector, namely plug-in hybrids. As the name suggests this car also uses an ICE and electric motor, but the electric motor's battery can also be charged by plugging the vehicle into the electricity grid.

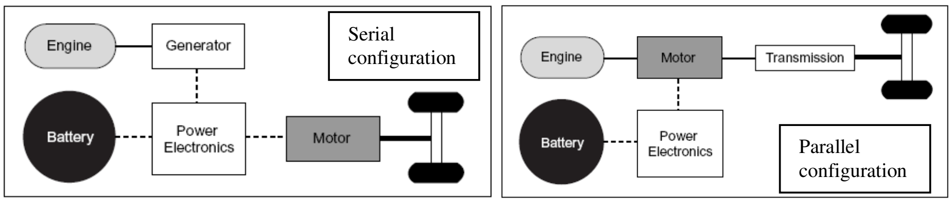


Figure 2.2: Configuration of a series and parallel hybrid electric drive train (Friedman, 2003).

2.3 Battery electric drive train

Contrary to the hybrid electric drivetrain a battery electric drive train only has on or more electric motors. This electric motor is driven by a battery which has to be charged by the electricity grid (Nagelhout & Ros, 2009). The battery is considered to be the crucial component in a battery electric drivetrain.

A battery is composed of one or more cells that consist of an anode, cathode, electrolyte and a separator within the electrolyte (Nagelhout & Ros, 2009). Energy is stored in a cell by charging it (i.e. plugging it into the electricity grid). Many batteries exist due to different materials used for the cell's components and in return these determine the characteristics of a battery (Nagelhout & Ros, 2009). One important characteristic of a battery is its energy density, the energy that can be stored per kilogram (Nagelhout & Ros, 2009). Currently, batteries with a lithium composition are considered to be the most promising (Nagelhout & Ros, 2009).

2.4 Fuel cell drive train

Fuel cells are electrochemical devices which can convert chemical energy into electrical energy directly (EG&G Technical Services Inc., 2004). The basic structure of a fuel cell consists of a porous anode and cathode and an electrolyte layer in between. This configuration is depicted in figure 2.3.

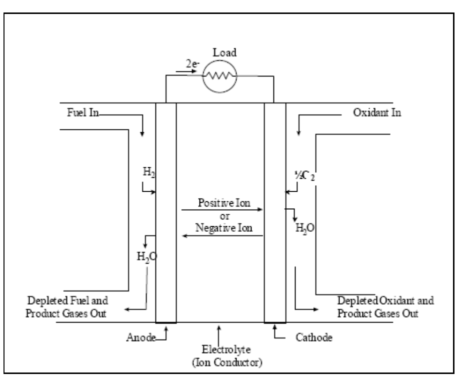


Figure 2.3: Basic structure of a fuel cell adopted from EG&G Technical Services Inc. (2004, p.21).

For operation, a fuel (often hydrogen) is supplied to the negative electrode, the anode, and an oxidant (mostly oxygen) is provided to the positive electrode, the cathode. The electrochemical reaction occurs at the anode and cathode and produces ions that pass the electrolyte. At the same time electric current which cannot pass the electrolyte performs work e.g. driving a vehicle (EG&G Technical Services Inc., 2004). Fuel cells differ from a battery electric drivetrain because a fuel cell operates as long as the fuel is continuously supplied while the battery in a battery electric drivetrain discharges when it is used.

Based on the used fuel, operation temperature and electrolyte multiple fuel cells can be classified (Abe, 2002; Crawly 2006a, 2006b, 2007a, 2007b):

- The proton exchange membrane electrolyte (PEMFC)
- Alkaline fuel cell (AFC)
- Phosphoric acid fuel cell (PAFC)
- Molton carbonate fuel cell (MCFC)
- Solide oxide fuel cell (SOFC)

The most appropriate area of application differs per fuel cell as they differ in their characteristics. Given the focus on transport in this research in combination with fuel cell characteristics, the most appropriate fuel cell technology for the remainder of the report is the PEMFC (EG&G Technical Services Inc., 2004; Crawley, 2006b).

3. Theory

3.1 Innovation systems

Innovation does not occur in isolation but rather in the context of interaction with customers, suppliers, competitors, private and public organizations (Lundvall, 1992; Nelson, 1993; Edquist, 2005). The context in which innovation occurs is referred to as Innovation Systems. An Innovation System is used to analyze innovation and technological change and this approach considers an innovation and diffusion of technology as both an individual and collective act (Hekkert et al., 2007a). The concept Innovation System is introduced by Freeman (1987, p.1) as:

> "The network of institutions in the public and private sector whose activities and interactions initiate, import, modify and diffuse new technologies"

Innovation Systems can be defined in several ways but they share key features. Innovations are developed within systems, existing of actors that contribute to innovation in different ways (Negro, 2007). Within Innovation Systems, the innovation is seen as a learning process by the involvement of different actors that exchange knowledge (Lundvall, 1992). Technological change is thus considered a recombination of knowledge instead of material development (Suurs, 2009). Since the introduction of the concept by Freeman (1987) several variants, based on their scale of analysis, have emerged. The Innovation System concept has been applied at a national level leading to a National Innovation System (Lundvall, 1992). The concept is also applied at a regional and sectoral level (Breschi & Malerba, 1997; Cooke et al., 1997).

Another delineation of an Innovation System is referred to as Technology Specific Innovation Systems (TSIS) which focuses on specific technologies. This approach makes it possible to analyze the strengths, weaknesses and dynamics of a system related to an emerging technology (Jacobsson & Johnson, 2000; Hekkert et al., 2007a). Such an Innovation System can be defined as:

> "A dynamic network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure and involved in the generation, diffusion, and utilization of technology" (Carlsson & Stankiewicz, 1991 p. 93).

A TSIS cuts through geographical and industrial boundaries by a focus on a technology or technological field. Furthermore, most TSIS studies analyze the development of an emerging technological innovation (Suurs, 2009). Given the subject of this research, the drivetrain technologies and alternative fuels which resemble a technology or technological field, the TSIS approach has been chosen as the most appropriate Innovation System delineation for this research.

Figure 3.1 illustrates the structure of a TSIS. The supply side can be characterized as where new technologies and technological knowledge is created (Suurs, 2009). The demand side in return can be seen as where technologies and knowledge are used (Suurs, 2009). The government concept consists of the governmental body and all the policy instruments. The knowledge infrastructure consists of knowledge institutes that generate, assess and transfer knowledge while the intermediary infrastructure consists of organizations that stimulate the interaction between the different Innovation System components (Suurs, 2009).

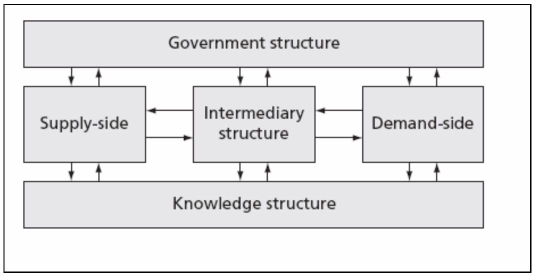


Figure 3.1: Components of the innovation system(Suurs, 2009 p. 48).

By performing a structural analysis, insights are gained in the systemic features that form drivers and barriers for technology diffusion (Suurs, 2009). A shortcoming of this Innovation System structure analysis is that it is quasi-static in character while it is important to understand the activities in the system and to pay attention to the factors that influence these dynamics (Negro, 2007). This shortcoming is addressed by a focus on Innovation System Functions in addition to a structure analysis (Suurs, 2009). This approach considers the TSIS as a system with a purpose that is served by the fulfillment of system functions (Suurs, 2009). Johnson (1998) introduced the Functions of Innovation Systems and referred to it as the activities needed for an Innovation System to perform well; i.e. to result in a successful technology development and diffusion. Based on different categories of functions, improvements to earlier studies and empirical studies, Hekkert et al. (2007a) proposed seven Innovation Systems functions, namely *(1) entrepreneurial activities,(2) knowledge development, (3) knowledge diffusion through networks, (4) guidance of the search, (5) market formation, (6) resources mobilization and (7) creation of legitimacy/counteract resistance to change*.

Entrepreneurial activities are essential in innovation (systems). Without entrepreneurs, innovation would not occur and the Innovation System would not exist (Negro, 2007). It is the entrepreneurs' task to turn the potential of new knowledge, networks, and markets into concrete actions for new business opportunities (Hekkert et al., 2007a) and overcome uncertainties associated with emerging technologies (Carlsson & Stankiewicz, 1991).

Considering that "*the most fundamental resource in modern economy is knowledge and, accordingly, that the most important process is learning*" (Lundvall, 1992 p.1), makes *knowledge development* an important function. Strongly related to this function is the function *knowledge diffusion through networks.* When knowledge is created, it becomes important that this knowledge is shared with other actors in the system, especially given the heterogeneous character of these systems (Hekkert et al., 2007a).

Guidance of the search embodies the process of selection when a set of technological options are available; variation as result of the function *knowledge creation* (Hekkert et al., 2007a). This process of selection can be executed by the government, industry and/or the market. Guidance of the search is more than just the matter of market or government influence, rather it is *"an interactive and cumulative process of exchanging ideas between technology producers, technology users, and many other actors, in which the technology itself is not a constant but a variable"*(Hekkert et al., 2007a p. 423).

Emerging technologies often face difficulties in competing with incumbent technologies. Most innovations are relatively crude and inefficient compared to the incumbent technology and offer only little advantages over the existing technologies as a result (Rosenberg, 1976). The function *market formation* aims at the protection of emerging technologies. This can be achieved by niche markets, where actors can learn, or by the creation of (temporary) competitive advantage with for example tax regimes or the formation of targets (Hekkert et al., 2007a).

Resources mobilization refers to both financial and human capital, which can be considered as crucial input for all activities within the Innovation System (Hekkert et al., 2007a). An emerging technology cannot be supported if it lacks financial and human resources or competences and skills of actors (Carlsson & Stankiewicz, 1991).

The last function *creation of legitimacy/counteract resistance to change* focuses on the activity to let the emerging technology become part of or even to overthrow the current incumbent regime (Hekkert et al., 2007a). Actors with vested interest in the incumbent regime will resist to the emerging technology. Advocacy coalitions can then function as a catalyst for the creation of legitimacy by putting a new technology on the agenda, then lobby for resources and tax regimes (Hekkert et al., 2007a).

3.2 Diffusion S-curve

Innovations do not become part of society out of the sudden, but are rather a diffusion over time which may be characterized by an evolution through certain stages. The diffusion rate of an innovation can be represented by a so-called diffusion S-Curve (Rogers, 2003) and is depicted in figure 3.2. The S-Curve is a representation of the diffusion process of most innovations. Such an S-curve starts with a pre-development phase in which a prototype is created. Then the take-off phase starts, in which a slight demand and commercial availability of the innovation emerges. The diffusion phase follows which is characterized by a fast increase in diffusion and decreasing amount of suppliers as a result of competition. The S-curve ends with the stabilization phase, in which the innovation becomes vested in the regime. The slope of the curve differs per innovation, depending on the rate of diffusion. If the rate of diffusion of an innovation is high, the S-curve will become steeper while the slope of the S-Curve will become more gradual when the rate of diffusion is low.

The technical CO_2 emission reduction potential is the maximum CO_2 emission reduction that may be achieved by a complete diffusion of a technology among society in 2020 and 2050. This suggests that the CO_2 emission reduction of alternative drivetrains and fuels that may be achieved is influenced by the extent to which diffusion has occurred in 2020 and 2050. In this approach an important aspect necessary for estimating the CO_2 emission reduction that may be achieved is the maximum achievable diffusion percentage for the years 2020 and 2050.

Grübler et al. (1999) indicated, by studying 265 diffusion processes, that transitions are typified by a relatively long period of gestation which is followed by a rapid take-off and diffusion phase. The analyzed diffusion processes include for instance the introduction of steam ships which had to compete with sail ships, competition between automobiles and carriages and the electrification of the railways which resemble situations the drivetrain technologies and alternative fuels are in know. The diffusion process has an average time span of 41 years, from take-off to stabilization, with a standard deviation of 42 years (Grübler et al., 1999). The substitution of sailships by steamships lasted for 55years while the substitution of carriages by automobiles only took 16 years. This indicates that the actual diffusion time of technologies among society can differ tremendously. The diffusion time of a technology thus is a crucial factor in determining the diffusion percentage of a technology. The study by Grübler et al. (1999) indicated that no average time-span that is known to overcome the pre-development phase of the diffusion S-curve exists.

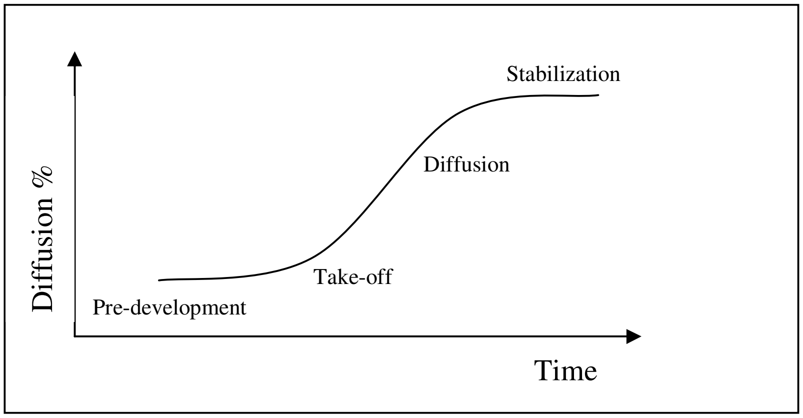


Figure 3.2. Diffusion Curve (Rogers, 2003).

3.3 Completeness of Innovation System and Diffusion S-curve

The diffusion S-curve of a technology can be divided in four stages as depicted in figure 3.2. The take-off phase is characterized by the emergence of a small commercial market. A commercial market only occurs if sufficient actors are involved and these have to serve the Functions of Innovation Systems sufficiently, since the absence of or the insufficient fulfillment of one single function or structure component may result in the breakdown of a complete TSIS (Suurs, 2009). The turning point in the S-curve (the middle of the S-curve) suggests that the Innovation System's structure and functions have to be served even better because the innovation has captured a considerable market share, it overruled the vested technology and became the dominant technology in society itself. With other words, it can be assumed that the more an Innovation System's structure is complete and the functions are served, the better the progress of a technology is along the diffusion S-curve and the more a technology may diffuse among society.

In this research it is assumed that the diffusion S-curve implicitly takes into account the Innovation System completeness and the extent to which Innovation System Functions are served, because the structure and functions have to be fulfilled to a certain extent in order to make progress along the diffusion S-curve possible. As a result the progress of an innovation along the diffusion S-curve is influenced by the extent to which the innovation structure is complete and functions are served. The Innovation System structure and Innovation System Function completeness for 2020 and 2050 cannot be indicated as a result of uncertainties by actors entering and leaving the innovation system and the extent to which functions will be addressed. Using the assumed relation between the theoretical concepts Innovation System completeness and diffusion S-curve allows doing CO_2 emission reduction estimations on the basis of diffusion percentages in the years 2020 and 2050 given a time-span needed for complete diffusion and implicitly takes into account a minimal structure completeness and function fulfillment as preconditions to make progress along the diffusion S-curve.

3.4 Costs of CO_2

In many cases, measures to reduce emissions lead to extra costs. By including the extra costs to prevent an amount of CO_2, a so-called cost-effectiveness may be arrived at. Including the cost-effectiveness in the analysis, provides economical insights with regard to the additional cost levels to reduce an amount of CO_2 with a drivetrain technology or alternative fuel. The cost-effectiveness of measures has to be in range with the price for CO_2 in 2020 and 2050 to form a feasible option to reduce CO_2 emissions from an economical point of view. Extensive literature exists considering the financial value for environmental damage and prevention costs. The estimated values of the executed studies indicate that a wide variety exists in the CO_2 prevention costs. This variety in costs to prevent CO_2 emission is a result of the suppositions taken that may differ per executed study. Examples of suppositions that influence the price for CO_2 are the oil prices and policy goals that are taken into account such as the Kyoto goals.

Taking into account the current price for a tonne of CO_2, € 20 – 25, and the execution of a comparison of several studies that estimate the costs to avoid a tonne of CO_2, CE (2008a) estimates the cost of CO_2 in 2020 to be 40 €/tonne and for 2050 it is estimated at 85 €/tonne CO_2. The estimated CO_2 prices of CE (2008a) take into account the post-kyoto-goals (20-30% reduction in 2020 compared relative to the 1990 levels).

3.5 Conceptual model

In this study, the Innovation System Performance is measured by both the completeness of the Innovation System structure and the fulfillment of the system functions. The completeness of the Innovation System structure and the fulfillment of the Innovation System Functions are crucial indicators for the potential of technological change (Hekkert et al., 2007a). It is assumed that the more actors become involved in the Innovation System and the more and the better functions are served by these actors, the higher the chance of technological progress of a drivetrain technology or alternative fuel. The Innovation System and Innovation System Functions influence the development, diffusion, and implementation of a technology (Negro, 2007). As a result, it is assumed that the better Innovation System Performance the higher the chance of technological and economical progress of a drivetrain or alternative fuel becomes. This implies that, the better the Innovation System Performance, the higher the chance that a large share of the potentials of drivetrain technologies and fuels may actually be exploited in 2020 and 2050.

As a result of uncertainties by actors entering and leaving the innovation system and the extent to which functions will be addressed the Innovation System Performance for 2020 and 2050 cannot be indicated. The Innovation System Performance is used to indicate the current fulfillment of the Innovation System and the Innovation System Functions. As a result, an overview of the weak spots is created where intervention may occur to achieve higher CO_2 emission reductions in 2020 and 2050. In the previous section a relation between Innovation System Performance and diffusion S-curve is assumed. In this research it is assumed that the diffusion S-curve implicitly takes into account the Innovation System Performance, since the structure and functions have to be fulfilled to a certain extent in order to make progress along the diffusion S-curve possible. The technical CO_2 potential and the diffusion S-curve together will be used to determine the CO_2 emission reduction of drivetrain technologies and alternative fuels in 2020 and 2050. In addition an overview of the weak spots in the current Innovation Systems where intervention may occur in order to capture a bigger part of the technical CO_2 emission reduction potential in the years 2020 and 2050 is constructed. Cost-effectiveness is included to create insights in the economical aspects of the drivetrain technologies and alternative fuels to diminish CO_2 emission compared to the price for CO_2 in 2020 and 2050. The foregoing results in the conceptual model depicted in figure 3.3. How these concepts will be measured, the operationalization, is elaborated on in the methodology section.

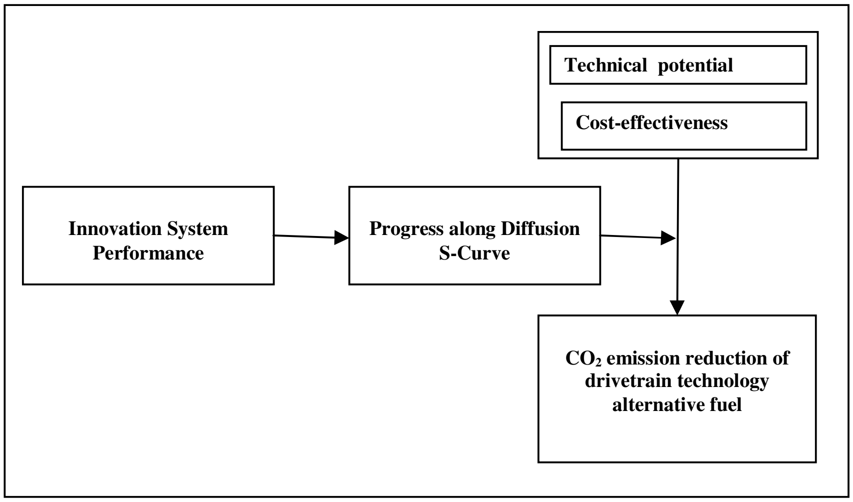


Figure 3.3: Conceptual model.

4. Methodology

In short, in this research the extent to which selected drivetrain technologies and alternative fuels can provide a contribution to CO_2 emission reduction for three segments of the transport sector is investigated. The extent to which these alternatives can contribute to CO_2 reduction is analyzed by the technical potential, the cost-effectiveness, the Innovation System Performance and the diffusion S-curve of these innovations. This section elaborates on the method used to analyze the possibilities of these innovations.

4.1 Drivetrain and alternative fuel selection

Section 2 comprised a pre-selection of alternative drivetrain technologies and fuels that are considered as possible alternatives for the aviation, freight road and maritime sector to diminish CO_2 emission. A selection of most promising alternatives is made for each sector by analyzing how the alternative drivetrains and fuels perform on important characteristics specific to that sector. Alternatives that perform equally or even better compared to the currently used drivetrain and fuel are selected to be analyzed on their technical potential, cost-effectiveness and Innovation System Performance.

4.2 Background scenarios

In order to investigate the possible CO_2 emission reduction, it is necessary to know how a specific sector develops toward 2020 and 2050. For the aviation and maritime sector both national and international projections are used, because these sectors are driven by international activity. For all three sectors, a high case approach in terms of CO_2 emission is adopted to illustrate possible reduction potentials. The high case projections, in terms of CO_2 emission, are primarily driven by population growth and high economic development which in return lead to high traffic demand, high energy use and prosperity.

For the projections of the Dutch aviation, freight and maritime sector the "Welfare and Environment" (WLO) projections are used (CPB, MNP, RPB, 2006). The Netherlands Environmental Assessment Agency (PBL) made CO_2 emission projections, based on four WLO scenarios (PBL, 2007). The scenario prognoses start in the year 2000 and end in 2040 and contain data about the energy consumption of different sectors. For this study, the value of energy consumption for 2050 is extrapolated linearly based on the growth between 2030 and 2040.

The four scenarios in the WLO study are named Global Economy, Strong Europe, Transatlantic Market and Regional Communities (CPB MNP RPB, 2006) [2]. The Global Economy scenario is characterized by high population growth, high economic development, international cooperation and a market-oriented perspective (CPB MNP RPB, 2006). Strong Europe is characterized by Europe being a strong player as European countries partly give up their sovereignty and act as one in solving for instance climate problems. In the Transatlantic Market scenario, nations keep part of their sovereignty and rather act on a national level of problem solving. Furthermore, the labor productivity and economic growth are higher than in Strong Europe while the population growth only increases slightly. The Regional Communities scenario is driven by a failure of political European institutional integration as nations do not give up their sovereignty. International problems are not addressed and economic growth is low. The Global Economy scenario forms the high case scenario in terms of CO_2 emission. The high case scenario, in terms of CO_2 emissions, is considered to illustrate the technical reduction possibilities.

[2] See CPB MNP RPB (2006) chapter 3 for a more in depth description of the four scenarios.

4.3 Technical potential and cost-effectiveness

The technical potential and cost-effectiveness of the innovations were investigated by performing desk research in combination with interviews with key stakeholders. The desk research comprised a literature study of both scientific journals and grey literature i.e. documents or working papers from government agencies or scientific research groups.

The technical potential is defined as *the maximum amount of emission reduction, expressed in CO_2 when considered from an isolated technical point of view*. The emissions of conventional and alternative fuels may differ in life cycle steps like production, distribution, storage, conversion and usage. Therefore, the whole well-to-wheel (WTW) cycle of alternative fuels is considered as it influences the total CO_2 emission reduction that can be achieved. The life cycle of drivetrain technologies is however not considered because data could not be found about the CO_2 emission during the production of alternative drivetrains. Findings on the emission reductions potentials (as a share of total emissions) are combined with projections of the volume development of each sector towards 2050. This results in the technical CO_2 emission reduction that can be achieved for each sector in 2020 and 2050.

The cost-effectiveness is considered *the costs that come along with the drivetrain technologies and alternative fuels to avoid a tonne CO_2 and expressed by* €/tCO_2 avoided. The cost-effectiveness for alternative fuels is calculated by the difference in CO_2 emission and production costs of an alternative fuel compared to the conventional fuel. To calculate the costs-effectiveness of drivetrain technologies the additional investment costs are multiplied by an annuity factor, based on the technical life time and an interest rate of 5 – 10%, and then divided by the difference in CO_2 emission compared to the conventional drivetrain. The calculated current cost-effectiveness of the drivetrains and fuels will be compared with the price of CO_2 in 2020 and 2050 to provide insights in the extent to which the current cost-effectiveness is in range of the costs to avoid a tonne CO_2 in 2020 and 2050.

4.4 Innovation System Performance

The Innovation System Performance is measured on the basis of the TSIS's structure as well the Functions of Innovation Systems. Both are indicators for the potential of technological change (Hekkert et al., 2007a). Although a TSIS is not limited by any sectoral or geographical boundaries and it is acknowledged that the development of the innovations is partly an international activity the Innovation System Performance is only investigated on its current fulfillment restricted to the Netherlands. The Innovation System Performance is analyzed by conducting interviews and in addition a literature study is executed. This analysis is performed for the current situation, thus an inventarisation of the current actors present and the Innovation System Functions served in the Innovation System is made[3]. An analysis of the TSIS cannot be done for 2020 and 2050 because of many and large uncertainties related to actors entering and leaving the system and key activities that will or will not be addressed by these actors. Furthermore, an inventarisation of the current system and function fulfillment in the Netherlands reveals the weak spots that could be addressed to better capture the CO_2 emission reduction potential in 2020 and 2050.

The innovation science group of Utrecht University developed a method for monitoring/evaluating transition processes; Innovation System analysis (Hekkert et al., 2007b). A part of this method is used for conducting this research. The method comprises three steps.

[3] A historic event mapping analysis will thus not be performed.

The first step in this method of evaluation focuses on the phase of development an innovation is currently in. The first step is to position the innovation on a hypothetical diffusion S-curve on the basis of interviews and literature. It can be expected that during the pre-development phase there will be no or only marginal demand or supply, so the quality of these components in the innovation system can be expected to be very weak or weak in the beginning of the S-curve. However, as an innovation evolves over time through these phases, more actors become involved and the structure of an Innovation System becomes more complete and therefore the chance for technological change becomes higher.

The second step focuses specifically on the structure of the TSIS. In this step it is revealed which actors form a part of a certain component of the innovation system. The components will be attributed a score based on their quality/size related to the actors and institutions varying from 1= very weak, 2= weak, 3= sufficient, 4= strong, to 5= very strong. This will be performed by a qualitative analysis based on information provided by experts and literature.

Step three aims at measuring the fulfillment of the Innovation System functions as proposed by Hekkert et al. (2007a). For each function a score, based on the present situation, will be attributed based on a five point likert scale in which 1= very weak, 2= weak, 3= sufficient, 4= strong, and 5= very strong. Questions pertaining to this step in the method of Hekkert et al. (2007b) are included for each function in Appendix I.

This information results in a current state overview of the Innovation System structure and its dynamics for each of the drivetrain technologies and alternative fuels. More precisely, it results in an overview of the actors currently involved and the fulfillment TSIS functions.

As a result of the assumption that a higher Innovation System Performance enlarges the chance that a bigger share of the potentials of drivetrain technologies and fuels may actually be exploited in 2020 and 2050 it would hold that in the ideal situation, the technical potential and cost-effectiveness will be achieved fully as a result of a perfectly fulfilled Innovation System structure in terms of quantity and quality and all Innovation System Functions are served very strongly. Since the quantity and quality of the Innovation System structure and the extent to which Innovation System functions are served are measured by a score of 1 – 5 the ideal situation refers to a total score of 85 points (25 for quantity, 25 for quality of structure and 35 for the innovation functions). Assessing scores to the quantity and quality of the innovation structure and the extent to which functions are served at this moment results in a total score that could be expressed as a percentage of the ideal situation.

4.5 Diffusion S-curve

It is assumed that a higher Innovation System Performance enlarges the chance that potentials of drivetrain technologies and fuels may actually be exploited in 2020 and 2050. However the Innovation System Performance is analyzed for the current situation and used to reveal the weak spots that may be addressed to since determining the Innovation System Performance for 2020 and 2050 would go in line with large uncertainties related to actors and function fulfillment.

As elaborated on in the theory section, it is assumed that the progress of a technology along the diffusion S-curve is determined by the Innovation System Performance. Relating the theoretical concepts of Innovation Systems and Innovation System Functions to the emergence of a commercial market, the take-off phase, suggests that all the components and functions have to be addressed sufficiently since the absence of or the insufficient fulfillment of one single function or structure component may result in the breakdown of a complete

TSIS (Suurs, 2009). We assume that all the components, in terms of quality and quantity, and system functions should at least score a three on the basis of the used five point likert scale. Expressing the total score of 51 points (15 for quality, 15 for quantity and 21 for functions) in an Innovation System Performance results in a minimal percentage score of 60% needed to start the take-off phase. The turning point (the middle of the S-curve) suggests the innovation has captured a considerable market share, overruled the vested technology and becomes the dominant technology in society itself which suggests that the Innovation System's structure and functions have to be served perfectly. This implies that all the components and functions must score a five on the basis of a five point likert scale which equals an Innovation System Performance of 85 points (25 for quality, 25 for quantity and 35 for functions) or 100%. Furthermore, if the development of the Innovation System Performance is lower, the CO_2 emission reductions will also become lower since the progress along the diffusion curve will become slower and it may even lead to the breakdown of a complete TSIS as a result of the absence of or the insufficient fulfillment of one single function or structure component (Suurs, 2009).

Combining the technical CO_2 potential with the diffusion S-curve allows making an estimation of the CO_2 reduction for 2020 and 2050. This estimation implicitly takes into account an improving Innovation System Performance toward 2020 and 2050. In this approach it is necessary to estimate the maximum achievable diffusion for the years 2020 and 2050. Grübler et al. (1999) analyzed that the average time-span from take-off toward stabilization is 41 years. No specific time-span exists for the period from pre-development phase towards the take-off phase which as a result remains an uncertain factor in indicating the actual CO_2 emission reduction potential in 2020 and 2050. For the drivetrains and fuels that are currently positioned in the pre-development phase a time-span of 5 years is assumed to at least be necessary to overcome the pre-development phase.

Assuming the pre-development phase to last for at least another 5 years means that the take-off phase will start in 2014 (or later) and only 6 years remain toward 2020 and 36 years toward 2050. Figure 4.1 points out that considering a time-span of 41 years results in a diffusion of 10% in 2020 and 95% in 2050. However Grübler et al. (1999) also pointed out that there is a great variety in the time span needed for diffusion of technologies. The time span needed to make a progress towards the stabilization phase is a crucial aspect in indicating the diffusion percentage of the technology among society. To acknowledge that the diffusion time of these drivetrain technologies and alternative fuels may very well be lower or higher than the average 41years a small sensitivity analysis has been performed to indicate how the diffusion time-span affects the diffusion of a technology. The diffusion percentage for 2020 and 2050 are depicted in table 4.1 using a time span of 20, 41 and 60 years for the period of take-off toward stabilization. The diffusion curves for 20 and 60 years are included in appendix II.

Table 4.1. Diffusion percentages for 2020 and 2050.

Time-span	Diffusion in 2020	Diffusion in 2050
20	25%	100%
41	10%	95%
60	5%	70%

In the report the average time-span of 41 years will be used to calculate the CO_2 emission reduction of the drivetrains and fuels. The technical CO_2 emission reduction potential for 2020 and 2050 is therefore multiplied by 10% for 2020 and with 95% for 2050 to arrive at a more realistic CO2 emission reduction that may be achieved by drivetrain technologies and alternative fuels. This more realistic reduction takes into account diffusion time of technologies and improving Innovation System and Innovation System functions. The precondition to achieve these diffusion percentages are that there is a continuous build-up of the TSIS, resulting in 60% fulfillment by 2014 and complete fulfillment around 2035 (the middle of the diffusion S-curve). If this precondition is not met, the CO_2 emission reduction by 2020 and 2050 will be lower accordingly.

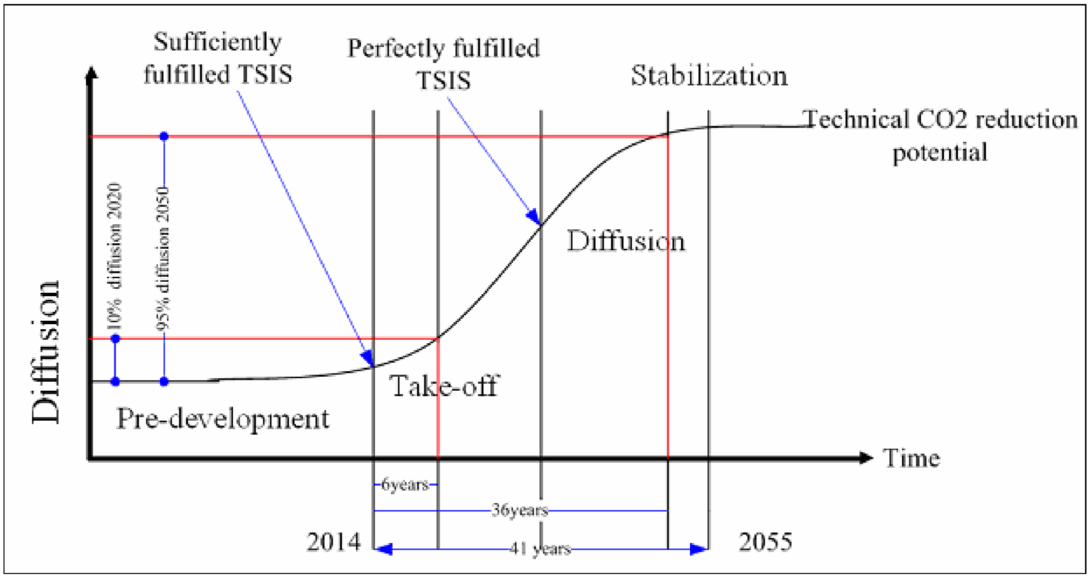


Figure 4.1: Diffusion percentage for 2020 and 2050 with a time span of 41 years for the period between take-off and stabilization

5. Aviation sector

This section presents the results for the aviation sector. First projections of aviation growth towards 2050 world wide will be set out. Second the development of the Dutch aviation sector will be discussed. Third a selection of promising drivetrain technologies and fuels will be made. The selected drivetrain technologies and alternative fuels will be described on the potential to diminish CO_2 emissions. Fourth, economical aspects will be addressed. The section ends with an overview of the innovation system structure and activities.

5.1 Aviation sector towards 2050

Aviation is considered an international activity. IPCC (2000) presented six projections of the CO_2 emission by world aviation. The low and high growth scenarios are reflected in figure 5.1. Another 16% of CO_2 emission is added to take into account the well-to-tank part (NETL, 2008).

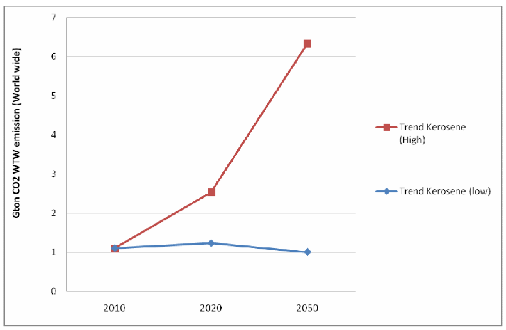


Figure 5.1: Total world wide aviation carbon dioxide emissions. Based on IPCC (2000) and NETL (2008).

Figure 5.1 reveals that CO_2 emission by aviation between 2010 and 2020 increase with 12 – 107%. In 2050 the CO_2 emission will be approximately 8,5% lower or 478% higher compared to 2010. This shows that the development of CO_2 emissions by the aviation sector is uncertain on the mid and long term. This wide variance is the result of factors that influence aircraft CO_2 emission such as economic growth, traffic demand and technological development of conventional technology which differ per scenario (IPCC, 2000).

5.1.1 Dutch Aviation sector towards 2050

The United Nations Framework Convention on Climate Change (UNFCCC) developed a univocal rule for assigning and measuring the exhaust of CO_2 in the atmosphere caused by the aviation sector (V&W, 2007). The UNFCCC-protocol excludes emissions of aviation from national data on CO_2 emission. The national emission of aviation is reported separately by linking the emission of airplanes with the usage of fuels, which are reported as international bunkers (V&W, 2007). International bunker fuels are sold at Schiphol Airport which makes it possible to assign aviation emissions to the Netherlands.

The Netherlands Environmental Assessment Agency (PBL) has CO_2 aviation emission projections, based on four different scenarios. The scenario prognoses contain simulated data about the energy consumption of the Dutch aviation bunker. The total CO_2 emission based on the Dutch aviation bunker is illustrated in figure 5.2. Again, another 16% of CO_2 emission is added for the well-to-tank part.

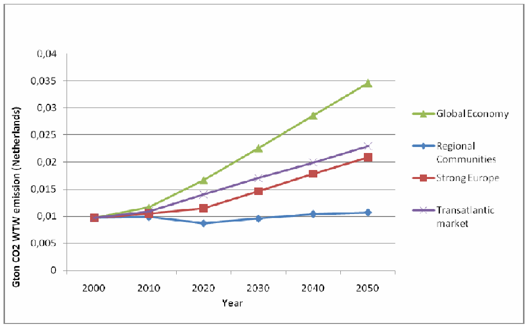


Figure 5.2: CO_2 emission of the Dutch aviation sector based on reported bunker fuels towards 2050. Note: The value for 2050 is extrapolated linearly. Data of the energy consumption is obtained from data sheets of the PBL and used to calculate the CO_2 emission in Gton using the reference value of 71,5kg CO_2/GJ kerosene.

Comparing figure 5.1 and 5.2 illustrates that the Netherlands, is responsible for a small share of the total world's aviation CO_2 emission. Knowing that the CO_2 emission of the world aviation contributes to a small part, 3 – 5%, of the total anthropogenic CO_2 towards 2050 even more indicates the small contribution of the international bunker located in the Netherlands.

In the remainder of the report the Global Economy scenario as high case scenario in terms of CO_2 emission will be considered to illustrate possible technical reduction potentials.

5.2 Alternative drivetrain and fuel selection

Several options exist to reduce the emission of CO_2 in the aviation sector. The emission of CO_2 can be influenced by the selected drivetrain, fuel, plane size, aerodynamics/design, logistic efficiency and travel time. In this report the focus is on drivetrain technologies and alternative fuels for aviation.

Some airlines, Atlantic, All Nippon, SAS, KLM, Air France, Gulf Air, Cargolux, and Air New Zealand, see the urgency to look for alternative and sustainable drivetrains and fuels (SAFUG, 2009). The need to look for alternatives is also associated with the fact that kerosene prices are an important economical driver for efficiency improvements (OECD, 2008). Approximately 30-40% of the operating costs are fuel costs. Over time, efficiency improvements have been achieved as a possible result. To illustrate, a Douglas Commercial flew approximately 6 passenger kilometers on 1 liter of fuel in 1970 while a Boeing 777 in 2006 could fly 44 passenger kilometers on 1 liter of fuel (Interview Verschoor, 2009). The foregoing indicates the earlier mentioned economical driver of the aviation sector to innovate. It, however, also shows that the aviation sector is currently driven by incremental innovation to improve the currently used drivetrain fuel combination; the gasturbine with Jet A-1 fuel also known as kerosene.

Aspects of drivetrain and fuel selection

An important technological characteristic for drivetrains in the aviation sector is the power to weight ratio. A drivetrain has to be lightweight since heavy engines reduce the revenueproducing payload and the drivetrain must have enough power to overcome the weight and drag. Like drivetrains, fuels also have to meet certain criteria that are important for the aviation sector. Criteria for fuels are the density (Kg/m^3), energy density (MJ/Kg and MJ/L), the freezing point (Chevron, 2006; Interview Gent van, 2009) and the fuel CO_2 intensity. Furthermore a similar performance level of aircraft to the current situation is used as a reference situation.

Drivetrain fuel combinations available

This sub-section comprises a description of the characteristics of the drivetrain fuel combinations for the aviation sector. Figure 5.3 illustrates the description of the several drivetrain fuel combinations given below. For the conventional drivetrain fuel combination values are set on 100 and the alternative drivetrain fuel combinations are relatively to this value.

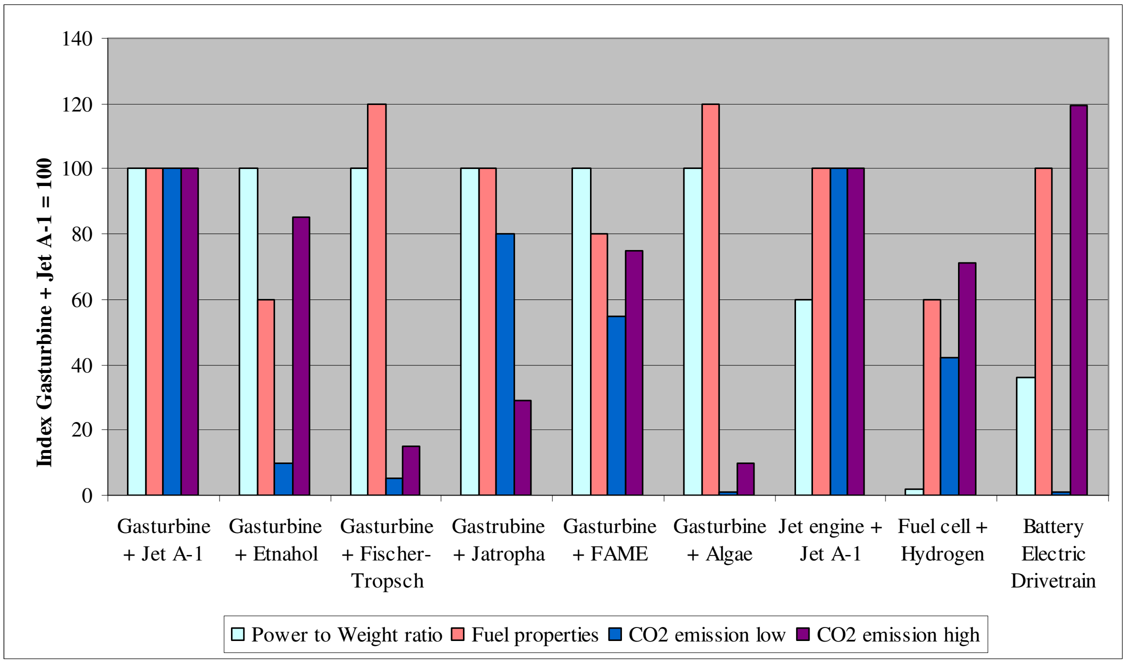


Figure 5.3: Aspects of drivetrain and fuel selection in the aviation sector. Characteristic performance of conventional drivetrain fuel combination is set on 100. Note: the characteristic fuel properties are based on several fuel properties aspects. If a fuel property was negative compared to the conventional fuel a percentage was subtracted from the 100% and when a fuel property aspect was better compared to the conventional fuel an percentage was added up. The characteristic fuel properties is thus expressed by an percentage compared to the conventional fuel but more by the fact whether fuel properties are equal, better or worse.

<u>Gasturbine with Jet A-1 fuel (Conventional drivetrain fuel combination)</u>

Power to weight ratio. The power to weight ratio of a gasturbine is approximately 5,00 kW/kg which currently is the highest ratio compared to alternative drivetrains (Shell, 2008).

Fuel properties. Jet A-1 fuel is the used fuel in the aviation sector. Its technical characteristics are a density of 800 Kg /m^3, an energy content of 43,2MJ/kg and 34,8 MJ/l, and a freezing point lower than -47°C (Shell, 2008). The alternative fuels and drivetrains have to meet these characteristics to be a potential alternative as it currently is the standard.

CO_2 intensity. The fuel CO_2 intensity of Jet A-1 fuel is considered poor as for each liter of kerosene combusted 2,6 kg CO_2 is emitted. Another 16% can be added to this for the production of kerosene (NETL, 2008). This CO_2 intensity value is used to compare the alternative options drivetrain fuel combinations with.

<u>Gasturbine with Ethanol</u>

Power to weight ratio. See above for gasturbine.

Fuel properties. Ethanol can be regarded an alternative that can be used as a fuel for the gasturbine. Ethanol has a density of 790 Kg/m^3, an energy content of 27,2MJ/kg and 22,0 MJ/l, and a freezing point lower than -115°C (Shell, 2008). Ethanol has a low energy content per kilogram as it weighs 60% more than the standard Jet A-1 fuel (NASA, 2006).

CO_2 intensity. The fuel CO_2 intensity performance of ethanol depends on aspects like the production method and feedstock input. Overall the fuel CO_2 intensity of ethanol is considered good as it can reduce between 15-55% when it is produced trough 1st generation and 55-90% by 2nd generation methods compared to fossil fuel (MNP, 2005).

<u>Gasturbine with Fischer-Tropsch Kerosene</u>
Power to weight ratio. See above for gasturbine.
Fuel properties. Kerosene produced by Fischer-Tropsch processes is regarded an alternative fuel. Fischer-Tropsch kerosene has very similar or even better characteristics than conventional kerosene, a density of 740 kg/m^3, an energy content of 44,0 MJ/kg, 32,5 MJ/l, and a freezing point lower than -50°C (Shell, 2008).
CO_2 intensity. The fuel CO_2 intensity performance of Fischer-Tropsch kerosene depends on aspects like the production method and feedstock input. Either the synthetic kerosene is produced through coal-to-liquid, gas-to-liquid or biomass-to-liquid processes. The fuel CO_2 intensity of biomass-to-liquid is far better than gas or coal-to-liquid processes. Kerosene produced from cellulose or hemicellulose containing materials, mostly woody materials or grass, using a Fischer Tropsch proces can achieve a CO_2 emission reduction of 90%, compared to conventional fuels (SenterNovem, 2009a) and between 85 and 95% according to MNP (2005). Another advantage comes from the fact that these liquid fuels are very clean since they are (almost) sulphur free (IPCC, 2000; Hamelinck et al., 2004; Refuel, 2006).

<u>Gasturbine with Jatropha biofuel</u>
Power to weight ratio. See above for gasturbine.
Fuel properties. Biokerosene produced from Jatropha is regarded an alternative fuel. Jatropha biofuel has a density of 880 kg/m^3, an energy content of 44,3 MJ/kg, 33,1 MJ/l, and a freezing point of -57°C (Boeing, 2009).
CO_2 intensity. Compared to conventional fuels, the fuel CO_2 intensity performance of biofuels from Jatropha can be considered good. The possible reductions of the Jatropha oil seeds are considered to be equal to the reduction potential of biodiesel from soybean which is about 80% according to Francis et al. (2005). SenterNovem (2009b) states a reduction potential of 27-71%. Such a variety is the result of taking into account possible land changes and soil qualities.

<u>Gasturbine with Fatty Acid Methyl Esther (FAME)</u>
Power to weight ratio. See above for gasturbine.
Fuel properties. FAME has a density of 880 Kg/m^3, an energy content of 37,5 MJ/Kg, 33,0 MJ/L, and a freezing point of -5°C (Shell, 2008). A drawback of FAME, also known as 1st generation biodiesel, is its freezing point of -5 °C (Parker, 2009).
CO_2 intensity. Compared to conventional fuels, the fuel CO_2 intensity of FAME is considered positive. During combustion FAME emits about 2,6 kg CO_2 per litre. However, part of this CO_2 is first absorbed during the growth of the feedstock. The possible CO_2 emission reduction of FAME is estimated at 25-45% (MNP, 2005).

<u>Gasturbine with algae biofuel</u>
Power to weight ratio. See above for gasturbine.
Fuel properties. Algae can serve as a biomass input for Fischer-Tropsch process. The biofuel then has the same characteristics as Fischer Tropsch Kerosene. Algae can also serve as input for the production of FAME.

CO_2 intensity. Depending on the usage of algae the CO_2 intensity varies (Parker, 2009). From interviewees it became clear that biofuels from algae are the most promising since algae have the highest energy density per hectare and have the highest potential in CO_2 reduction. The exact CO_2 emission reduction value could no be found in literature but since literature and interviewees speak promising about algae it is assumed that algae biofuel can reduce 90% or more CO_2 compared to conventional aviation fuels.

<u>*Jet engine with Jet A-1 fuel*</u>

Power to weight ratio. The power to weight ratio of a jet engine is approximately 3,00 kW/kg, which is lower than the currently used gasturbine (Shell, 2008). The usage of a jet engine would result in a decrease of revenue producing payload and efficiency losses.
Fuel properties. See above for Jet A-1 fuel characteristics.
CO_2 intensity. See above for Jet A-1 fuel CO_2 intensity

<u>*Fuel cell with Hydrogen*</u>

Power to weight ratio. The power to weight ratio of a fuel cell is 0,10 kW/kg which is considerably lower than the power to weight ratio of a gasturbine. A fuel cell is 50 times heavier when it needs to produce an equal amount of power compared to the gasturbine.
Fuel properties. Hydrogen can be regarded an alternative energy carrier for a fuel cell. Hydrogen has a density of 70 kg/m^3, an energy content of 120MJ/kg and 8,4 MJ/l, and a freezing point of -259°C (Shell, 2008). Hydrogen, due to its lightweight and its energy content results in the need for a large storage capacity as 4,3 times more fuel volume for an equal energy content as the conventional aircraft is needed, which forces drastic airplane design changes (NASA, 2006; Janic, 2008; OECD, 2008).
CO_2 intensity. A fuel cell with hydrogen as an energy carrier does not emit any CO_2 during operation. CO_2 may be emitted during the production of hydrogen. When hydrogen is produced with sustainable energy, for instance wind or solar energy, no CO_2 will come free. If hydrogen is produced in a less sustainable way, steam reforming of natural gas or electrolysis of fossil produced electricity, between 0,87 – 1,7 kilogram CO_2 will be emitted per litre of hydrogen (Passier et al., 2008). Probably the biggest drawback of hydrogen as energy carrier for the aviation sector comes from one of its biggest advantages, namely that it only produces water when operated. This advantage becomes a disadvantage at high altitudes, since water vapor is a greenhouse gas at high altitude (Anslow, 2008). Hydrogen fueled planes will result in three times as much as today's produced water vapor by aircraft and as a consequence increases the chance of climate change (Anslow, 2008).

<u>*Battery electric drivetrain*</u>

Power to weight ratio. Using an electric motor driven by batteries results in power to weight ratio losses. The power to weight ratio of a NiCad and Li-ion battery are respectively 0,15 kW/kg and 1,80 kW/kg (Shell, 2008). While the Li-ion battery has a higher power to weight ratio than NiCad batteries it is still considerably lower than the power to weight ratio of the gasturbine.
Fuel properties. -
CO_2 intensity. Electricity can be produced by conventional technologies emitting CO_2, approximately 387 gram/kWh in the Netherlands (NuZakelijk, 2009) which is 3,6 kilogram CO_2 by electricity production equal to the energy content of one liter kerosene. Some methods of electricity production, solar, wind, geothermal, do not produce any CO_2.

Based on the previous information it is clear that the currently used gasturbine has the highest power to weight ratio and a transition toward other drivetrains results in losses. Furthermore it is indicated that Fischer-Tropsch, Jatropha and algae biofuels seem promising alternative fuels. A study by Parker (2009) also indicates these three options as possible aviation fuels to reduce CO_2 emission. In the remainder of the report biokerosene produced by a Fischer-Tropsch process, biokerosene from the Jatropha and biokerosene produced by algae will be further analyzed on their potential. Table 5.1 projects the technical potential of the three selected drivetrain fuel combinations.

Combining the CO_2 reduction potentials of FT Kerosene, Jatropha derived biokerosene and biokerosene from micro algae produced with data on the aviation CO_2 development results in the technical reduction potential which is depicted in figure 5.4.

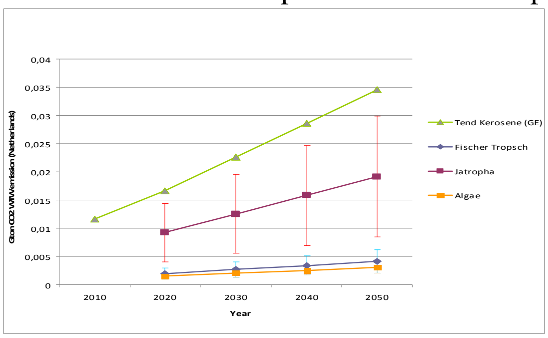


Figure 5.4: Dutch aviation technical CO_2 emission reduction potential. The graph hold a trend line of CO_2 emission in aviation towards 2050. For Fischer-Tropsch kerosene a bandwidth of 85-95% CO_2 emission reduction is considered. For Jatropha a bandwidth of 21-80% CO_2 emission reduction and for biokerosene from algae a bandwidth of 90-99% CO_2 emission reduction is considered.

5.3 Economical aspects

Besides the technical CO_2 emission reduction potential, cost-effectiveness is of importance. It is possible that one alternative with a higher reduction potential comes along with far higher costs. The cost-effectiveness expressed in €/tCO_2. First costs in €/GJ and €/litre are provided, which are used to estimate the cost-effectiveness.

<u>Fischer-Tropsch Kerosene</u>

Studies that describe the production of Fischer-Tropsch kerosene on the basis of biomass were not found. Studies do focus on the Fischer-Tropsch processes with biodiesel as a product. The Fischer Tropsch process holds the formation of long hydrocarbon chains which are cut into desired lengths, depending on the fuel to be produced. Due to the fact that the liquid properties can be changed and optimized systematically it is possible to produce kerosene instead of diesel. Given the possibility of changing the length of hydrocarbon chains it is assumed that the production costs of producing Fischer-Tropsch kerosene are equal to Fischer-Tropsch diesel.

Production costs. Considering the production costs of Fischer-Tropsch it becomes clear that variance exists among studies. Some studies make estimations of 8 - 11 €/GJ (Daey Ouwens & Faaij, 2000). Others estimate production costs of 11 - 13 €/GJ (UCE, 2000; SenterNovem, 2000; Uil den, 2001). However much higher values of 18 - 19 €/GJ are also estimated (Thuijl, et al., 2003). A production costs of 9 – 13 €/GJ equals a production cost 0,31 – 0,45 €/litre for Fischer Tropsch fuels. Van Vliet et al. (2009) performed an analysis of different Fischer Tropsch diesel production processes and indicated that a conversion process with coal or natural gas as an input leads to fuel costs of 6 – 13 €/GJ. On the contrary, a comparison by Vliet van et al. (2009) of biomass to liquid Fischer-Tropsch processes showed costs between 15 – 18 €/GJ with extremes of 24, 29 and 41 €/GJ. DENA (2006) estimates the costs of Fischer Tropsch fuel (diesel) with biomass as an input to be above 1 €/litre. DENA (2006) further estimates that this value can become lower as result of technical optimization and

lower biomass costs. Some studies estimate that the production costs of Fischer-Tropsch fuels will decrease to below 9 €/GJ on the long term (Faaij, 2000; UCE, 2000).
Cost-effectiveness. Data about the cost effectiveness in aviation were not found. Self performed first order calculations, considering the costs for the production of Fischer-Tropsch oil, indicated a cost effectiveness of 105 – 273 €/tCO_2.

<u>Jatropha</u>
Production costs. It is estimated by Henning (2003) that 1 liter of oil from the jatropha seeds costs between €0,60 – 0,73[4]. These values are underpinned by Ruud van Eck who estimates the production costs of Jatropha oil to be around 660 €/tonne which is 0,60 – 0,70 €/litre (Luchtvaartnieuws, 2009). As a result of uncertainties due to quality of land and extractable oil content the IISD (2008) estimated the costs of jatropha oil production to vary from 350-1200[5] €/tonne of jatropha oil. Energie Transitie (2009) performed a study that estimates the production and transportation costs of jatropha oil to be 5,4 €/GJ in 2006, decreasing to 4,4 €/GJ in 2030.
Values about the conversion costs of Jatropha oil into biokerosene were not found as a result of the few test flights that have been performed on jatropha derived kerosene. Furthermore organizations did not share information containing economic aspects because of commercial confidentiality. Biokerosine was only used on a small scale for some test flights which resulted in prices that could not compete with the conventional kerosene (Luchtvaartnieuws, 2009). Considering biodiesel instead of biokerosene, the production costs are estimated to be 0,41 – 0,55 €/litre (Dilligent Energy Systems, 2008). The IISD (2008) estimated the refining costs at 449 – 1297 €/tonne of biodiesel. This brings the total costs of jatropha biodiesel to 798 – 2494 €/tonne (IISD, 2008). Whether these values are similar to those of biokerosene produced from jatropha can be argued since the production process is more complex as all oxygen and impurities has to be separated from the oil and kerosene during the transesterfication process. The higher complexity of this process makes it plausible to assume that the production costs of biokerosene by Jatropha become higher.
Cost-effectiveness. Data about the cost effectiveness in aviation were not found. Self performed first order calculations, considering the costs for the production of Jatropha oil, indicated a cost effectiveness of -41 – 37 €/tCO_2.

<u>Micro algae</u>
Production costs. Several studies attempt to indicate the algae oil production costs from large scale algae farms. Benemann & Oswald (1996) executed an analysis in which they estimate the costs of algae oil production to vary between 0,22 – 0,39 €/litre[6] in 2008 (Schenk et al., 2008). The costs estimations by Benemann & Oswald (1996) assumed 400 hectares of open ponds, using either pure CO2 or fluegas from a coal-fired power station with a production capacity of 30–60 g/ m^2/ day with 50% algal lipid yield. Another analysis estimated the costs of algae oil production to be 0,42 €/litre (Huntley & Redalje, 2006). Huntley & Redalje (2006) assume a production capacity of 70.4 g/ m^2 /day and 35% algal lipid yield. The estimated costs are theoretically possible but have not yet been achieved in practice (Schenk et al., 2008).
Chisti (2007) estimated the production costs of micro algae biomass at 2,16 – 2,78 €/Kg depending on the utilized system. Assuming an oil weight ratio of 30%, the costs of algae oil becomes 6,47 – 8,47€/litre[7]. Due to technology development and economies of scale, Chisti

[4] $1 = € 0,89 (2003).
[5] $1 = € 0,68 (2008).
[6] $1 = € 0,68 (2008) and 1bbl = 159liter.
[7] $1 = € 0,73 (2007).

(2007) estimated a decrease in costs which would result in 1,02 – 1,32 €/litre algae oil. It is expected, as a result of the early development stage of algae derived biofuels that cost reductions can and will be achieved (IEA, 2008). Values about the costs of algae oil conversion into biokerosene are lacking for the same reasons as it does for biokerosene produced from Jatropha or Fischer Tropsch kerosene.
Cost-effectiveness. Data about the cost effectiveness in aviation were not found. Self performed first order calculations, considering the costs for the production of algae oil, indicated a cost effectiveness of 1932 – 2863 €/tCO_2.

Table 5.1 summarizes the technical potential and cost-effectiveness of a gasturbine in combination with Fischer-Tropsch kerosene, jatropha biofuel and algae biofuel.

Table 5.1. Technical potential and cost-effectiveness of alternative drivetrain fuel combination for the Netherlands.

Drivetrain fuel combination	**Technical potential (CO_2 emission reduction)**			**Cost-effectiveness**
	%	**2020 (Mton)**	**2050 (Mton)**	**€/tCO_2 avoided**
Gasturbine + jet A1 fuel (standard)	-	16,7 Mton emitted	34,6 Mton emitted	-
Gasturbine + Fischer-Tropsch Kerosene	85-95%	14,2 – 15,8	29,4 – 32,9	105 – 273
Gasturbine + Jatropha Biofuel	27-80%	4,5 – 13,3	9,2 – 27,7	-41 – 37
Gasturbine + Algae Biofuel	90-99%	15 – 16,5	31,1 – 34,3	1932 – 2863

5.4 Land and feedstock availability

The technical potential is in practice difficult to reach in practice since other aspects like the availability of feedstock, the usage of the alternative fuel (blend or pure) and the development of the technology also influence the CO_2 reduction potential.

To illustrate, micro algae systems seem very promising as they can already produce 15-300 times more oil for biofuel production than traditional crops (kg/ha) and it is even expected that this will become more over time (NASA, 2007; Schenk et al., 2008). From a world perspective it would require algae ponds with a total size of Maryland, that is $3,4*10^6$ hectares, to supply the 2004 world's aviation with 322billion liter biofuel assuming 94705 litre/hectare/year (NASA, 2006). In 2020 the world aviation would need $4,4*10^6$ – $9,0*10^6$ hectare of land with algae ponds. In 2050 this will become $3,6*10^6$ – $2,3*10^7$ hectare of land with algae ponds to fulfill the aviation needs.

The Netherlands are capable of producing 30 ton per hectare per year of algae biomass at this moment and it is expected to become 50 ton per hectare per year which is a large quantity compared to other biomass (Energy Transition, 2008). The fuel requirement for the Netherlands in 2020 would become 6,7 Billion litre of fuel which equals $7,1*10^4$ hectare of land with algae ponds. In 2050 even $1,5*10^5$ hectare of algae ponds are needed to fulfill the fuel demand reported as bunker fuels. This means that for 2020 1,7% and in 2050 3,6% of the Netherlands needs to be build with algae ponds. Taking into account that algae by far enjoy a higher energy and production capacity than other feedstocks means that substantial more hectares of land are needed to cover the aviation fuel need with other biomass.

5.5 Innovation system performance

The technologies for the production of biofuels by Fischer Tropsch, algae or with Jatropha are being developed/under development. Both the second and third generation biofuel for the usage as jet fuel are considered to be in the pre-development phase of the hypothetical diffusion S-Curve (Interview Gent van, 2009; Interview Komen; 2009; Interview Verschoor, 2009). This is underpinned by the fact that these generation biofuels are relatively immature (Sims et al., 2008). The third generation biofuels can be considered to be somewhat behind the second generation biofuels on the hypothetical diffusion curve since the third generation biofuel from algae are a more recent technology.

The next sub-sections comprise a description of the current Dutch Innovation System structure and Innovation System Function fulfillment for the three earlier selected alternative drivetrain fuel combinations. The three biofuels will be considered together in one Technology Specific Innovation System as these technologies are related and share many actors. Considering the three biofuels together will result in a biofuel aviation technology specific innovation system.

5.5.1 Biofuel aviation innovation system structure

In this sub-section the five components of the Dutch biofuel aviation TSIS are analyzed on their current state in terms of quality and quantity. The analysis of the quality and quantity is based upon gathered information by conducted interviews with experts in the field, as they are actors in the TSIS, and a literature study. Interviews were conducted with the Dutch Royal Airlines (KLM), Platform Duurzame Luchtvaart (PDL), TUDelft- cleanera project, TNO, PeakOil Nederland, Energy Valley and SenterNovem.

Biofuel Aviation TSIS

Supply side

The supply side of the innovation system mainly comprises small biofuel producing companies with a predominant focus on biofuels, biomass producing and supplying companies and large vested traditional oil companies with small(er) interests in biofuels since their predominant business is in fossil fuels. Such large oil companies invest in biofuels because their current oil resources will become more scarce in the future, because of increasing demand for greener fuels and because of the obligation to blend biofuels with fossil fuels for road transport.

The supply side is considered small but large enough in terms of quantity as at this moment the demand side only needs small quantities of biofuel for test flights and pilot projects. The quality of the supply side is between weak and sufficient since it mainly holds small starting companies with the core business in biofuels or biomass and new process technologies which may not yet be fully developed technically.

Demand side

The demand side of the innovation system includes airlines, companies that own and utilize airplanes and Dutch regional and international airports. Currently only small amounts of biofuel are used in the aviation sector as input fuel for test flights and pilot projects. Some parties of the demand side, such as the Dutch Royal Airlines (KLM), accelerate and stimulate a transition towards biofuels by initiating a cooperation project with a party from the supply side, Algae Link. Some airlines formed a group, the Sustainable Aviation Fuels Users Group (SAFUG), to guarantee a sustainable future.

The demand side is considered weak in terms of quantity since it comprises a small demand for biofuels by airlines as input for test flights and projects. In terms of quality the demand side is considered sufficient.

Intermediary structure

The intermediary infrastructure consists of a Dutch intermediary that specifically aims at aviation, namely Platform Duurzame Luchtvaart. This intermediary operates under the European formed Sustainable Aviation Network Europe.

SenterNovem, another intermediary organization, aims at providing a link between government and organizations. Besides these intermediaries also Non Governmental Organizations (NGO's), such as Greenpeace and World Wildlife Fund, form a part of the intermediary infrastructure. These organizations do have an interest in sustainable aviation but mainly because they have an interest in a sustainable world in general.

As the intermediary infrastructure only comprises one independent Dutch intermediary that specifically aims at aviation and one intermediary that is an agency of the Ministry of Economic Affairs it is considered very weak in terms of quantity. The quality of the intermediary structure is considered good as Platform Duurzame Luchtvaart tries to link different organizations. However, parties that do not belong to the intermediary infrastructure also contact other parties. This occurs between organizations within the same innovation system component, such as NASA with TUdelft, or from different components, such as KLM and AlgaeLink. Because of such direct links the role of the intermediary infrastructure may become less important.

Government structure

The government structure of the Innovation System comprises national, European and global governmental bodies due to the international character of aviation. When restricted to the Netherlands the government structure holds the Ministry of Economic Affairs, Ministry of Agriculture, Nature and Food Quality and the Ministry of Transport, Public Works and Water Management with sub-departments Directorates-general Civil Aviation and Maritime affairs and Transport, Public Works and Water Management Inspectorate. From an international perspective the European Commission, the European Aviation Safety Agency, the Federal Aviation Administration and International Civil Aviation Organization form have to be included. The European Aviation Safety Agency and the Federal Aviation Administration form two big involved parties as they are responsible for the certification processes of engines and fuels and as a result also for the certification of biofuels. Currently, the certification of biofuels that allows using biofuel as a fuel in the aviation is still in progress and can be considered to hamper the transition. As became clear from the interviewees, airlines are ready to use biofuels, only they are not allowed because biofuels are not certified as an aviation fuel yet. It is believed by experts that this certification process will be complete within a few years (Interview Gent van, 2009; Komen, 2009; Verschoor, 2009).

The quality of the Dutch government structure is hard to identify because it is indirect en directly steered and controlled by the European Commission. Furthermore, Mark Verschoor (2009) doubted the quality of the government as a lot of turn over occurs; Politicians remain in their function for a (relatively) too short period of time to build up a thorough knowledgebase. The quantity seems sufficient as several ministries form part of the Innovation System.

Knowledge infrastructure

Knowledge institutes which are part of the Dutch biofuel aviation TSIS are TNO and ECN. The knowledge infrastructure also consists of universities, such as TUdelft with the Cleanera project, and research institutes that perform research on biofuels in general. Important international knowledge developers are NASA and ONERA.

Ronald van Gent (2009) and Marc Verschoor (2009) both argue that the Dutch knowledge institutes currently generate al lot of broad and generic knowledge which results in a strong knowledge base. On the contrary, Thijs Komen (2009) states that knowledge institutes do have a role in the creation of knowledge, but that airlines do possess more and better knowledge as a result of the focus of knowledge institutes which is not on aviation predominantly.

Based on this information, the quality of the knowledge structure is considered to be between weak and sufficient since the majority of the created knowledge is broad and generic. In terms of quantity, the knowledge structure is strong and is sometimes even further strengthened by airlines that also invest in the creation of knowledge.

Figure 5.5 illustrates important actors of the technology specific innovation system with regard to biofuels for the aviation sector. Table 5.2 summarizes the quantity and quality of the different Innovation Systems components.

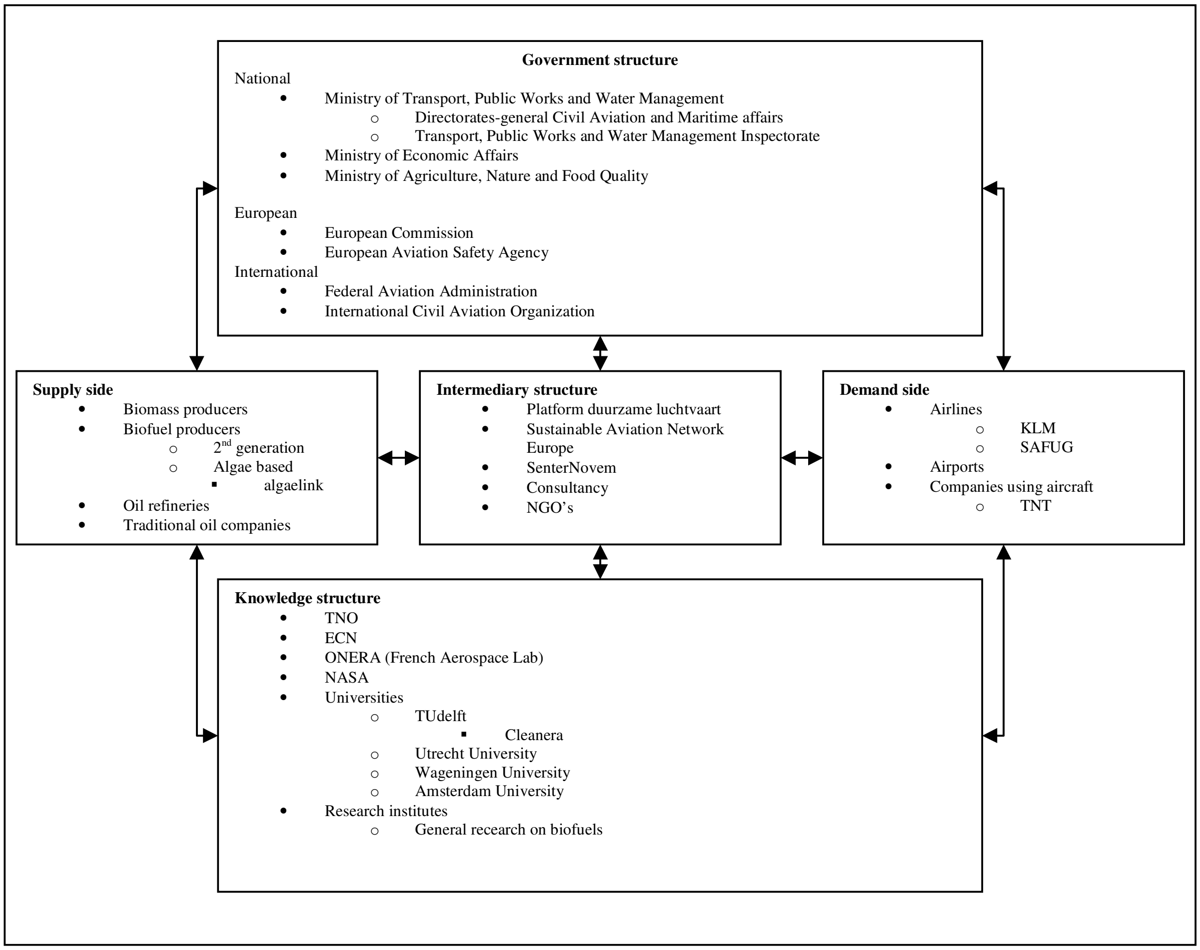


Figure 5.5: The Biofuel Aviation Technology Specific Innovation System.

Table 5.2. Score of quantity and quality per Innovation System component. 1 = very weak, 3 = sufficient and 5 = very strong

Component	*Quantity*	*Quality*
Supply Side	3	2 – 3
Demand Side	2	3
Intermediary Infrastructure	1	4
Government Structure	3	1 – 2
Knowledge Infrastructure	4	2 – 3

5.5.2 Biofuel aviation innovation system functions

The analysis of the current innovation system function fulfillment is based upon gathered information through interviews with experts in the field and a literature study. Interviews were conducted with the Dutch Royal Airlines (KLM), Platform Duurzame Luchtvaart (PDL), TUDelft- cleanera project, TNO, PeakOil Nederland, Energy Valley and SenterNovem.

Entrepreneurial activities.

Within the Netherlands a small amount of entrepreneurial activities, in terms of quality and quantity, can be identified. Lelystad Airport executes a project that investigates the possibilities of producing and using biofuels produced from rapeseed (Interview Verschoor, 2009). The Dutch Royal Airlines (KLM) can be considered an entrepreneur with respect to sustainability given that it executes a project on biofuels (Interview Komen, 2009). Another airline which is involved in biofuels is Virgin Airlines. Both Airlines see the necessity to constantly improve their sustainability performance.

In general, entrepreneurial activities may be identified at companies that are involved in the production of 1st, 2nd or 3rd generation biofuels. Currently, there are no direct suppliers of biofuels produced from algae's, Fischer Tropsch biomass or Jatropha in the Netherlands for the aviation sector on a commercial level. The entrepreneurial activities mainly hold the performance of test flights and pilot projects such as cooperation between Shell and Coheron to build a biomass Fischer-Tropsch plant. In 2007, Shell also started the realization of a test facility for the development of biofuels from algae. So far, large scale Fischer-Tropsch plants only use fossil fuels, coal or natural gas, as input for the production of synthesis gas. Shell has an installation in Malaysia, which produces Fischer-Tropsch liquids derived from natural gas and a Fischer-Tropsch production plant is realized by SASOL which uses coal as an input (Thuijl et al., 2003). Possibilities for gasification of biomass for the production of synthesis gas are currently being investigated (Thuijl et al., 2003; Interview Benning, 2009; Interview Rabé, 2009).

A Dutch company named AlgaeLink opted for the photobioreactor cultivation method. During interviews with Marc Verschoor (2009) and Thijs Komen (2009) it became clear that large scale algae producing firms exist but that produced algae are used for other purposes than the production of biofuels, namely products with higher revenues such as medicine. Currently, KLM has connections with sixty algae producers all over the world with a geographical gravity point in the United States (Interview Komen, 2009). Thijs Komen (2009) argues that the Dutch entrepreneurial activities lag behind the entrepreneurial activities in for instance the United States. This statement is underpinned by Marc Verschoor (2009) and Ronald van Gent (2009) which both argue that the scale of operation is much smaller in the Netherlands.

Summarizing the foregoing reveals that entrepreneurial activities take place within the Netherlands. The centre of the activities is located in the United States. Some airlines, like KLM and Virgin, have their own internal driver to make their airline as sustainable as possible. This results in a score 2 (weak) for the function entrepreneurial activities.

Knowledge development

News articles, research studies on biofuels, pilots and testflights that are performed reflect the attention for the creation of knowledge with respect to biofuels for the aviation sector. The creation of knowledge mainly holds theoretical knowledge development and to a smaller extent knowledge development in practice.

An important knowledge gap in the aviation sector related to biofuels is formed by the absence of studies that perform life cycle assessments. Therefore the impact of biofuels on CO_2 emission reduction in the aviation sector can be considered uncertain.

The foregoing illustrates that knowledge creation related to biofuels and the aviation sector occurs. Knowledge institutes primarily develop theoretical knowledge while a knowledge institute like TUdelft with the cleanera project also aims to develops, more applied knowledge. Airlines and biofuel producers also create knowledge by executing test flights and pilots. Life cycle analyses for Fischer-Tropsch kerosene, Jatropha or algae in the aviation sector are currently lacking. The function knowledge creation will be assigned the score 2 (weak).

Knowledge diffusion
The diffusion of knowledge is not straightforward. In the first place the extent to which diffusion of knowledge occurs depends on the organization which possesses the knowledge. A university for instance publishes their findings in scientific journals which are publicly accessible. Other knowledge institutes or private organizations mostly publish less and keep the most important knowledge to theirselves from an economic point of view.

With respect to biomass and biofuels in general a lot of symposia and conferences take place. These events form the place were knowledge can be diffused among others. Specific symposia or conferences about the possibilities for biofuels in the aviation sector do not exist, although, parts of conferences or symposia are sometimes related to alternative fuels (Interview Verschoor, 2009). Also for these organized events, symposia and conferences it holds that new developments, breakthroughs and other (valuable) knowledge are only slightly shared with others.

The previous information indicates that conferences, symposia and other events where the diffusion of knowledge can occur are initiated for biomass, biofuels and aviation in general. However, only less valuable knowledge is shared with others because companies want to strengthen their position compared to others. Some knowledge institutes, mostly universities, diffuse knowledge by publishing it in scientific journals. This results in a score 2 (weak) for the function knowledge diffusion.

Guidance of the search
Thijs Komen (Interview, 2009) argues that it lacks of an incentive for (airline) organizations and governmental bodies to invest in sustainable aviation as they do not see the profit of it. However, some (airline) organizations do recognize the urgency of a sustainable aviation sector. KLM and some other parties share a sustainable vision and founded SAFUG. This group, consisting of Virgin Atlantic, All Nippon, SAS, KLM, Air France, Gulf Air, Cargolux, and Air New Zealand, stands for criteria that guarantee a sustainable long term vision in the aviation sector and promote and accelerate the introduction of biofuels (SAFUG, 2009).

The Dutch as well as the European government are less involved in creating a univocal view of reducing greenhouse gas by technological options. On a national level, a broad aviation memorandum was published (V&W, 2009). This memorandum only shortly points out the urge for knowledge and innovation and the possibility of biofuels to reduce CO_2. From a

European point of view, the European Emission Trading Scheme that aims at reducing CO_2 will be introduced in 2012. Another European generic act that sets reduction targets for the year 2020 is the Clean Sky vision 2020. Both acts try to stimulate innovation and sustainability in a generic way by setting emission targets and do not focus on specific technological CO2 reducing options.

A univocal vision toward the use of biofuels, from Fischer Tropsch, Jatropha and algae, for aviation exist but a selection of an alternative is lacking. The vision is carried by airlines, airports, knowledge institutes, biofuel producers and to a lesser extent by the government. The government, both national and European, only stimulates innovation and sustainability by generic measures. This results in a score 2 (weak) for the function guidance of the search.

Market formation

Theoretically, all airplanes should be able to fly on biofuels as long as their characteristics are comparable to those of kerosene. Currently, no biofuel aviation market exists with the exception of the demand for biofuels needed to perform test flights and pilots. The absence of a market can be explained since Fischer-Tropsch, Jatropha and algae kerosene are still in the pre-development phase and commercial markets start to develop during the take-off phase.

As a commercial aviation market for biofuels, since these are in the pre-development phase, is currently absent, the function market formation is assigned the score 1 (very weak).

Resource mobilization

Whether the government supports the development of sustainable biofuels for aviation enough is debated. Governmental support in terms of financial resources is claimed to be lacking by the aviation sector and a lot of bureaucratic rules have to be met before financial support is approved for (Interview Gent van, 2009; Komen, 2009; Verschoor, 2009). On the contrary, the government believes that their support for sustainable aviation is adequate.
The availability of human resources is good in terms of quality and quantity. Within the government structure the chance of a lack of human resources with aviation related knowledge is present since councils remain for a relatively (too) short period in their function to build up aviation expertise/knowledge.

The above shows a tension between airlines and the government about the (financial) support of the government. Furthermore the quality of human resources of governmental organizations is debated by some. This results in attributing the function resource mobilization a score 2 (weak).

Creation of legitimacy/counteract resistance to change

None of the interviewees expect an active resistance to change by any party for the implementation of sustainable biofuels or any other innovation in general. Ronald van Gent (2009) argues that resistance comes forward out of factors as safety, weight, volume, fire risk etcetera, however these can be considered legitimate.

What must be noticed are the vested interest in oil and gas of traditional oil companies. These traditional oil companies will not make a transition towards biofuels that easily until they eventually need to do this, either by a strong pressure of other parties or due to the scarcity of their (fossil) fuel sources (Interview Gent van, 2009; Komen, 2009; Verschoor, 2009. Although parties that resist to a transition towards biofuels in the aviation sector cannot be identified some lobby groups that may counteract any resistance to change can be recognized.

Examples are environmental organizations such as Greenpeace and World Wildlife Fund. The earlier mentioned SAFUG that stimulates the introduction of biofuels can also be considered a coalition for biomass fuels.

Considering the absence of any actor that actively resists to a transition towards sustainable biofuel aviation, the recognition that some parties only want to switch to biofuels when they really have to and finally the presence of several groups that do want a transition towards more sustainable aviation, results in the attribution of a score 4 (strong) to the function Creation of legitimacy/counteract resistance to change.

The results are summarized in figure 5.6. Figure 5.6 illustrates the score per function for the biofuel aviation TSIS. It illustrates to what extent the different innovation system functions are currently fulfilled.

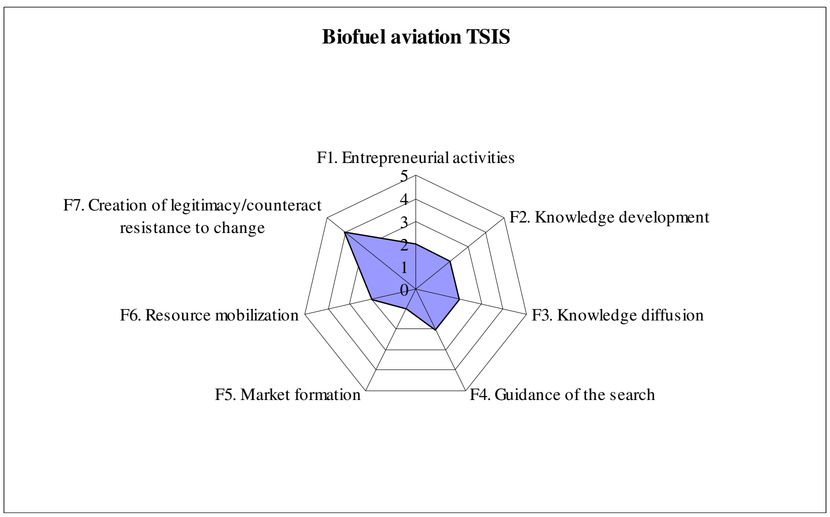


Figure 5.6: Score per function for the biofuel aviation technology specific innovation system.

6. Freight transport sector

This section presents the results for freight road transport. First the projections of freight road transport growth towards 2050 of the Netherlands are set out. Second, a selection of promising drivetrain technologies and fuels is made. The selected drivetrain technologies and alternative fuels are described on their potential to diminish CO_2 emissions. Fourth, economical aspects are addressed. The section ends with an overview of the innovation system structure and current fulfillment of innovation system activities.

6.1 The Ducth freight sector towards 2050

Freight transport by road consists of heavy duty vehicles. Heavy duty vehicles comprise long-haul trucks and distribution trucks. Figure 6.1 shows projections of the Dutch freight transport by road development towards 2050 in terms of CO_2 production for the total sector based on datasheets of the PBL, using CBS data. During the production of fossil fuels CO_2 is emitted. According to NETL (2009) this life cycle step accounts for 19% of the total CO_2 emission. The values reflected in figure 6.1 are the PBL datasheet values plus another 19% for the well-to-tank part.

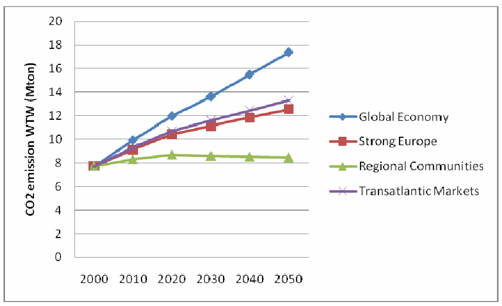


Figure 6.1: CO_2 emission of the Dutch freight transport by road towards 2050. Note: The value for 2050 is extrapolated linearly.

In the Global Economy scenario freight transport emits up to 55% more CO_2 in 2020 compared to the level of 2000 increasing towards 125% in 2050. The Regional Communities scenario indicates an increase of 13% in 2020 and 10% in 2050 compared to the CO_2 level in 2000. For the remainder of the freight transport section, only the Global Economy scenario, as high case scenario in terms of CO_2 emission, is used to illustrate possible technical reduction potential of alternative drivetrain technologies and fuels.

In-house datasheets of the PBL classifies the CO_2 emission of road transport in weight classes The classification holds trucks with weight classes of 3,5-10 tonne, 10-20 tonne and >20 tonne, and lorries. Since the freight sector exists of long-haul trucks and distribution trucks it is assumed in this study that CO_2 emission by the lightest weight class can be assigned to urban distribution and the highest weight class and lorries comprise CO_2 emissions that are assigned to long-haul transport. It is assumed that trucks of weight class 10-20 tonne drive in urban surroundings as well as on highways. Therefore this weight class is split of which 50% is assigned to distribution trucks and 50% is assigned to long haul trucks. The CO_2 emission, including 19% of the well-to-tank part (NETL, 2008), is depicted in table 6.1 for both categories and indicates that long-haul transport is responsible for a large share of CO_2. The classification in distribution and long-haul trucks is considered since the possible drivetrain technologies and alternative fuels differ for distribution and long-haul transport as will become clear in section 6.2.

Table 6.1. CO2 emission per category in Mton. Global Economy Scenario				
	Year	*2000*	*2020*	*2050*
Distribution Trucks	Total	0,9	1,5	2,5
Long-haul Trucks	Total	6,8	10,5	14,9

6.2 Alternative drivetrain and fuel selection

There are several options to reduce the emission of CO_2 emission in the freight road sector. The emission of CO_2 is influenced by the drivetrain, fuel, size, aerodynamics/design, logistic efficiency, speed/traveltime. In this report the focus will only be on the drivetrain technology and selected fuel. Furthermore a similar performance level of distribution and long haul trucks to the current situation is used as a reference situation.

Aspects of drivetrain and fuel selection

Aspects for appropriate drivetrain and fuel selection differ for distribution and long-haul transport. For long-haul transport the driving range is important while for urban distribution a small(er) driving range can be sufficient. Limiting local emission forms a crucial aspect for urban distribution drivetrain fuel combinations while this is of less importance in long-haul transport.

Drivetrain fuel combinations available

This sub-section comprises a description of drivetrain fuel combinations characteristics for the freight road sector. Figure 6.2 illustrates the description of the several drivetrain fuel combinations provided below. For the conventional drivetrain fuel combination values are set on 100 and the alternative drivetrain fuel combinations are relatively to this value.

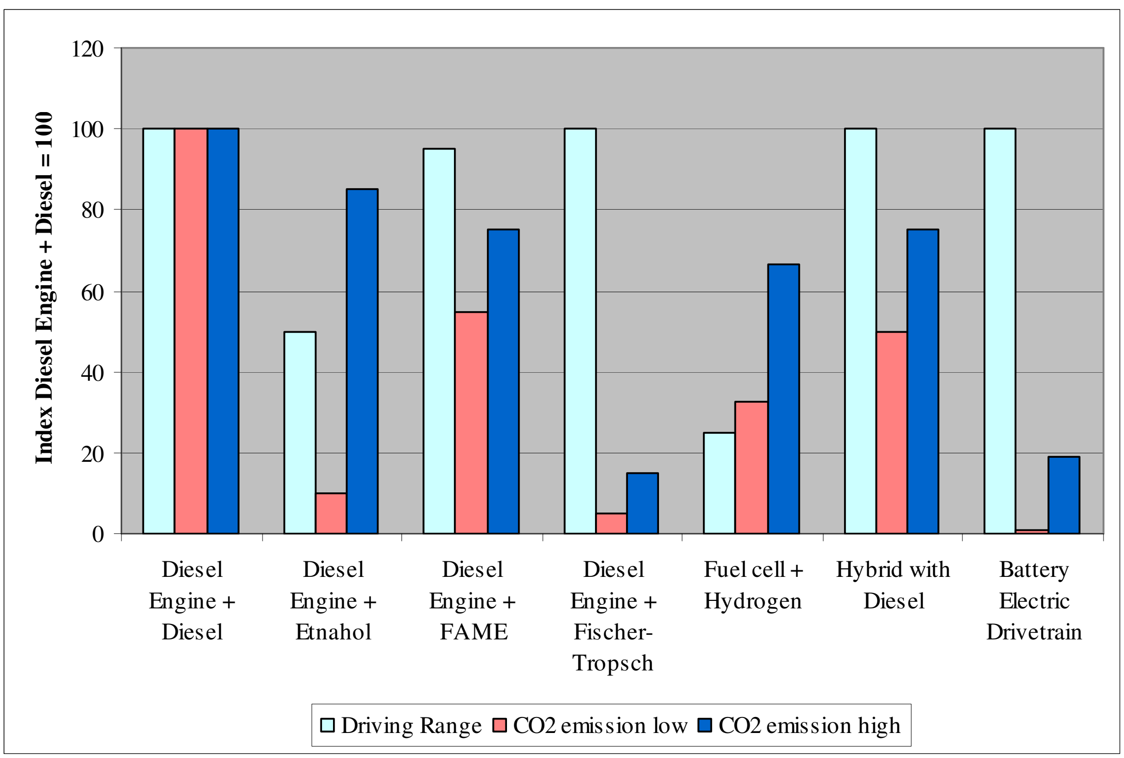


Figure 6.2: Aspects of drivetrain and fuel selection in the aviation sector. Characteristic performance of conventional drivetrain fuel combination is set on 100.

Diesel engine with Diesel (Conventional drivetrain fuel combination)

Driving range. Currently, practically all trucks use a diesel engine and diesel fuel. The driving range of diesel trucks using diesel fuel is considered good as it forms the standard these days.
CO_2 intensity. The fuel CO_2 intensity of diesel fuel is relatively high compared to the alternatives in depicted in figure 6.2. For each liter of diesel combusted 2,6 kg CO_2 is emitted. Another 19% can be added for the production of diesel (NETL, 2008). Diesel fuel currently forms the dominant fuel for trucks and is used to compare the alternative fuels with.

Diesel engine with Ethanol

Ethanol is to a certain extent compatible with diesel engines. For higher blends, above the percentage of which manufacturers guarantee normal performance and operation, engine modifications have to be made. Furthermore, ethanol is predominantly considered as a gasoline substitute.
Driving range. Driving on ethanol results in a lower driving range due to the lower energy content, of 27,2MJ/kg and 22,0 MJ/l (Shell, 2008), compared to diesel fuel with 42,5 MJ/kg or 36,4MJ/l.
CO_2 intensity. The fuel CO_2 intensity performance of ethanol depends on aspects like the production method and feedstock input. Overall the fuel CO_2 intensity of ethanol is better than fossil diesel, figure 6.2, as it can reduce between 15-55% of CO_2 when it is produced with a 1^{st} generation technology and 55-90% of CO_2 by 2^{nd} generation cellulose methods compared fossil diesel (MNP, 2005).

Diesel engine with Fatty Acid Methyl Esthers (FAME)

Diesel engines can operate on low blends of Fatty Acid Methyl Esther (FAME) without any adoptions. In the Netherlands it is guaranteed by the automotive industry that all vehicles can use blends of 5% biodiesel. For higher blends or 100% biodiesel, engine modifications become necessary (Fuelswitch, 2009).
Driving range. The driving range becomes slightly lower compared to fossil diesel. This is the result of a lower energy content, of 37,5 MJ/kg and 33 MJ/l (Shell, 2008), compared to diesel.
CO_2 intensity. Compared to conventional diesel, the CO_2 intensity of FAME is better. MNP (2005) estimates the CO_2 emission reduction of FAME at 25-45%.

Diesel engine with Fischer Tropsch biodiesel

Driving range. The driving range is comparable to fossil diesel as result of the slightly higher energy content, namely 43,2MJ/kg (Essom, 2008) or 36,9 MJ/l (CSIRO, 2001) compared to 42,5 MJ/kg or 36,4 MJ/l of fossil diesel.
CO_2 intensity. The fuel CO_2 intensity performance of Fischer-Tropsch diesel depends on aspects like the production method and feedstock input. Either the diesel is produced through coal-to-liquid, gas-to-liquid or biomass-to-liquid processes. The fuel CO_2 intensity of biomass-to-liquid is relatively better than gas or coal-to-liquid processes. Diesel produced with a Fischer Tropsch proces can achieve a CO_2 emission reduction of 90% according to SenterNovem (2009a) and between 85 and 95% according to MNP (2005). Another advantage comes from the fact that these liquid fuels are very clean since they are (almost) sulphur free (IPCC, 2000; Hamelinck et al., 2004; Refuel, 2006).

Fuel Cell with Hydrogen

A fuel cell hydrogen combination can be used to operate a vehicle. The driving range depends on the amount of hydrogen stored on board and the way that it is stored. On board storage of hydrogen is one of the biggest barriers (HyWays, 2007; Hoen et al., 2009). Hydrogen can be compressed and stored in tanks, but this results in an increase in weight and a decrease of

revenue producing load that can be transported. Liquid storage requires a temperature of -253 °C which comes along with a substantial energy demand (Hoen et al., 2009).
Driving range. The energy density of liquid hydrogen is 25% of the energy density of diesel fuel (Peckham, 2002). To achieve a comparable driving range with a fuel cell liquid hydrogen combination, four times as much fuel storage capacity is needed.
CO_2 intensity. During operation, a fuel cell hydrogen combination does not emit any CO_2. If hydrogen is produced with renewable energy no CO_2 will be emitted. If hydrogen is produced in a less sustainable way, steam reforming of natural gas or electrolysis of fossil produced electricity, between 0,87 – 1,7 kilogram CO_2 will be emitted per litre of hydrogen (Passier et al., 2008).

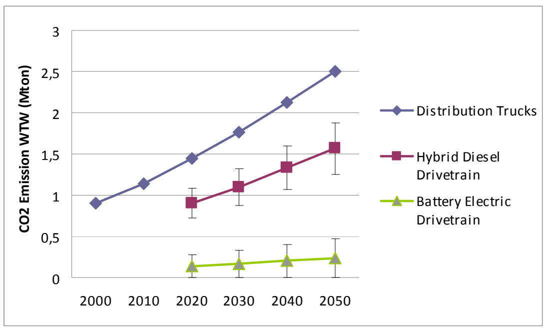
<u>Hybrid with Diesel</u>
Hybrid drivetrains, depending on the configuration, use both an electric motor and diesel engine. A parallel hybrid drives the vehicle directly with the electric motor or the diesel engine. In a series hybrid, the diesel engine is used to generate electricity for the electric motor. A plug in hybrid partly drives the truck with electricity from the electricity grid. When the batteries are out of electricity a switch is made to the diesel engine.
Driving range. The driving range of the hybrids is dependent on the capacity of the battery and the diesel engine but is considered to be sufficient for urban distribution. For long-haul transport the driving range is considered to be lower. Long haul transport occurs at high constant speeds which results in low to zero energy loss recovery of braking. The truck will be driven by the diesel engine most of time. The diesel fuel storage tanks are however smaller to compensate for the weight and space of the electromotor resulting in less fuel and a lower driving range.
CO_2 intensity. Hybrid vehicles can store energy losses that are released during breaking. At low speeds and during acceleration the electromotor assists the diesel engine. As a result the efficiency of the dieselmotor becomes higher which lowers the fuel usage with 25% - 30% (CE, 2008b; Technology review, 2009). A hybrid drivetrain configuration is designed by e-Traction. Their series hybrid electric drivetrain uses a diesel engine that generates electricity for two in-wheel electric motors. Such a configuration is able to reduce emission by 50% (Technology review, 2009). The fossil diesel can be replaced by biofuels which even further lowers the emission but does not affect the local emission.

<u>Battery electric drivetrain</u>
Driving range. Using a by batteries driven electromotor as drivetrain results in efficiency losses compared to the conventional diesel engine. To drive half the range, 800km, of a conventional diesel engine truck, 85% of the weight capacity is used for the storage of batteries (Peckham, 2002). This results in a decrease of revenue producing payload capacity or driving range.
CO_2 intensity. Electricity can be produced by conventional technologies emitting CO_2. Sustainable methods of electricity production, like solar, wind or geothermal do not produce any CO_2. Furthermore, an electric vehicle does not emit CO_2 during operation.

The previous information and figure 6.2 indicate that for long-haul vehicles, which mostly operate at constant speeds and power, hybrid drivetrain technologies are not effective. Furthermore, since long-haul vehicles travel over large distances, battery electric drivetrains and fuel cell hydrogen combination are not very suitable given storage capacity and driving range problems. The best suited options for long-haul transport then becomes the use of a diesel engine with FAME or Fischer-Tropsch diesel, because ethanol and hydrogen affect the driving range considerably.

For distribution trucks, the driving range is of less importance. For urban distribution a drivetrain fuel combination that does not emit any CO_2 forms an option. The fuel cell hydrogen combination could be an option in urban surroundings. However, such a combination has a big disadvantage related to the storage of hydrogen. More viable options for distribution trucks are a hybrid drivetrain fuel combination or a battery electric drivetrain. To summarize, a hybrid diesel combination, a battery electric drivetrain, a diesel engine FAME combination and a diesel engine Fischer-Tropsch diesel combination will be further analyzed in the remainder of this section. Table 6.2 projects the technical potential of the four selected drivetrain fuel combinations.

Combining the CO_2 reduction potential of a diesel engine FAME or Fischer Tropsch fuel combination with emissions of long-haul transport results in the technical reduction potential for long-haul transport. Combining the CO_2 reduction potential of a hybrid electric diesel fuel combination and a battery electric drivetrain with emissions of distribution transport results in the technical reduction potential. The reductions are depicted in figure 6.3.



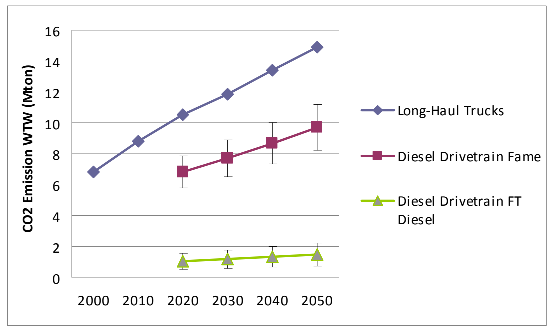


Figure 6.3: Technical potential for Dutch distribution and long haul transport. Both graphs hold a trend line of CO_2 emission towards 2050. A bandwidth of 25-50% emission reduction is considered for a hybrid diesel combination. The emission reduction bandwidth for battery electric drivetrains is 89-100%. This is assumed on the fact that the well to tank accounts for 19% of the CO_2 when fossil energy is used and by using renewable energy no CO_2 is produced or emitted. For FAME a bandwidth of 25-45% emission reduction is used. For Fischer-Tropsch diesel a bandwidth of 85-95% CO_2 emission reduction is considered.

6.3 Economical aspects

Besides the technical CO_2 emission reduction potential, the cost-effectiveness is of importance. It is possible that one alternative with a higher reduction potential comes along with considerable higher costs. As mentioned in the method section, the cost-effectiveness is measured in €/tCO_2. First costs in €/GJ and €/litre are provided, which are used to estimate the cost-effectiveness.

<u>Hybrid diesel combination</u>

Production costs. The production cost of diesel is in the order of 0,55 €/l (15 €/GJ)[8]. Hybrid vehicles enjoy a bigger driving range compared to battery electric vehicles since hybrids consist of an electric motor and a diesel engine. This driving range advantage, however, comes along with higher costs (Hoen et al., 2009). This is acknowledged by Wout Benning (Interview, 2009) who estimated the additional costs, compared to conventional distribution trucks, to vary between € 20.000 - 40.000, depending on the truck size. Uyterlinde et al. (2008) states that the additional costs are € 10.000 – 40.000.

A company called e-Traction, currently provides city busses with their serial hybrid direct drive system. Such a serial hybrid bus direct drive system is more expensive than

[8] Average value of Europe's Energy Portal (2009) and Kampman & Boon (2005).

conventional systems. Arjan Heinen (Interview, 2009) believes that the hybrid system can become competitive with the conventional system in a few years, especially since the cost of ownership is lower.
Cost-effectiveness. Assuming a technical lifetime of 6 years, an interest rate of 5 – 10%, investment costs of €10.000 – 40.000, a fuel usage of 5 l/km and a total of 40000 kilometers driven per year results in a cost-effectiveness of -18 – 1307 €/tCO_2 avoided for hybrid drivetrains which can reduce 25 – 50% CO_2 emission. For these values it holds that €177 is subtracted as result of fuel saving costs.

Battery electric drivetrain
Production costs. A battery electric vehicle uses electricity from the national grid which is stored in batteries. The production costs of conventional produced electricity is 11 €/GJ (Mierlo van & Macharis, 2005). For the Netherlands, the industrial electricity price is 30 €/GJ and the domestic electricity price is 79 €/GJ (Europe's Energy Portal, 2009)[9]. The production costs of energy from renewable energy sources are 26€/GJ for wind energy, 17 – 56 €/GJ for biomass and 128 – 146 €/GJ for photovoltaic solar power (ECN, 2008). The production costs of fossil diesel are approximately 15 €/GJ (0.55 €/litre) which indicates that renewable energy sources are more expensive. It is expected that the production costs of electricity will drop as result of further technological development (Daey Ouwens, 2006).
Another important aspect is the battery, which is in fact the heart of the vehicle. Battery prices currently range between € 10.000 – 15.000 and have a capacity of 20 – 30 kWh (Hoen et al., 2009). It is believed that battery prices will drop in near future and that the energy capacity will increase when mass production of batteries will start (BERR, 2008). This is expected as a result of battery research and development for other purposes which have contributed to the improvement of batteries.
Cost-effectiveness. Assuming a technical lifetime of 6 years, an interest rate of 5 – 10%, investment costs of €25.000 – 52.500 to provide a total of 70 kwh (the same as e-Traction uses for bus applications), a fuel usage of 5 l/km and a total of 40.000 kilometers driven per year and using the values of ECN (2008), results in a cost-effectiveness for wind energy of 328 – 730 €/tCO_2 avoided, biomass in a cost-effectiveness of 222 – 1083 €/tCO_2 avoided and photovoltaic solar power results in a cost effectiveness of 1528 – 2142 €/tCO_2 avoided.

Diesel engine with FAME
Production costs. Kampman & Boon (2005) estimate the production cost of biodiesel at 15 – 29 €/GJ and the production cost of fossil diesel being about 15 €/GJ.
Cost-effectiveness. Assuming the costs of fossil diesel to be €0,593/litre, Kampman & Boon (2005) estimated the cost effectiveness of biodiesel to be 0 – 625 €/tCO_2eq. Doornbosch & Steenblik (2007) estimate the costs effectiveness of biodiesel to be 240 – 920 €/tonne CO_2. However, these values are for passenger cars and will, as result of a different tank to wheel part, differ and be higher for long-haul transport.
Considering a CO_2 emission reduction of 25 – 45%, the costs of diesel and FAME resulted in a first order estimation of the cost-effectiveness to be -66 – 531 €/tCO_2 avoided.

Diesel engine with Fischer-Tropsch diesel
Production costs. A comparison by Vliet van et al. (2009) of biomass to liquid Fischer-Tropsch processes showed costs of 15 – 18 €/GJ with extremes of 24, 29 and 41 €/GJ. Kampman & Boon estimate the production costs at 11 – 21 €/GJ.

[9] 1GJ = 278kWh

Cost-effectiveness. Assuming the costs of fossil diesel production to be €0,593/litre, Kampman & Boon (2005) estimated the cost effectiveness of Fischer Tropsch diesel, derived from biomass, to be -50 – 150 €/tCO_2eq. However, these values are for passenger cars and will, as result of a different tank to wheel part, be higher for long-haul transport.
On the basis of the CO_2 emission reduction of 85-95% and the costs of diesel and Fischer-Tropsch biodiesel resulted in an estimation of the cost-effectiveness to be 3 – 363 €/tCO_2 avoided.

Table 6.2 summarizes the technical potential and cost-effectiveness of a diesel engine with FAME or Fischer-Tropsch biofuel, a battery electric drivetrain and a hybrid diesel drivetrain using diesel fuel.

Table 6.2. Technical potential and cost-effectiveness of alternative drivetrain fuel combination for the Netherlands.

Drivetrain fuel combination	**Technical potential (CO_2 emission reduction)**			**Cost-effectiveness**
	%	**2020 (Mton)**	**2050 Mton**	**€/tCO_2 avoided**
Distribution Trucks				
Diesel engine + Diesel (standard)	-	1,4 Mton emitted	2,5 Mton emitted	-
Hybrid Diesel + Diesel	25-50%	0,4 – 0,7	0,6 – 1,3	- 18 – 1307
Battery Electric Drivetrain (sustainable energy)	81-100%	1,2 – 1,4	2,0 – 2,5	Wind: 328 – 730 Biomass: 222 – 1083 Photovoltaic: 1528 – 2142
Long haul Trucks				
Diesel engine + Diesel (standard)	-	10,5 Mton emitted	14,9 Mton emitted	-
Diesel engine + FAME	25-45%	2,6 – 4,7	3,7 – 6,7	- 66 – 531
Diesel engine + Fischer-Tropsch	85-95%	8,9 – 10	12,7 – 14,1	3 – 363

6.4 Innovation system performance

The next sub-sections comprise a description of the current Dutch innovation system structure and innovation system function fulfillment for the four earlier selected alternative drivetrain fuel combinations. Hybrid diesels and battery electric drivetrains are considered together in one technology specific innovation system as these technologies are related and share actors. This results in an electricity freight road technology specific innovation system. The same holds for FAME biodiesel and Fischer-Tropsch biodiesel leading to a biofuel freight road transport technology specific innovation system.

Currently, emphasis in terms of research, development and concept testing, is put on hybrid diesel drivetrains and battery electric drivetrains for an application in freight transport. For biofuels it holds that small percentages are blended with conventional fuels as a result of obligations by the government.

Assuming a hypothetical diffusion S-curve, hybrid diesel drivetrains, battery electric drivetrains and Fischer-Tropsch biodiesel fuels can be categorized in the pre-development phase. FAME biodiesel, as a result of blend obligations by the government, is considered to be in a take-off phase. When, however, higher blends of FAME are regarded the fuel is also positioned in the pre-development phase.

6.4.1 Electricity freight road innovation system structure

In this sub-section the five components of the electricity freight road transport TSIS are analyzed on their current state in terms of quality and quantity. The analysis of the quality and quantity is based upon gathered information by conducted interviews with experts in the field and performing a literature study. Interviews were conducted with a supplier of drivetrain/components (E-traction), truck manufacturers (DAF and Mercedes), intermediaries

(SenterNovem and TNO), knowledge institutes (HAN-HTS autotechniek and TNO) and governmental bodies (RWS-DVS).

Electricity freight road transport TSIS

Supply side

Considering the supply side of the electricity TSIS it comprises suppliers of components or complete drivetrains. Most of the suppliers of components or complete systems cooperate with truck manufacturers to assembly and test full electric or hybrid trucks. The manufacturers of trucks are big international organizations. The producers and suppliers of components and drivetrains are both large international and small national organizations. For instance, the international organization Etan develops gearboxes as core business besides the development of hybrid drivetrains. A smaller organization with a core business in alternative drivetrains is e-Traction which develops series hybrid drivetrains with in-wheel motors.

The supply side of the electricity TSIS comprises both large and smaller organizations. The quality is assumed to be sufficient as different actors in this component work together in order to assemble and test (hybrid) electric trucks. The actors invest in the process of manufacturing and testing (hybrid) electric trucks. The quantity is considered very weak to sufficient as currently no (hybrid) electric trucks are manufactured commercially, but in return no demand exists. (Hybrid) electric trucks are currently only developed with the purpose of pilots, for instance TNT who is using full electric trucks in Rotterdam, or to be tested by truck manufacturers.

Demand side

The demand side of the electricity freight transport TSIS comprises transport organizations. More precise the transport organizations, or parts of organizations, that perform urban distribution instead of long haul transport.

In terms of quantity the demand side is considered very weak since not one distribution organization was found which uses hybrid or battery electric trucks. On the basis of a test pilot, TNT uses electric trucks in Rotterdam. With regard to quality, the demand side is between weak and sufficient as some organizations, like TNT, see the urge for sustainable drivetrains and fuels while other organizations do not.

Intermediary structure

The electric freight road transport TSIS comprises several intermediary organizations. SenterNovem is one of the intermediaries. SenterNovem initiated the High Tech Automotive Systems program to provide a link between the government, the industry and knowledge institutes related to the automotive sector. One part of the program is about electric drivetrains. Other intermediaries are Automotive Technology Centre (ATC) and Federation Holland Automotive.

Both in terms of quality and quantity the intermediary infrastructure is considered sufficient, since intermediaries currently initiate projects to stimulate the cooperation between government, industry and knowledge institutes and to enhance the chance of successful introduction of electric drivetrains.

Government structure

The government structure comprises the Ministry of Economic Affairs, the Ministry of Housing, Spatial Planning and the Environment, and the Ministry of Transport, Public Works and Water Management with sub-departments Transport, Public Works and Water Management Inspectorate.

In terms of quantity the government structure is sufficient since related ministries are involved. In terms of quality it is debatable whether the governmental bodies are involved enough as the government currently acts passively and leaves the market to decide upon the alternative drivetrain or fuel that will be utilized. Whether this is positive or negative is depended of believes in free market economy or planned economy.

Knowledge infrastructure
The knowledge infrastructure comprises knowledge institutes as TNO and ECN. Furthermore the knowledge infrastructure involves several universities and HAN-HTS autotechniek. To a certain extent the knowledge infrastructure is strengthened by organizations that are supplier and developers of components or complete electric drivetrains as these organizations also develop knowledge.

The knowledge infrastructure is considered strong in terms of quality since fundamental as well as applied knowledge is developed by the knowledge institutes. In terms of quantity the knowledge infrastructure is sufficient due to the wide variety of knowledge institutes.

Figure 6.4 illustrates important actors of the technology specific innovation system considering diesel hybrid and battery electric drivetrains for the freight road sector. Table 6.3 summarizes the quantity and quality of the different Innovation Systems components.

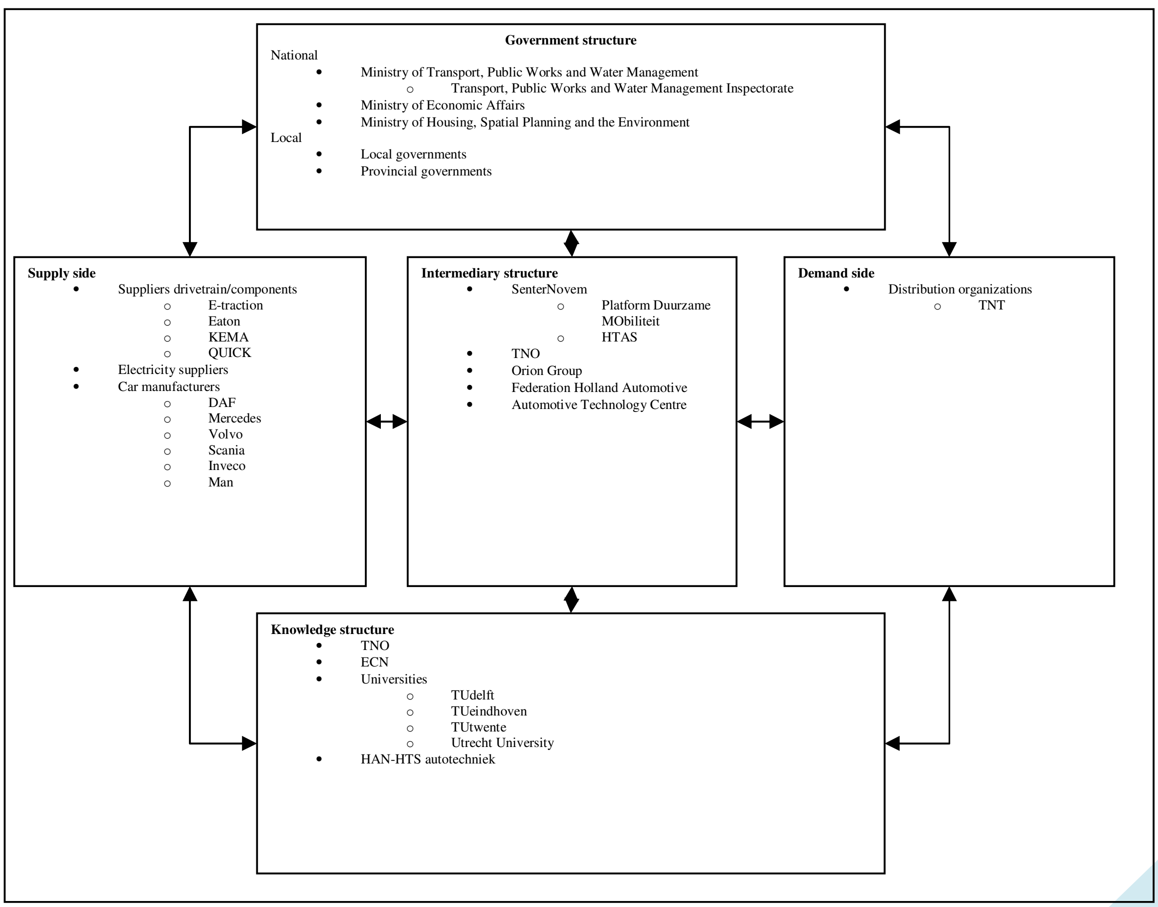


Figure 6.4: The Electricity Freight Road Transport Technology Specific Innovation System.

Table 6.3. Score of quantity and quality per Innovation System component. 1 = very weak, 3 = sufficient and 5 = very strong		
Component	*Quantity*	*Quality*
Supply Side	1 – 3	3
Demand Side	1	2 – 3
Intermediary Infrastructure	3	3
Government Structure	3	1 – 5
Knowledge Infrastructure	3	3 – 4

6.4.2 Electricity freight road innovation system functions

Electricity freight road transport TSIS

Entrepreneurial activities.

With respect to electric drivetrain components or complete systems sufficient suppliers exist. The activities, as a result of the fact that their systems differ from the conventional fossil fuel using drivetrains, are considered as entrepreneurial activities. Many different suppliers and truck manufacturers are involved in (hybrid) electric drivetrain systems. e-Traction develops and supplies a complete new hybrid system which is considered an entrepreneurial activity. e-Traction develops a series hybrid system that drives in-wheel electric motors. e-Traction designs, engineers, develops and improves the series hybrid in-wheel system all by its own.
Currently TNT conducts a pilot in which two full electric trucks in Rotterdam are experimented with on their possibility to use in urban distribution. The pilot by TNT is considered an entrepreneurial activity since other examples were not found.

The foregoing illustrates that only a small amount of organizations perform activities that may be considered entrepreneurial activities. This results in a score 2 (weak) for the function entrepreneurial activities.

Knowledge development

The development of knowledge with respect to (hybrid) electric drivetrain components or systems is evolving fast. This high development of knowledge creation can be explained by activities for the development and stimulation of electric light duty vehicles. As result of the many knowledge institutes that emphasize on (hybrid) electric drive train technologies the knowledge base can be considered well developed and even still developing. These days, a lot of research is on the development of a storage battery that is light weighted, small, safe, cheap, can deliver high power and that recharges fast (Nagelhout & Ros, 2009). The increasing development of knowledge can be indicated as well by the number of patents that has been applied for. Between 1990 and 2003, the number of patents that has been applied for with respect to batteries is approximately twice the amount of patents that have been applied for with respect to other technologies (Nagelhout & Ros, 2009).

The knowledge development of (hybrid) electric drivetrain components or systems is very strong and still developing in terms of knowledge and experience creation as result of test-drives and pilot projects. This results in the score 3 (sufficient) for the function knowledge development.

Knowledge diffusion

Electricity is a hot issue these days as possible replacement for fossil fuels. This results in many symposia and conferences. However a lot of focus is on (hybrid) electric light-duty vehicles. During the interviews held witch truck manufacturing organizations it became clear that suppliers of drivetrain systems or components contact truck manufacturers to share their knowledge about electric systems and their possible implementation in heavy-duty vehicles. E-Traction with its serial diesel hybrid in-wheel motor system shares his knowledge about the possibilities widely by contacting all kinds of organizations ranging from manufactures to universities.

The above indicates that conferences, symposia and other events where the diffusion of knowledge can occur are initiated for (hybrid) electric drivetrain in general. Actors within the innovation system actively share and diffuse their knowledge with other actors, most likely potential partners or customers, in the Innovation System. This results in a score 3 (sufficient) for the function knowledge diffusion.

Guidance of the search

Currently, governmental bodies stimulate projects that are broad and generic. In doing so, governmental bodies stimulate innovation in the transport sector but do not steer towards a preferred alternative drivetrain or fuel in specific. With other words, the government stimulates innovation broadly, however, it acts passively by leaving the industry to decide upon the drivetrain technology or alternative fuel to reduce CO_2. Whether this is positive or negative depends on believes in free market economy or planned economy. On the basis of interviews held with truck manufacturing organizations it was pointed out that truck manufacturing organizations investigate the possibilities of several possible drivetrains and alternative fuels. Thus besides governmental bodies, the automotive truck industry also does not decide between the drivetrain technologies and alternative fuels. Local governmental bodies, those of Rotterdam and Amsterdam, do specifically promote electric transport with the projects Rotterdam Climate Initiative and Electric Amsterdam.

From the interviews it became clear that a shared vision toward the usage of diesel hybrids and battery electric drivetrains for urban distribution transport does exist. However a shared vision of one potential rich alternative does not exist between actors since they have an interest in different drivetrain technologies or alternative fuels. This results in a score 2 (weak) for the function guidance of the search.

Market formation

Currently, no (hybrid) electric freight transport market exists with the exception of TNT that conducts a pilot project. The absence of a market (demand and supply) is the result of the absence of a sufficiently fulfilled system. In return, the absence of a fulfilled system can be explained by the pre-development phase in which the (hybrid) electric drivetrain currently is.

To summarize, a commercial (hybrid) electric truck market is absent at this moment. The function market formation is assigned the score 1 (very weak).

Resource mobilization

Governmental bodies do not provide financial resources to one alternative drivetrain or fuel in specific and in addition mainly focus on light-duty vehicles. Local governmental bodies of Rotterdam and Amsterdam do promote electric drivetrain technologies, although primarily for light-duty vehicles.

The heavy-duty automotive industry invests in (hybrid) electric drivetrains. Whether these investments are adequate is difficult to indicate. The availability of human resources is sufficient in terms of quantity and quality.

The above indicates that the investments by governments are debatable since more emphasis is put on light-duty vehicles. The investments done by the heavy duty vehicle industry are difficult to evaluate. The human resources are sufficient enough. This results in attributing the function resource mobilization a score 2 (weak).

Creation of legitimacy/counteract resistance to change
None of the interviewees expect an active resistance to change by any party for the development and successful implantation of (hybrid) electric drivetrains

The interviewees did notice the vested interest in oil and gas of traditional oil companies. These traditional oil companies will not make a transition until they eventually need to do this, either by a strong pressure of other parties or due to the scarcity of fossil fuel. A score 3 (sufficient) to the function creation of legitimacy/counteract resistance to change is appointed.

Figure 6.5 illustrates the score per function for the electric road transport TSIS. It presents to what extent the different innovation system functions are currently fulfilled.

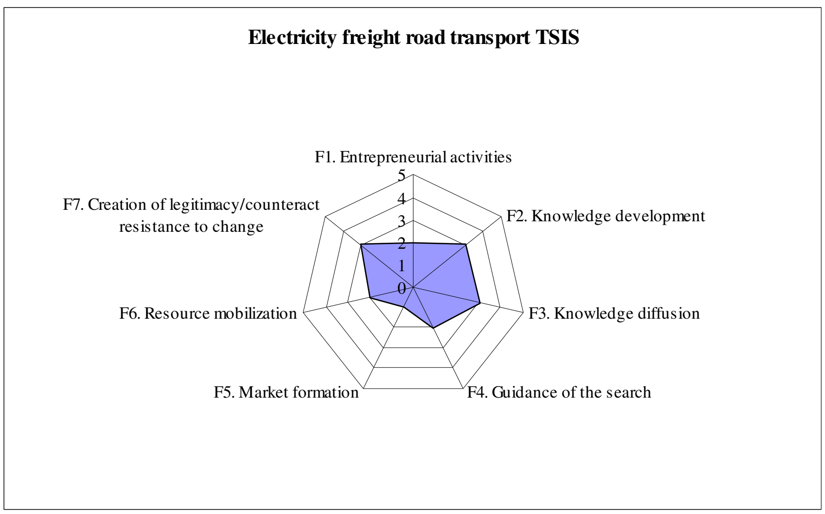


Figure 6.5: Score per function for the electricity freight road transport technology specific innovation system.

6.4.3 Biofuel freight road innovation system structure

In this sub-section the five components of the biofuel freight road transport TSIS are analyzed on their current state in terms of quality and quantity. The analysis of the quality and quantity is based upon gathered information by conducted interviews with experts in the field and performing a literature study. Interviews were conducted with truck manufacturers (DAF and Mercedes), intermediaries (SenterNovem, TNO and Energy Valley), knowledge institutes (HAN-HTS autotechniek and TNO) and governmental bodies (RWS-DVS).

Biofuel freight road transport TSIS

Supply side
The supply side of the biofuel freight road TSIS comprises small organizations of which the production of biofuel and biomass is their core business. Furthermore the supply side comprises the larger traditional oil companies. Traditional oil companies have an interest in biofuels as their core business of fossil fuels may become more scarce and an obligation

exists for blending biofuels with fossil fuels in road transport in the Netherlands. Truck manufactures are also part of the supply side developing the biofuel using trucks.

The biofuel TSIS supply side is considered sufficient enough in terms of quantity because currently biofuel is only needed in small amounts to comply with the biofuel obligation and for pilots and test drives. The quality of the supply side is between weak and sufficient since it mainly holds small starting companies with the core business in biofuels or biomass and new process technologies which may not yet be fully developed technically. The quality of the truck manufacturers is sufficient as the truck concept is practically the same as in conventional trucks.

Demand side
The biofuel TSIS demand side comprises transport organizations. More precise the transport organizations, or parts of a transport organization, that perform long haul road transport of any kind.

In terms of quantity the demand side is considered weak since transport organizations do not use long haul transport trucks that drive completely on biodiesel or on high blends. Long haul transport, and all other road transport, only drives on low blends as a result of the biofuel blend obligations. In terms of quality the demand side is weak as some organizations see the urge for sustainable drivetrains and fuels while others do not.

Intermediary structure
The intermediary structure with respect to the biofuel freight road transport TSIS includes SenterNovem. SenterNovem initiated the GAVE project (gaseous and liquid climate neutral energy carries). GAVE is a government program with as main task to support the implementation of European guidelines for biofuels to accelerate the introduction of biofuels in the transport sector. Furthermore, SenterNovem has an advanced biofuel working group that also aims to accelerate the introduction of biofuels. Another intermediary foundation is Energy Valley. Energy Valley tries to strengthen the economical development of the northern regions of the Netherlands by aiming at regional chances of sustainable innovation, more precisely of biomass and biofuels.

The quality and quantity the intermediary infrastructure is considered sufficient, since intermediaries currently initiate projects to stimulate interaction between government, industry and knowledge institutes and enhance a successful introduction of biofuels.

Government structure
The government structure consists of the Ministry of Economic Affairs, the Ministry of Housing, Spatial Planning and the Environment, the Ministry of Agriculture, Nature and Food Quality and the Ministry of Transport, Public Works and Water Management with sub-department Transport, Public Works and Water Management Inspectorate.

In terms of quantity the government structure is sufficient since the related ministries are involved. In terms of quality it is debatable whether the governmental bodies are involved enough as the government currently acts passively and leaves the market to decide upon the alternative drivetrain or fuel that will be implemented in transport modes. Whether this is positive or negative is depended of believes in free market economy or planned economy.

Knowledge infrastructure
The knowledge infrastructure comprises TNO, ECN and CE as research institutes. Furthermore the knowledge infrastructure involves several universities, with Wageningen University being very important, and HAN-HTS autotechniek. To a certain extent the knowledge infrastructure also comprises organizations that are supplier and developers of biofuel and biomass since these develop knowledge in practice.

The knowledge infrastructure is considered strong in terms of quality since fundamental as well as applied knowledge is developed by research institutes and universities. In terms of quantity the knowledge infrastructure is sufficient due to the wide variety of knowledge institutes.

Figure 6.6 projects important actors of the technology specific innovation system considering FAME and Fischer-Tropsch biodiesel for the freight road sector. Table 6.4 summarizes the quantity and quality of the different Innovation Systems components.

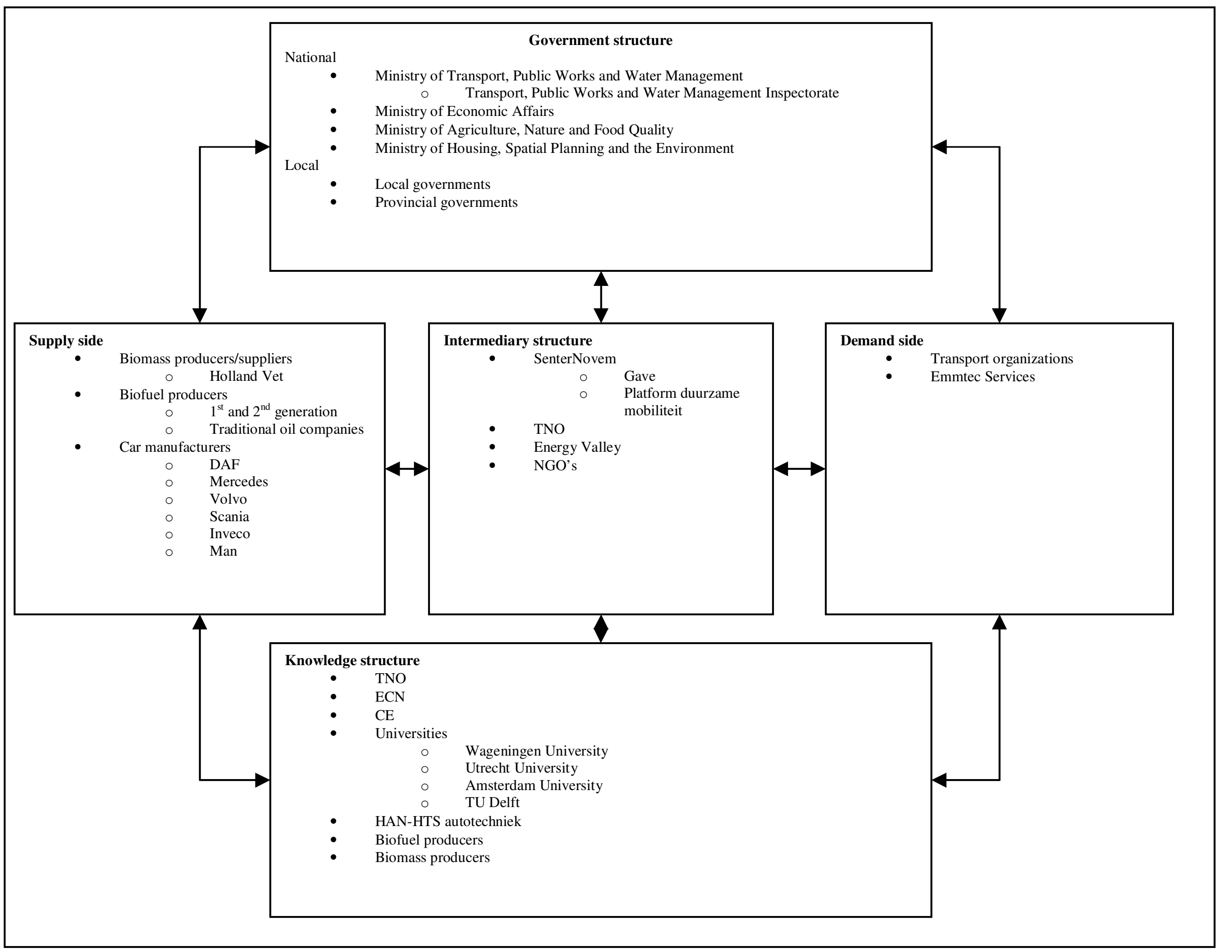


Figure 6.6: The Biofuel Freight Road Transport Technology Specific Innovation System.

Table 6.4. Score of quantity and quality per Innovation System component. 1 = very weak, 3 = sufficient and 5 = very strong		
Component	*Quantity*	*Quality*
Supply Side	3	2 – 3
Demand Side	2	2
Intermediary Infrastructure	3	3
Government Structure	3	1 – 5
Knowledge Infrastructure	3	4

6.4.4 Biofuel freight road innovation system functions

Biofuel freight road transport TSIS

Entrepreneurial activities.

Entrepreneurial activities for biofuels in the freight road transport TSIS can be found in the activities of harvesting both 1st and 2nd generation biomass and development of Fame and 2nd generation Fischer-Tropsch biodiesel. Emmtec Services initiated a pilot project, currently in the start up phase, in which it drives its trucks by using biodiesel produced from rape seed as fuel (SenterNovem, 2009c) A 2nd generation entrepreneurial activity is the pilot project of Shell and Coheron to build a biomass Fischer-Tropsch plant. Currently, large scale Fischer-Tropsch plants only use fossil inputs. Possibilities for gasification of biomass for the production of synthesis gas are currently being investigated (Thuijl et al., 2003; Interview Benning, 2009; Interview Rabé, 2009).

The foregoing illustrates that entrepreneurial activities occur but can be considered very scarce. This results in a score 1 (very weak) for the function entrepreneurial activities.

Knowledge development

Many knowledge institutes are involved in the biofuel innovation system. Almost all knowledge institutes focus their knowledge development on the light duty vehicle sector as this is the dominant road transport sector. Created knowledge, mainly theoretical knowledge, is to a certain extent also functional in the heavy-duty sector as these are related sectors using the same technological drivetrains but it, however, results in knowledge gaps for the heavy-duty sector.

Less emphasis is put on the execution of projects in which pure biofuels or high blends are used as a fuel in heavy-duty vehicles. Finally, a lot of uncertainty comes from the absence of CO_2 life cycle well-to-tank analyses of biofuels applied in heavy-duty vehicles.

The foregoing points out that knowledge development with respect to biofuels for heavy-duty vehicles is scarce but developing. The dominant part of created knowledge for heavy-duty vehicles and biofuels is the result of knowledge created primarily for light-duty vehicles. The function knowledge creation is assigned the score 2 (weak).

Knowledge diffusion

With respect to biomass and biofuels in general a lot of symposia and conferences take place. These events form the place were knowledge can be diffused among others. Specific symposia or conferences about the possibilities for biofuels in the heavy-duty sector do exist but are scarce. Currently Volvo is conducting the Volvo Trucks Biofuel Tour (Stichting Milieunet, 2008). The biofuel tour holds seven trucks that drive on different biofuels. Volvo wants to make clear that it is possible to drive on biofuels and that clear guidelines and policy have to be created. Furthermore knowledge is diffused and shared with other parties through scientific journals

The above indicates that conferences, symposia and other events where the diffusion of knowledge can occur are initiated for biomass and biofuels in general. More specific symposia or conferences are scarce. This results in a score 2 (weak) for the function knowledge diffusion.

Guidance of the search
Currently, governmental bodies stimulate projects that are broad and generic. In doing so, governmental bodies stimulate innovation in the transport sector but do not steer towards a preferred alternative drivetrain or fuel in specific. With other words, the government stimulates innovation, however, it acts passively by leaving the industry to decide upon the drivetrain technology or alternative fuel to reduce CO_2. On the basis of held interviews with truck manufacturing organizations it was pointed out that truck manufacturing organizations investigate several possible drivetrains and alternative fuels on their possibilities. Thus besides governmental bodies, the automotive truck industry also does not decide between the drivetrain technologies and alternative fuels for now.

From the interviews it became clear that a shared vision toward the usage of biofuels, Fischer-Tropsch and FAME biodiesel, for long-haul transport exists. However a shared vision of the most potential rich alternative does not exist between actors that believe in different drivetrain technologies or alternative fuels. This results in a score 2 (weak) for the function guidance of the search.

Market formation
At this moment only a low blend biofuel market exists for all road transport in the Netherlands (Interview te Buck, 2009). Considering higher blends or pure biodiesel it can be concluded that a market is lacking. The absence of a market is the result of the absence of a sufficiently fulfilled system. In return, the absence of a well fulfilled system can be explained by the pre-development phase in which biofuels are currently in.

To wind up the foregoing, the commercial high blend or pure biofuel truck market is lacking at this moment. A low blend market however exists. The function market formation will be assigned the score 1 (very weak).

Resource mobilization
As mentioned earlier, governmental bodies do not stimulate one specific drivetrain technology or alternative fuel. The government does finance research and pilots with regard to biofuels but yet again not with regard to heavy-duty vehicles in specific. The heavy-duty vehicle sector benefits from investments done in the light-duty vehicle sector. The industries, both the biofuel as well as the automotive truck industry, do invest in biomass, biofuels and heavy-duty vehicles. Whether these investments are enough is difficult to indicate.
From the interviews it became clear that for this moment, sufficient human resources are available in terms of quantity and quality (Interview Mesman, 2009).

The above written indicates that the investments by governments are debatable since more emphasis is put on light-duty vehicles and the investments by industries are hard to indicate. This results in attributing the function resource mobilization a score 2 (weak).

Creation of legitimacy/counteract resistance to change
None of the interviewees expect an active resistance to change by any party for the development and successful implantation of biofuels in the heavy-duty sector.

The interviewees did notice the vested interest in oil and gas of traditional oil companies. These traditional oil companies will not make a transition until they eventually need to do this, either by a strong pressure of other parties or due to the scarcity of fossil fuel. The function creation of legitimacy/counteract resistance to change is assigned the score 3 (sufficient).

Figure 6.7 illustrates the score per function for the biofuel road transport TSIS. It presents to what extent the different innovation system functions are currently fulfilled.

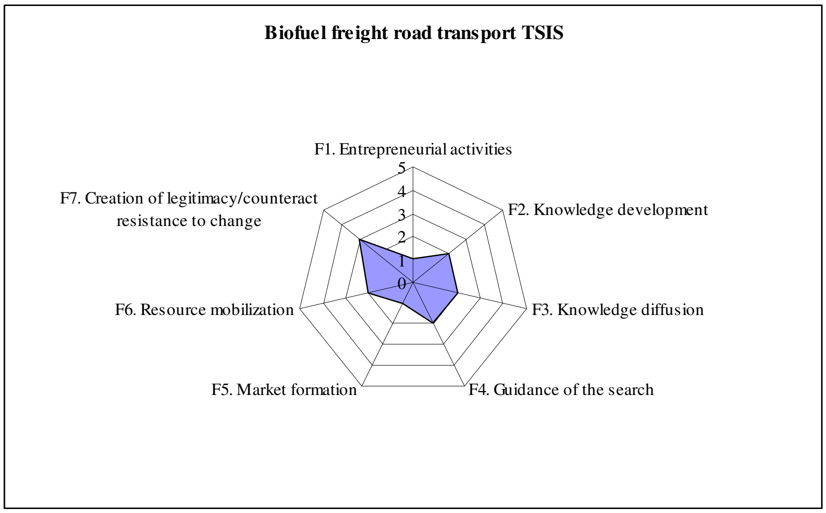


Figure 6.7: Score per function for the biofuel freight road transport technology specific innovation system.

7. Maritime sector

This section presents the results for the maritime sector. First world wide projections of maritime transport growth towards 2050 are set out. Second the development of the Dutch maritime sector is discussed. Third a selection of promising drivetrain technologies and fuels is made. Then selected drivetrain technologies and alternative fuels are described on their potential to diminish CO_2 emissions. Fourth, economical aspects are addressed. The section ends with an overview of the innovation system performance considering its structure and functions.

7.1 Maritime sector towards 2050

The maritime transport operates on an international level. Considering a world perspective, IMO (2008) presented six projections of the CO_2 emission by world maritime transport. The high and low emission projections are reflected in figure 7.1.

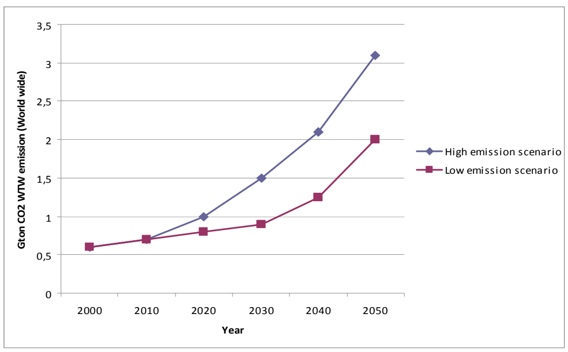


Figure 7.1 Total world wide maritime carbon dioxide emissions. Based on IMO (2008).

Figure 7.1 reveals that CO_2 emission by maritime transport between 2000 and 2020 increase with 33 – 66%. In 2050 the CO_2 emission will be approximately 233 – 416% higher compared to 2000. This shows that the development of CO_2 emissions by the maritime sector is uncertain on the mid and long term. This wide range is the result of differences in efficiency improvements levels and growth of seaborne transport, economic growth, and population growth. The high scenario is driven by a very rapid economic growth, population growth that peaks in mid-century while the low emission scenario is driven by emphasis on local solutions to economic social and environmental sustainability, intermediate economic growth and continuous increasing population (IMO, 2008). In the remainder of the report the high scenario, in terms of CO_2 emissions, is considered.

7.1.1 Dutch maritime sector towards 2050

The Netherlands Environmental Assessment Agency (PBL) reported the energy consumption of the maritime sector, based on fuels reported as bunker fuels, for four different scenarios (Hoen et al., 2006). In the data a distinction is made between sea vessels and inland vessels. Using CO_2 emission values per energy content the total CO_2 emission of sea vessels and inland vessels for the Netherlands were calculated for the different scenarios. In this report it is assumed that all sea vessels use heavy fuel oil (HFO) and that inland vessels use (Marine) diesel.

The total CO_2 emission is illustrated in figure 7.2 for sea and inland vessels. The CO_2 emission also include the CO_2 emissions during the well-to-tank part, namely 6,65 kg/GJ for HFO and 7,9 kg/GJ for maritime diesel (TME, 2003; EUCAR et al., 2006).

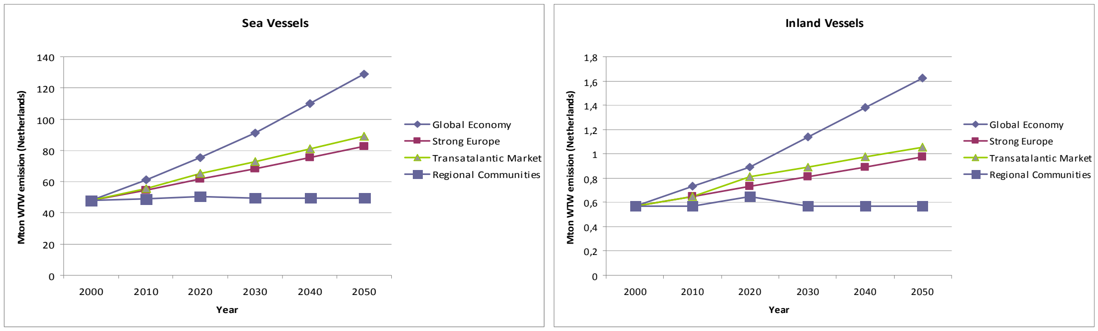


Figure 7.2: CO_2 emission of the Dutch maritime sector towards 2050. Note: The values for 2050 are extrapolated linearly. Data of the energy consumption is obtained from Hoen et al. (2006) and used to calculate the CO_2 emission in Gton using the reference values of 77,4kg CO_2/GJ HFO and 73,3kg CO_2/GJ Diesel for the tank-to-wheel part and 6,65 kg/GJ for HFO and 7,9 kg/GJ for diesel for the well-to-tank part.

Comparing figure 7.1 and 7.2 illustrates that the Netherlands, is responsible for a significant share of the total world's maritime CO_2 emission, namely 7,7 – 9,5 % in 2020 and 4,2 – 6,5 % in 2050.

In the remainder of the report the Global Economy scenario as high scenario in terms of CO_2 emission is considered.

7.2 Alternative drivetrain and fuel selection

There are several options to reduce the emission of CO_2 in the maritime sector. The emission of CO_2 is influenced by the drivetrain, fuel, size, hull design, logistic efficiency and speed/traveltime. In this report the focus will be on the drivetrain technology and selected fuel only and furthermore a similar performance level of inland and sea vessels to the current situation is used as a reference situation. A non drivetrain fuel option is to be found in lowering the vessel's speed. A company lowered the speed of its vessels from 25 to 20 knots which resulted in fuel savings, and thus CO_2 emission reduction, of 40 – 50% (OECD, 2008).

Aspects of drivetrain and fuel selection

Aspects for appropriate drivetrain and fuel selection differ for sea and inland vessels. Sea vessels mainly operate at a constant speed for a long distance. Important for the drivetrain fuel selection of a sea vessel is the distance that it can overcome (Interview Anink & Krikke, 2009). Inland vessels cross smaller distances and have the opportunity to refuel again on their route but are still limited by sailing radius (Interview Anink & Krikke, 2009). Inland vessels also travel most of their time at constant speeds which makes an efficient engine load of importance. A final aspect, for both sea and inland shipping, for the selection of a drivetrain and fuel combination is the CO_2 intensity and how this compares to the currently used drivetrain and fuel combination.

Drivetrain fuel combinations available

This sub-section comprises a description of drivetrain fuel combinations characteristics for the maritime sector. Figure 7.3 illustrates the description of the several drivetrain fuel combinations given below. For the conventional drivetrain fuel combination values are set on 100 and the alternative drivetrain fuel combinations are relatively to this value.

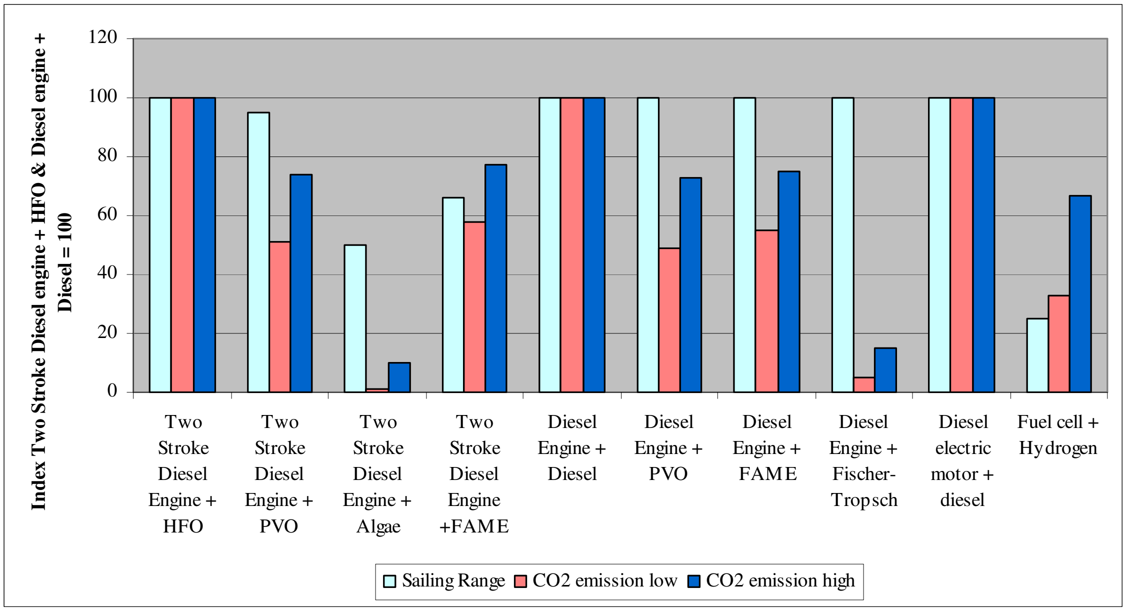


Figure 7.3: Aspects of drivetrain and fuel selection in the aviation sector. Characteristic performance of conventional drivetrain fuel combination is set on 100.

<u>Two stroke diesel engine with HFO (Conventional drivetrain fuel combination)</u>
Currently, almost all sea vessels use large two stroke diesel engines with HFO as a fuel.
Range. As such a drivetrain fuel combination currently is the standard for sea vessels, it is assumed that the distance which a vessel can overcome with such a combination is sufficient enough.
CO_2 intensity. During combustion, HFO emits 77,4 kg CO_2/GJ (PBL Data sheets). This value is used to compare the CO_2 intensity of the alternative drivetrain and fuel combinations with.

<u>Diesel engine with marine diesel (Conventional drivetrain fuel combination)</u>
Currently, most inland vessels use diesel engines with (marine) diesel as a fuel.
Range. The range an inland vessel can overcome with this propulsion system and fuel is assumed to be sufficient as it currently forms the standard.
CO_2 intensity. During combustion, marine diesel emits 73,3 kg CO_2/GJ (PBL Data sheets). This value is used to compare the CO_2 intensity of the alternative drivetrain and fuel combinations with.

<u>Two stroke diesel engine with pure vegetable oil (PVO)</u>
The two stroke diesel engines that are designed for HFO can also run on PVO without any problems (MAN Diesel, 2006). PVOs, for instance from jatropha oil, palm oil, rapeseed oil or soy oil, have more or less similar technological features such as density, viscosity and a lower heating value (Jiménez Espadafor, 2009). As a result PVOs may be used as a HFO substitute.
Range. The lower heating value of PVOs is approximately 4% lower compared to HFO (Jiménez Espadafor, 2009). Due to the lower heating value and the somewhat lower density, the energy introduced in each cycle is lower (Jiménez Espadafor, 2009). As a result the sailing range of a PVO using vessel is considered lower but sufficient.
CO_2 intensity. Considering the whole life cycle chain, PVO can reduce CO_2 emissions by 57% compared to diesel (Aberson, 2008). Comparing the CO_2 emission of diesel and HFO, PVO as a substitute for HFO is able to diminish CO_2 emissions by 55%. SenterNovem estimates savings, compared to diesel of 27 – 51% (Senternovem, 2009d) which is approximately 26 – 49% compared to HFO

Two stroke diesel engine with algae oil

Algae oil forms another possible substitute fuel for HFO (Opdal & Hojem, 2008). However, compared to fossil oil, bio-oil from algae differs considerably in its density and viscosity (Miao et al., 2004). In addition Miao et al. (2004) state that bio-oils from algae are not as stable as fossil oil due to the higher oxygen content.

Range. Algae bio-oil has a lower energy content, namely 29 MJ/kg (25MJ/l) compared to 42 MJ/kg (42 – 56 MJ/l) of HFO (Mia et al., 2004). This means that to overcome the same distance more algae bio-oil will be needed.

CO_2 intensity. Depending on the production method the CO_2 intensity varies (Parker, 2009). During cultivation of algae, CO_2 is absorbed. When the algae are grown they have to be dried and the oil has to be extracted. In this process of algae drying and oil extraction the CO_2 is emitted due to machinery. The exact CO_2 emission reduction value could no be found in literature but since literature and interviewees speak promising about algae it is assumed that algae can reduce 90% or more CO_2 compared to conventional HFO.

Two stroke diesel engine with FAME

Pure vegetable oils can be used as an input to produce FAME.

Range. FAME and HFO respectively have an energy density of 33MJ/l (Shell, 2008) and 39,5 MJ/l (Jiménez Espadafor, 2009). When FAME is used a significant lower distance can be overcome as result of a decrease in energy content per liter compared to HFO.

CO_2 intensity. Compared to conventional fuels, the CO_2 intensity of FAME is considered positive. MNP (2005) estimates the CO_2 emission reduction of FAME at 25-45% related to fossil diesel. Related to HFO the CO_2 emission reduction is about 23 – 42 %.

Diesel engine with pure vegetable oil (PVO)

The marine diesel engines designed for the use of fossil diesel cannot use PVO without the chance of complications. This is the result of the higher viscosity and density that PVOs have (MAN Diesel, 2006).

Range. The range of an inland vessel on PVO is considered to be equal to the distance an inland vessel on diesel can overcome as result of energy densities being respectively 35,2 MJ/l and 36,4 MJ/l (Jiménez Espadafor, 2009).

CO_2 intensity. Considering the whole life cycle chain, PVO can reduce CO_2 emissions by 57% compared to diesel (Aberson, 2008). SenterNovem estimates savings, compared to diesel of 27 – 51% (Senternovem, 2009d).

Diesel engine with FAME

Pure vegetable oils can be further converted into FAME which can be used as a fuel for inland vessels.

Range. If FAME is used, instead of marine diesel, an equal distance can be overcome as result of more or less a similar energy content.

CO_2 intensity. Compared to conventional fuels, the CO_2 intensity of FAME is considered positive. MNP (2005) estimates the CO_2 emission reduction of FAME at 25-45%.

Diesel engine with Fischer-Tropsch biodiesel

Range. Synthetic Fischer Tropsch diesel with biomass feedstock as an input results in more or less an equal sailing range as result of a slightly higher energy content, namely 43,2MJ/kg (Essom, 2008) or 36,9 MJ/l (CSIRO, 2001) compared to 42,5 MJ/kg or 36,4 MJ/l of fossil diesel.

CO_2 intensity. The fuel CO_2 intensity performance of Fischer-Tropsch diesel depends on aspects like the production method and feedstock input. Either the diesel is produced through coal-to-liquid, gas-to-liquid or biomass-to-liquid processes. The fuel CO_2 intensity of biomass-to-liquid is far better than gas or coal-to-liquid processes. Diesel produced with a Fischer Tropsch proces can achieve a CO_2 emission reduction of 90% according to SenterNovem (2009a) and between 85 and 95% according to MNP (2005).

Diesel electric motor with diesel

Another possible alternative for sea and inland vessel may be provided by diesel generators that drive electric motors. When multiple smaller diesel generators are used it is possible to switch generators on and of depending on the power demand at that time which allows to continuously operate at or near the most efficient engine load. However, like mentioned earlier, inland and sea vessels operate on constant speed most of the time which makes such an system of multiple diesel electric motors impractical since no diesel generators have to be switched on or off during operation at constant speed.

Range. The range a diesel electric ship could overcome is considered to be comparable to a conventional sea or inland vessel, because the same fuel is used and the diesel generator and electric motor need to deliver the same power as a normal diesel engine which operates near most efficient engine load.

CO_2 intensity. The CO_2 intensity is considered equal to the conventional system. A better CO_2 intensity is only to be expected when due to maneuvers the speed will fluctuate heavily and diesel generators will be switch on and of accordingly.

Fuel cell with hydrogen

A fuel cell hydrogen combination can theoretically be used to operate a vessel. The sailing range depends on the amount of hydrogen stored on board and the way that it is stored. On board storage of hydrogen is one of the biggest hurdles and becomes increasingly problematic with higher storage requirements (HyWays, 2007; Hoen et al., 2009).

Range. The energy density of liquid hydrogen is 25% of the energy density of diesel fuel (Peckham, 2002). To achieve a comparable driving range with a fuel cell liquid hydrogen combination, four times as much fuel storage capacity is needed.

CO_2 intensity. During operation, a fuel cell hydrogen combination does not emit any CO_2. CO_2 can be emitted during the production of hydrogen. If hydrogen is produced with renewable energy no CO_2 will be emitted. If hydrogen is produced in a less sustainable way, steam reforming of natural gas or electrolysis of fossil produced electricity, between 0,87 – 1,7 kilogram CO_2 will be emitted per litre of hydrogen (Passier et al., 2008).

The previous information indicates that for sea vessels the most viable option is found in the two stroke engine with PVO. Bio-oil from algae as a fuel substitute for HFO is instable due to a higher oxygen content and even has considerably different density and viscosity characteristics. For inland vessels most viable options have to be found in the use of biofuels, more precise by FAME or Fischer Tropsch synthetic diesel with biomass as an input.

Diesel electric drivetrains only form a viable alternative when a vessel operates at fluctuating speeds and as a result engine loads which allows to switch diesel generators on and of to continuously operate on or near optimum engine efficiency. However, as result of sailing at continuous speed, the engine load does not fluctuate and it is expected that conventional diesel engines will operate at or near its optimum efficiency. Hydrogen in combination with a fuel cell does not form a viable option because it influences the sailing range negatively due to storage capacity requirements. The storage of hydrogen on board forms another barrier.

Table 7.1 projects the technical potential of the two stroke diesel engine with PVO for sea vessels and the diesel engine with FAME or Fischer Tropsch diesel as drivetrain fuel combinations for inland vessels.

Combining the CO_2 reduction potential of the selected drivetrain fuel combinations with the CO_2 emissions of sea and inland vessels of the Netherlands towards to 2050 results in the technical reduction potential for the maritime sector. The technical reduction potential for sea and inland vessels is depicted in figure 7.4.

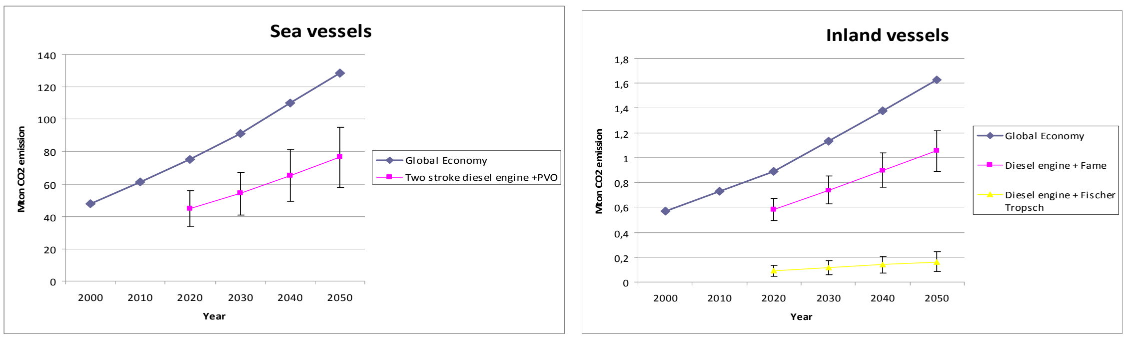


Figure 7.4: Technical potential for sea and inland vessels. Both graphs hold a trend line of CO_2 emission towards 2050. A bandwidth of 26-55% emission reduction is considered for the two stroke diesel engine PVO combination. For a diesel engine FAME combination a bandwidth of 25-45% emission reduction is used. For Fischer-Tropsch diesel a bandwidth of 85-95% CO_2 emission reduction is considered.

7.3 Economical aspects

Besides the technical CO_2 emission reduction potential, cost-effectiveness is of importance. It is possible that one alternative with a higher reduction potential comes along with far higher costs. The cost-effectiveness is measured by €/tCO_2. First costs in €/GJ and €/litre are provided, which are used to estimate the cost-effectiveness.

Two stroke diesel engine with pure vegetable oil (PVO)

Production costs. The costs of PVO depend on the feedstock that is used. Opdal & Hojem (2007) estimate the costs at 14 €/GJ for palm oil, 18 €/GJ for soya oil and 19 €/GJ for rape oil. The costs of heavy fuel oil are approximately 11 €/GJ (Opdal & Hojem, 2007).

Cost-effectiveness. Assuming the costs of HFO at 11€/GJ, the costs of PVO between 14 – 19 €/GJ and a CO_2 emission reduction of approximately 26 – 55%, resulted in a first order estimation of the cost-effectiveness to be 65 – 366 €/tCO_2 avoided

Diesel engine with FAME

Production costs. Kampman & Boon (2005) estimate the production cost of biodiesel at 15 – 29 €/GJ. The costs of marine diesel oil is approximately 13 €/GJ (Opdal & Hojem, 2007).

Cost-effectiveness. Assuming the costs of marine diesel on 13€/GJ, the costs of FAME between 15 – 29 €/GJ and a CO_2 emission reduction of 25 – 45%, resulted in a first order estimation of the cost-effectiveness to be 55 – 788 €/tCO_2 avoided

Diesel engine with Fischer-Tropsch biodiesel

Production costs. A comparison by Van Vliet et al. (2009) of biomass to liquid Fischer-Tropsch processes showed costs of 15 – 18 €/GJ with extremes of 24, 29 and 41 €/GJ. The costs of marine diesel oil is approximately 13 €/GJ (Opdal & Hojem, 2007).

Cost-effectiveness. On the basis of a CO_2 emission reduction of 85-95% and the costs of marine diesel and Fischer-Tropsch biodiesel resulted in an estimation of the cost-effectiveness of 26 – 406 €/tCO_2 avoided.

Table 7.1 summarizes the technical potential and cost-effectiveness of sea vessels with a two stroke diesel engine with PVO diesel engine and inland vessel with a diesel engine with FAME or a diesel engine using Fischer-Tropsch diesel.

Table 7.1 Technical potential and cost-effectiveness of alternative drivetrain fuel combination for the Netherlands.

Drivetrain fuel combination	**Technical potential (CO_2 emission reduction)**			**Cost-effectiveness**
	%	**2020 (Mton)**	**2050 Mton**	**€/tCO_2 avoided**
Sea Vessels				
Two stroke diesel engine + HFO (standard)	-	75,5 Mton emitted	128,6 Mton emitted	-
Two stroke diesel engine + PVO	26-55%	19,6 – 41,5	33,4 – 70,7	65 – 366
Inland Vessels				
Diesel engine + Diesel (standard)	-	0,9 Mton emitted	1,6 Mton emitted	-
Diesel engine + FAME	25-45%	0,2 – 0,4	0,4 – 0,7	55 – 788
Diesel engine + Fischer-Tropsch	85-95%	0,8 – 0,86	1,4 – 1,5	26 – 406

7.4 Innovation system performance

The next sub-sections comprise a description of the current Dutch innovation system structure and innovation system function fulfillment for the three earlier selected alternative drivetrain fuel combinations. PVO, FAME and Fischer-Tropsch biodiesel are considered together in one technology specific innovation system as these technologies are related and share actors. This results in a biofuel maritime transport technology specific innovation system.

Currently, a little emphasis, in terms of research, development and concept testing, is put on the application of alternative biofuels in vessels. This may be the result of several factors. For both sea and inland vessels it holds that they are relatively fuel efficient (Hoen et al., 2009). Furthermore the fuels, especially HFOs, are relatively inexpensive which does not trigger a search for alternatives. Finally, CO_2 emission of sea shipping is not regulated since most of the shipping activity occurs in non territorial waters and vessels may use any fuel.

PVOs, FAME and Fischer-Tropsch diesels are currently not applied in vessels. The commercial use of these fuels in vessels is thus absent. This results in categorizing the three biofuels for sea and inland vessels in the pre-development phase of a hypothetical diffusion S-curve.

7.4.1 Biofuel maritime Innovation system structure

In this sub-section the components of TSISs are analyzed on their current state in terms of quality and quantity. The analysis is based upon gathered information by conducted interviews with experts in the field and performing a literature study. Interviews were conducted with intermediaries (SenterNovem and Energy Valley), knowledge institutes (Scheepsbouw Nederland and TNO) and a propeller/motor supplier (HRP).

Biofuel maritime transport TSIS

Supply side

The supply side comprises biofuel and biomass suppliers on the one hand and motor/propeller suppliers and shipbuilders on the other hand. It seems that these organizations do not interact with each other on the possibilities for biofuels on their implementation in maritime transport.

The supply side is considered sufficient in terms of quantity and quality with respect to ship, propeller and motor suppliers as sufficient of these organization exist. The quantity and quality of biomass and biofuel suppliers for biofuels in maritime transport is very weak because currently no biofuels are used as a fuel for the maritime sector.

Demand side

The demand side of the biofuel maritime transport TSIS comprises both national and international maritime transport organizations and individual ship owners.

In terms of both quality and quantity the demand side is considered very weak because the organizations and ship owners use HFO and marine diesel oil as fuels. As far as known, no demand for biofuels exists among maritime transport organizations and individual ship owners for sea ships. For inland shipping, Argos Oil initiated a pilot to test biodiesel as a fuel for inland vessels in 2006 which eventually started in 2009 (Maritiem Nederland, 2006; Argos Oil, 2009).

Intermediary structure

The intermediary infrastructure with respect to the biofuel maritime transport TSIS comprises intermediary SenterNovem. SenterNovem initiated the GAVE project (gaseous and liquid climate neutral energy carries). GAVE is a government program with as main task to support the implementation of European guidelines for biofuels to accelerate the introduction of biofuels in the transport sector. Furthermore, SenterNovem has an advanced biofuel working group that also aims to accelerate the introduction of biofuels. However, the dominant part of the GAVE project and advanced biofuel working group is on the road transport sector. Holland Marine Equipment (HME), 'centre for maritime innovation', 'knowledge centre sustainable ship' and 'platform ship emissions' are four specific maritime related intermediaries that enhance a more sustainable maritime sector initiating and supporting organizations in their knowledge development and diffusion

In terms of quantity the intermediary infrastructure is considered sufficient. However, in terms of quality the intermediary infrastructure is very weak, because, as far as known, currently these intermediaries do not fulfill an intermediary roll by bringing actors together.

Government structure

The government structure comprises national and international governmental bodies due to the international character of maritime transport. Restricted to the Netherlands the government structure holds the Ministry of Economic Affairs, the Ministry of Agriculture, Nature and Food Quality, the ministry of Housing, Spatial Planning and the Environment and the Ministry of Transport, Public Works and Water Management with sub-departments Directorates-general Civil Aviation and Maritime affairs and Transport, Public Works and Water Management Inspectorate. The International Maritime Organization also forms part of the government structure when an international perspective is considered.

In terms of quantity the government structure is sufficient since the related ministries are involved. In terms of quality the government structure is considered very weak or weak because currently only for inland vessels some general emission regulation exists. Furthermore, the government does not stimulate specific use of biofuels for both sea and inland maritime transport.

Knowledge infrastructure

The knowledge infrastructure comprises research institutes TNO and CE. Furthermore the knowledge infrastructure involves university TUdelft department of Maritime Technique. Kenniscentrum Duurzaam Schip is a specific institute that develops (applied) knowledge for the maritime transport sector.

The knowledge infrastructure is considered weak since fundamental as well as applied knowledge is developed by research institutes and universities but only a little emphasis is put on knowledge development of biofuels as fuel in sea and inland vessels. With regard to quantity, the knowledge infrastructure is sufficient enough since different knowledge developer are involved.

Figure 7.5 projects the important actors of the technology specific innovation system considering PVO, FAME and Fischer-Tropsch biodiesel as fuel for maritime sea and inland vessels. Table 7.2 summarizes the quantity and quality of the different Innovation Systems components.

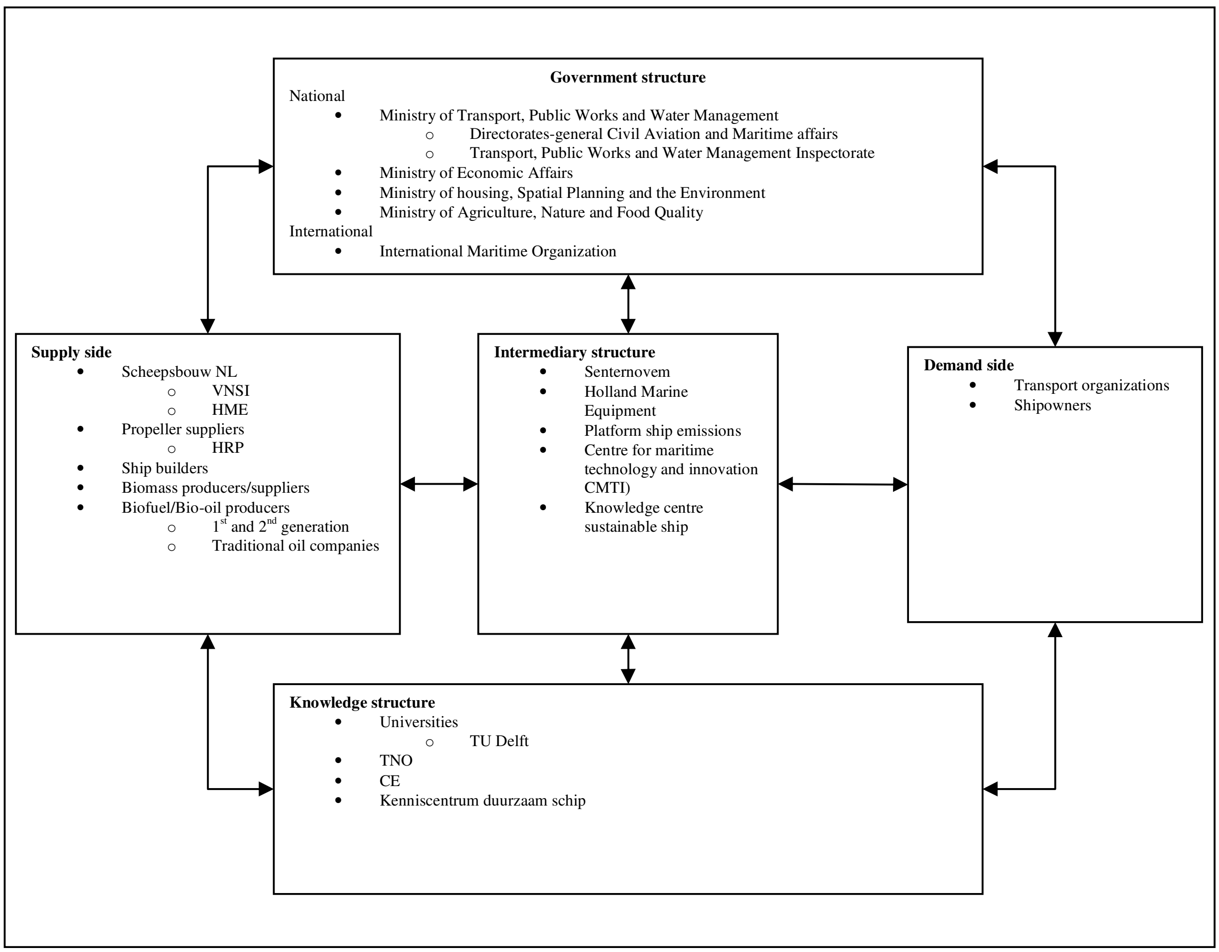


Figure 7.5: The Biofuel Maritime Transport Technology Specific Innovation System

Table 7.2. Score of quantity and quality per Innovation System component. 1 = very weak, 3 = sufficient and 5 = very strong		
Component	*Quantity*	*Quality*
Supply Side	1 – 3	1 – 3
Demand Side	1	1
Intermediary Infrastructure	3	1
Government Structure	3	1 – 2
Knowledge Infrastructure	3	2

7.4.2 Biofuel maritime innovation system functions

Entrepreneurial activities.

With respect to biofuels as a fuel for vessels, only two pilots are considered as entrepreneurial activities. Argos Oil initiated a pilot to test biodiesel as fuel for inland vessels in 2006 which started in 2009 (Maritiem Nederland, 2006; Argos Oil, 2009). Another project is executed in the province Friesland. In this project a small amount of vessels, approximately 35, use biodiesel or PVO as a fuel (SenterNovem, 2009e). These projects are entrepreneurial activities since they are the first using biodiesel as a fuel for vessels.

Other entrepreneurial activities are to be found in the companies that are involved in the production of 1st and 2nd generation biofuel. Currently, there are no direct suppliers of commercially produced PVO, FAME or biofuels from Fischer Tropsch biomass in the Netherlands for the maritime sector.

The foregoing illustrates that only a small amount of vessels currently use biofuels. The pilots related to the use of biofuels in vessels only consider inland vessels. With respect to sea vessels no data on projects could be found. This results in the score 1 (very weak) for the function entrepreneurial activities.

Knowledge development

With regard to the use of biofuel as a fuel for sea and inland vessels, the development of knowledge occurs at small scale compared to road transport. Some scholars investigate biofuels on their possibility to be used as a fuel for vessels. Furthermore some research institutes produce general knowledge for vessels of which parts focus on biofuels as a fuel for vessels.

The foregoing points out that knowledge development with respect to biofuels for maritime transport currently occurs but is very scarce. The marginal attention for and development of knowledge related to the use of biofuels in vessels probably is the result of the lack of interest by ship owners and transport organizations due to economical factors (Interview Anink & Krikke, 2009). The function knowledge creation is assigned the score 2 (weak).

Knowledge diffusion

With respect to biomass and biofuels in general a lot of symposia and conferences take place. Specific symposia or conferences about the possibilities for biofuels as a fuel in the maritime sector do exist but are scarce. Intermediary ‘Platform ship emissions’ initiated seminars for representatives of the Dutch maritime industry. What to do with CO_2 emitted by shipping and the rich potential of alternative propulsion were central themes during these seminars (Platform scheepsemissies, 2009).

The above written indicates that conferences, symposia and other events where the diffusion of knowledge can occur are initiated for biomass and biofuels in general. More specific seminars are initiated by intermediary 'Platform ship emissions'. This results in a score 3 (sufficient) for the function knowledge diffusion.

Guidance of the search
The Dutch intermediary SenterNovem initiated a subsidiary program to stimulate the development and diffusion of knowledge and innovation to enhance sustainable maritime transport (SenterNovem, 2009f). The program, 'Subsidy Maritime Innovation' supports projects that execute feasibility studies, industrial research, pre-competition development and knowledge diffusion (SenterNovem, 2009f). This program does not specifically focus on biofuels but is considered a generic program stimulating any kind of innovation in the maritime sector.

To summarize, no specific biofuel vessel stimulation measures or programs exist. As in any other transport segment, the government does not stimulate an innovation in specific but operates broadly. This results in a score 2 (weak) for the function guidance of the search.

Market formation
Currently, no biofuel martime market exists with the exception of biofuel demand by organizations needed to conduct pilots. The absence of a commercial market can be explained since biofuels for maritime transport are still in the pre-development phase

As a commercial maritime market for biofuels is currently absent, the function market formation is assigned the score 1 (very weak).

Resource mobilization
As indicated by the function guidance of the search, the government does finance research and pilots with regard to biofuels and the maritime sector separately. The government does not aim at stimulating biofuels as a fuel for vessels in specific.
The maritime industry currently does not see the necessity to invest in biofuels. Only the projects of province Friesland and Argos Oil have been identified as investments in biofuels as a vessel fuel. It is assumed that the investments in biofuels as a fuel for vessels by the Dutch maritime industry are insignificant.

The above written indicates that the investments by government and maritime industry are debatable. This results in attributing the function resource mobilization a score 1 (very weak).

Creation of legitimacy/counteract resistance to change
During the interview with Anink and Krikke of Scheepsbouw Nederland (Interview Anink & Krikke, 2009) it became clear that the currently used fuel in shipment, especially sea shipping, are very cheap. A transition towards the usage of biofuels may lead to resistance from individual ship-owners and transport organizations due to economical aspects (Interview Anink & Krikke, 2009). No active lobby groups related to the maritime transport sector were identified during held interviewees. A score 2 (weak) to the function creation of legitimacy/counteract resistance to change is appointed

Figure 7.6 illustrates the score per function for the biofuel maritime transport TSIS. It presents to what extent the different innovation system functions are currently fulfilled in the Netherlands.

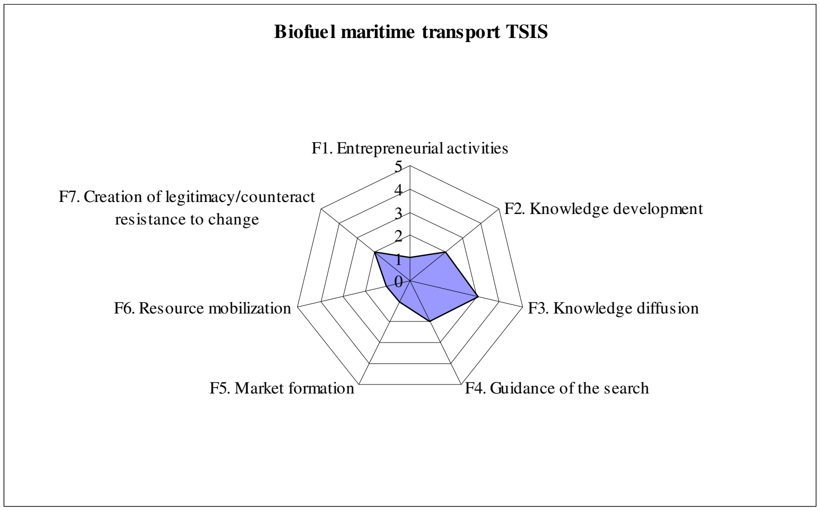


Figure 7.6: Score per function for the biofuel maritime technology specific innovation system.

8. Conclusion

In this report an analysis is made for the aviation, freight road and maritime sector with regard to the possibility to diminish CO_2 emission. CO_2 emission may be reduced in several ways. This report considered alternative drivetrain technologies and alternative fuels only.

Aviation Sector

With regard to the aviation sector, gasturbines in combination with Fischer-Tropsch kerosene, Jatropha and algae derived fuels are selected as most promising options. Table 5.1 indicates the technical reduction potential for alternative fuels in the aviation sector.

Insight in the performance of the Biofuel Aviation Technology Specific Innovation System is created by scoring the Innovation System Structure and the Innovation System Functions. As a result, weak spots in the current Innovation System Performance have been identified and are depicted in figure 8.1.

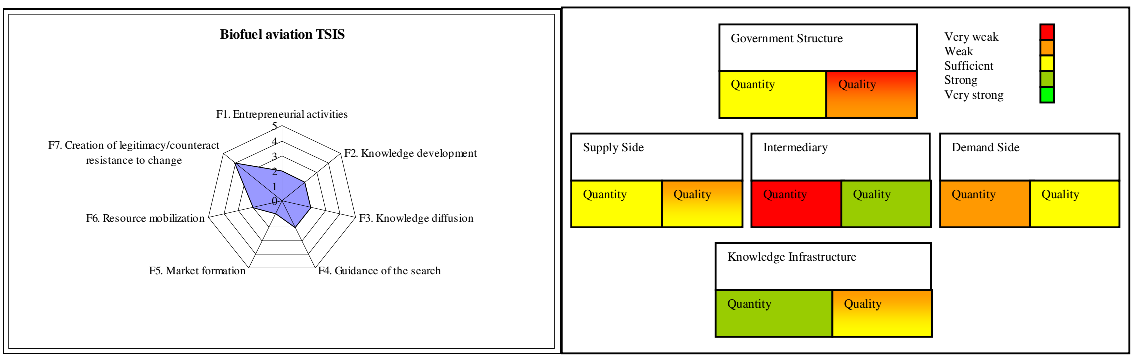


Figure 8.1: Score per function and structure quality and quantity for the biofuel aviation technology specific innovation system.

With regard to the quantity of the innovation system, the demand side and intermediary infrastructure are fulfilled insufficiently. The supply side, the government structure and the knowledge infrastructure lack in terms of quality. With regard to the Innovation System Functions it is indicated that six out of seven functions currently score insufficient of which one scores very weak. The individual scores appointed for the quality and quantity of the structure and the extent to which innovation system functions are served are summed up and depicted in table 8.1. Relating the total score of the biofuel aviation TSIS with the ideal situation in which all components and functions are served completely indicates a current Innovation System performance of 47 – 50 %.

Table 8.1. Innovation structure and function score for the biofuel aviation TSIS	
Innovation System structure quantity	13
Innovation System structure quality	12 – 15
Innovation System Function	15
Total	40 – 43
Innovation System Performance (% of ideal TSIS)	47 – 50

Taking into account the pre-development phase in which these biofuels currently are and the average time-span for diffusion leads to multiplying the technical CO_2 emission reduction potential of the three biofuels with the maximum achievable diffusion percentages for 2020 and 2050. These values are estimated at 10% for 2020 and 95% for 2050. This results in an CO_2 emission reduction in the aviation sector in 2020 and 2050 by alternative biofuels. The outcomes are depicted in table 8.2. A condition to achieve these CO_2 emission reductions is an improving Innovation System Performance over time and take-off in 2014.

Table 8.2. CO_2 emission reduction potential and Cost-effectiveness.

	Achievable CO_2 emission reduction				**Cost-effectiveness**
	Absolute (Mton)		*Percentage*		*€/tCO_2 avoided*
	2020	*2050*	*2020*	*2050*	
Fischer-Tropsch	1,4 – 1,6	27,9 – 31,3	8,5 – 9,5	81 – 90	105 – 273
Jatropha	0,45 – 1,3	8,7 – 26,3	2,7 – 8,0	25 – 76	-41 – 37
Algae	1,5 – 1,65	29,5 – 32,6	9,0 – 9,9	85 – 94	1932 – 2863

Table 8.2 indicates that these three biofuels form promising options to reduce CO_2 emission in the aviation sector from a technical perspective. A study by CE (2008a) estimates the cost of CO_2 in 2020 to be 40 €/tonne and for 2050 it is estimated at 85 €/tonne. Comparing the current costs-effectiveness with the estimated price for CO_2 in 2020 and 2050 points out that reducing CO_2 emission with algae comes with costs to avoid CO_2 that are too high. The cost-effectiveness of Fischer-Tropsch is already very close to the price for CO_2 in 2050. This indicates that for 2020 kerosene derived from jatropha or Fischer Tropsch form options from an economical point of view at this moment. However, cost reductions may be expected in the future which results in better cost-effectiveness for the three biofuels. This does not imply that Fischer-Tropsch and algae biokerosene are unsuitable options, but rather it indicates that (Innovation System and Innovation System Function) improvements have to occur to lower the current cost-effectiveness towards 2020 and 2050.

Freight Road Sector

With regard to the freight road sector, a hybrid diesel and battery electric drivetrain for distribution trucks and diesel engines using FAME or Fischer-Tropsch diesel were identified as most promising options for long haul transport. Table 6.2 indicates the technical reduction potential for distribution and long-haul trucks drivetrain technologies and fuels.

Insight in the performance of the Electricity Freight Road Technology Specific Innovation System was created by scoring the Innovation System Structure and the Innovation System Functions. As a result, weak spots in the current Innovation System Performance have been identified and are depicted in figure 8.2.

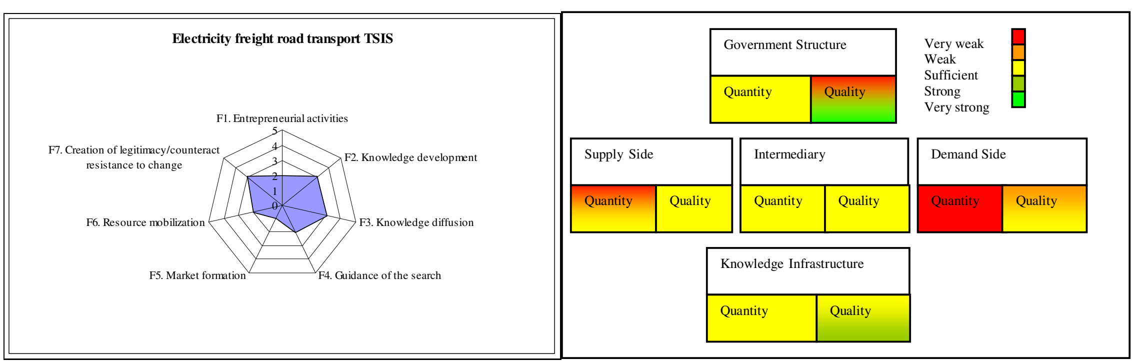


Figure 8.2: Score per function and structure quality and quantity for the electricity freight road technology specific innovation system.

Considering the Electricity Freight Road Technology Specific Innovation System it may be concluded that several components lack in terms of quality, supply and demand side, and quantity, demand side and government structure. With respect tot the Electricity Freight Road TSIS, four out of seven functions are served insufficiently. Adding up the scores for the

Innovation System's quality, quantity and the Innovation system functions resulted in a current Innovation System performance of 46 – 55 %. This is depicted in table 8.3.

Table 8.3. Innovation structure and function score for the electricity freight road TSIS	
Innovation System structure quantity	11 – 13
Innovation System structure quality	12 – 18
Innovation System Function	16
Total	39 – 47
Innovation System Performance (% of ideal TSIS)	46 – 55

Insight in the performance of the Biofuel Freight Road Technology Specific Innovation System was created by scoring the Innovation System Structure and the Innovation System Functions. As a result, weak spots in the current Innovation System Performance have been identified and are depicted in figure 8.3.

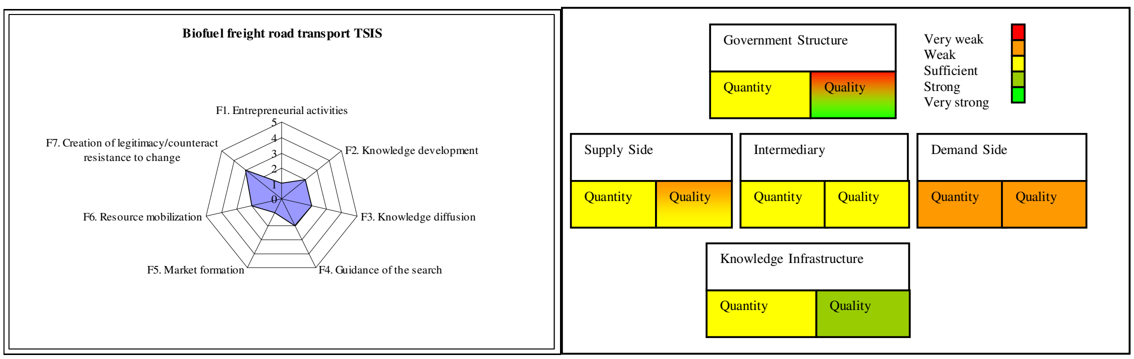


Figure 8.3: Score per function and structure quality and quantity for the biofuel freight road technology specific innovation system.

With regard to the Biofuel Freight Road TSIS, six out of seven functions are served insufficiently with two functions even being served very weak. Regarding the quantity and quality it must be mentioned that the quantity of all components, with the exception of the demand side, are considered to be sufficient. The supply side, the demand side and the government structure lack in terms of quantity. Adding up the scores for the Innovation System's quality, quantity and the Innovation system functions resulted in a current Innovation System performance of 46 – 52 %. This is depicted in table 8.3.

Table 8.4. Innovation structure and function score for the biofuel freight road TSIS	
Innovation System structure quantity	14
Innovation System structure quality	12 – 17
Innovation System Function	13
Total	39 – 44
Innovation System Performance (% of ideal TSIS)	46 – 52

Multiplying the technical CO_2 emission reduction values with the maximum achievable diffusion percentages for 2020 and 2050 results in a CO_2 emission reduction for the freight road transport sector by alternative fuels and drivetrain technologies for 2020 and 2050. This is depicted in table 8.5. A condition to achieve these CO_2 emission reductions is an improving Innovation System Performance over time and take-off in 2014.

Table 8.5. CO_2 emission reduction potential and Cost-effectiveness.					
	Achievable CO_2 emission reduction				**Cost-effectiveness**
	Absolute (Mton)		*Percentage*		*€/tCO_2 avoided*
	2020	*2050*	*2020*	*2050*	
Distribution Transport					
Hybrid Diesel	0,04 – 0,07	0,6 – 1,2	2,9 – 5,0	23 – 49	-18 – 1307
Battery Electric (Wind)	0,12 – 0,14	1,9 – 2,4	8,6 – 10	76 – 95	328 – 730
Battery Electric (Biomass)	0,12 – 0,14	1,9 – 2,4	8,6 – 10	76 – 95	222 – 1083
Battery Electric (Photovoltaic)	0,12 – 0,14	1,9 – 2,4	8,6 – 10	76 – 95	1528 – 2142
Long-haul transport					
FAME	0,26 – 0,47	3,5 – 6,4	2,5 – 4,5	24 – 43	-66 – 531
Fischer-Tropsch	0,89 – 1,0	12,1 – 13,4	8,5 – 9,5	81 – 90	3 – 363

Table 8.5 indicates that the biofuels and (hybrid) electric drivetrains form promising options to reduce CO_2 emission in the freight road sector from a technical perspective. From an economical perspective it is pointed out that the current cost-effectiveness is considerably higher than the estimated prices to avoid CO_2 in 2020 and 2050 by CE (2008a). The lower cost-effectiveness values of FAME, Fischer-Tropsch and hybrid diesel are already in range of the estimated prices for CO_2 in 2020 and 2050. This does not imply that the battery electric drivetrains are unsuitable options, but rather it indicates that (Innovation System and Innovation System Function) improvements have to occur to lower the current cost-effectiveness towards 2020 and 2050.

Maritime Sector

With regard to the maritime sector, a two stroke diesel engine PVO combination for sea vessels and a diesel engine FAME or Fischer-Tropsch combination were identified as most promising options for inland vessels. Table 7.1 indicates the technical reduction for alternative fuels in the maritime sector.

Insight in the performance of the Biofuel Maritime Technology Specific Innovation System was gathered through the Innovation System Structure and the Innovation System Functions. As a result, weak spots in the current Innovation System Performance have been identified and are depicted in figure 8.4.

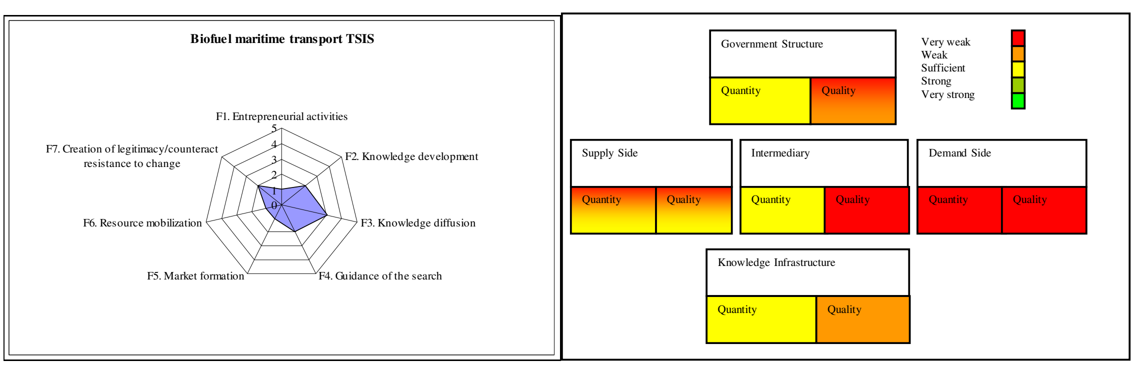


Figure 8.4: Score per function and structure quality and quantity for the biofuel maritime technology specific innovation system.

It is pointed out that components lack in terms of quality, quantity or both. The supply and demand side lack in terms of quantity, while all components of the Innovation System lack in terms of quality. With regard to the Innovation System Functions it is indicated that six out of seven functions score insufficiently of which three functions even score very weak. This total score of the components and functions is summarized in table 8.6. Relating the total score of the biofuel maritime TSIS with the ideal situation indicates a current Innovation System performance of 34 – 40 %.

Table 8.6. Innovation structure and function score for the biofuel maritime TSIS	
Innovation System structure quantity	11 – 13
Innovation System structure quality	6 – 9
Innovation System Function	12
Total	29 – 34
Innovation System Performance (% of ideal TSIS)	34 – 40

Multiplying the technical CO_2 emission reduction values with the maximum achievable diffusion percentages for 2020 and 2050 results in a CO_2 emission reduction for the maritime transport sector with alternative biofuels for 2020 and 2050. This is depicted in table 8.7. A condition to achieve these CO_2 emission reductions is an improving Innovation System Performance over time and take-off in 2014.

Table 8.7. CO_2 emission reduction potential and Cost-effectiveness.					
	Achievable CO_2 emission reduction				**Cost-effectiveness**
	Absolute (Mton)		*Percentage*		*€/tCO_2 avoided*
	2020	2050	2020	2050	
Sea Vessels					
PVO	1,96 – 4,15	31,7 – 67,2	2,6 – 5,5	25 – 52	65 – 366
Inland Vessels					
FAME	0,02 – 0,04	0,38 – 0,67	2,2 – 4,4	24 – 42	55 – 788
Fischer-Tropsch	0,08 – 0,09	1,33 – 1,43	8,9 – 9,6	83 – 89	26 – 406

Table 8.7 indicates that these three biofuels form promising options to reduce CO_2 emission in the maritime sector from a technical perspective. Comparing the current cost-effectiveness with estimated costs for CO_2 in 2020 and 2050 by CE (2008b) points out that the price for CO_2 in 2020 is in the range of the current cost-effectiveness bandwidth of Fischer-Tropsch. The cost-effectiveness of the other two biofuels is only a bit higher than the price for CO_2 in 2020. This implies that (Innovation System and Innovation System Function) improvements have to occur to lower the current cost-effectiveness towards a value in 2020 and 2050 that is in line with the estimated values by CE (2008b).

In all four analyzed TSISs it was pointed out that the government structure currently lacks in terms of quality. This is the result of the fact that the government stimulates all innovations in general. With other words, they act passively and leave the market to decide upon which alternative is best. Whether this is positive or negative depends on believes in free market economy or planned economy. It is expected that neither the government nor the industries solely will decide upon which alternative is most suitable in the sectors but rather that this will be done as a collective act. Contrary to the national government, some local governments do stimulate specific projects such as the Rotterdam Climate Initiative and Amsterdam Electric. This is most likely the result of the smaller budgets which makes it impossible for local governments to stimulate multiple innovative drivetrains or alternative fuels.

Comparing the four analyzed TSIS points out that the Innovation System performance for the aviation and freight road sector are approximately 50% while the maritime biofuel TSIS has a performance of only 34 – 40%. This may possibly be explained by the attitude of actors in these sectors. The maritime sector currently lacks a driver to innovate and to diminish CO_2 emissions. This can be explained by facts that the maritime sector, especially sea vessels, are very fuel efficient, the fuels that they use have low costs and regulations related to emission limitations and fuel standards is lacking.

Overall, alternative drivetrain technologies and fuels may thus contribute in diminishing the CO_2 emission in the aviation sector, the maritime sector and the freight road sector in 2020 and 2050. Biofuels form a possibility for all three sectors and (hybrid) electric drivetrains form a suitable option in the sub-sector distribution trucks. The drivetrain technologies and alternative fuels are very promising from a technical point of view. However, it is also pointed out that most of the drivetrain technologies and alternative fuels come along with a current cost-effectiveness that is higher than the estimated price for CO_2 in 2020 and 2050. This does not imply that these drivertain technologies and alternative fuels are unsuitable options, but rather that significant (Innovation System and Innovation System Function) improvements have to occur to improve the current cost-effectiveness towards 2020 and 2050. Significant CO_2 reductions may be achieved in these sectors. However, drivetrain technologies and alternative fuels alone seem not adequate for preventing disproportionate climate change towards 2050. The main point is that both industry and government should act and invest in diminishing CO_2 emissions by improving the current Innovation System's quality and quantity and Innovation System Functions, otherwise the aviation, freight road and maritime sector will indeed become the forgotten sectors.

9. Recommendations

Since the report indicated that the CO_2 emission reduction for 2020 and 2050 is an outcome of the Innovation System development and the progress along a diffusion S-curve suggests that the CO_2 emission reduction may be improved by strengthening those components that fall short in terms of quality and/or quantity and the Innovation System Functions that are currently served insufficiently. Improving the weak spots in the Innovation System and the Innovation System functions enlarges the chance that potentials of drivetrain technologies and fuels may actually be exploited in 2020 and 2050.

Furthermore a relation is assumed between the Innovation System Performance, expressed by the Innovation System Structure and the Innovation System Functions, and the diffusion S-curve. This provides insights in the functions and structure components that should be addressed, to accelerate the diffusion of a technology. Further research on the relation between Innovation Systems and the progress along a diffusion S-curve is recommended as it might provide useful insights in the diffusion of innovations among sectors in general.

Figure 8.1, 8.2, 8.3 and 8.4 illustrate the weak spots of the current Technology Specific Innovation Systems. Because it is assumed that to start a take-off, all components and functions have to be addressed sufficiently it is possible to point out which components, in terms of quality and quantity, and functions have to be addressed more to let a take-off occur. This results in enlarging the chance that a higher share of the potentials of drivetrain technologies and fuels may actually be exploited in 2020 and 2050.

To make a take-off possible of biofuels in the aviation sector, the quality of the government structure, the supply side and the knowledge infrastructure have to be improved. Considering the quantity the intermediary infrastructure and demand side have to be addressed. With regard to the Innovation System Functions the functions *entrepreneurial activities, knowledge development, knowledge diffusion, guidance of the search, market formation* and *resource mobilization* have to be served more by actors. For now, the most important step that needs to be performed in the biofuel aviation TSIS seems to be the certification of biofuels by (international) governments.

To let a take-off occur of (hybrid) electric drivetrains in the freight road sector, the quality of the government structure and the demand side have to be improved. Considering the quantity the supply and demand sides have to be improved in terms of quantity to become sufficiently addressed. With regard to the Innovation System Functions *entrepreneurial activities, guidance of the search, market formation* and *resource mobilization* have to be served more by actors. Pilots and demonstrations of (hybrid) electric trucks may help to improve the demand side's quantity as the technically feasibility is demonstrated. These pilots and demonstrations could be initiated by the supply side and/or the government.

For a take-off of biofuels to occur in the freight road sector, the quality of the government structure, the supply side and the demand side have to be improved. Considering the quantity only the demand side has to be improved in terms of quantity to become sufficiently addressed. With regard to the Innovation System Functions *entrepreneurial activities, knowledge development, knowledge diffusion, guidance of the search, market formation* and *resource mobilization* have to be served more by actors. Again, pilots and demonstration projects may help to improve the demand side's quantity. Furthermore it may provide insights in the feasibility and CO_2 emission of high blend or pure biofuels for heavy duty vehicles.

A take-off of biofuels in the maritime sector only occurs if the quality of the government structure, the supply side, the demand side, the knowledge infrastructure and intermediary infrastructure are improved. The demand and supply side have to be improved in terms of quantity to become sufficiently addressed. With regard to the Innovation System Functions *entrepreneurial activities, knowledge development, guidance of the search, market formation, resource mobilization* and *creation of legitimacy/ counteract resistance to change* have to be served more by actors. Considering the maritime biofuel TSIS it can be concluded that almost everything, in terms of structure and functions, has to improve. It is important that the demand side changes its behavior and attitude toward the use biofuels. A driver to innovate and to diminish CO_2 emissions in the maritime sector is currently absent as a result of an high fuel efficiency, the low cost fuels that this sector uses and the absence of regulations related to emission limitations and fuel standards is lacking. Besides the necessity of the demand side to change its attitude, governmental bodies could create an incentive to innovate and diminish CO_2 emissions in this sector by implementing regulations and fuel standards.

Improving the Innovation System's structure and functions should be a collective act of both industries and governmental bodies. In the four analyzed Innovation Systems it is pointed out that the national governmental bodies are currently characterized by their passive attitude. The government should not act (too) passively, because it can be a strong actor in the Innovation System aiming at the improvement of functions. Innovation System Functions that may be addressed to by governmental bodies are *knowledge development, knowledge diffusion, guidance of the search, market formation* and *(financial) resource mobilization.* In doing so, the government acts as an example for industries which in return may pick up incentives to also invest in improving the Innovation System structure and Innovation System Functions. How the government should address the functions that are currently served insufficiently forms a study on its own and such a study is recommended. This may provide detailed insights in actions that governmental bodies and policy makers can perform to improve the performance of a Technology Specific Innovation System and enlarge the chance that a higher share of the potentials of drivetrain technologies and fuels may actually be exploited in 2020 and 2050.

Final, it is expected that the cost-effectiveness levels will improve over time as a result of an improving Innovation System and the extent to which Innovation System Functions are served. How the cost-effectiveness levels of the drivetrain technologies and alternative fuels may improve towards 2020 and 2050 as result of the Innovation System Performance could however not be indicated. The improvement of the cost-effectiveness is expected to be a result of, among other factors, technological development, demand and supply, infrastructure availability, economies of scale, oil price development and oil scarcity. The cost-effectiveness development is not elaborated on in this research but certainly forms an interesting point on which research is recommended as it provides insights in the potential of drivetrain technologies and alternative fuels from an economical perspective.

10. Discussion

Several uncertainties and assumptions play a role in this research. In this study the CO_2 emission reduction potential of drivetrain technologies and alternative fuels are investigated. Since there are more greenhouse gases, this study does not provide insights in the total greenhouse gas emission and possible reductions in the three sectors. A delineation toward CO_2 emissions instead of an delineation toward total greenhouse gases, has been made because data were not available with regard to the emission reduction potentials of drivetrain technologies and alternative fuels.

A point of attention is the process of assessing the performance of the Innovation System structure components and Innovation System functions. The scores may be considered somewhat arbitrary as other studies can assign different scores. However, the assignment of scores is based on a thorough literature study and information gathered during interviews with experts/actors of the Innovation System.

Another issue is the choice to use high case projections in terms of CO_2 emissions. The high case projections are used to illustrate the reduction possibilities of drivetrain technologies and alternative fuels in a high case scenario. It is however not to be expected that actual growth of the Netherlands in terms of economics and traffic demand will increase that much. If lower projections were to be used the CO_2 emission reductions would differ. Therefore the CO_2 emission reductions are also provided in percentages. Because of the high projections, the results can be considered maximal CO_2 emission reductions and lower projections provide lower CO_2 emissions and emission reductions in 2020 and 2050.

In the estimation of the CO_2 emission reduction and the avoidance cost for 2020 and 2050 it is assumed that the time-span for the drivetrains and fuels to make a transition from the pre-development phase to the take-off phase is 5 years. This time-span, which influences the diffusion rate in 2020 and 2050 considerably, is arbitrary and may differ per drivetrain and fuel. However, like mentioned in the literature a time-span for this transition is unknown and as a result is set on 5 years in this report for all drivetrains and fuels. However, it may be expected that the time-span with regard to alternative fuels is somewhat shorter compared to drivetrain technologies since alternative fuels do not involve changes to the currently used infrastructure. Furthermore, for the time-span needed from take-off to stabilization the mean value of 41 years, indicated by Grübler et al. (1999) was used. This value was the result of a study which analyzed 265 diffusion processes including processes similar to the diffusion of alternative drivetrain technologies and alternative fuels. The time-span needed for diffusion is an important factor in determining the CO_2 emission reduction. A shorter time-span enlarges the maximum achievable diffusion percentage for 2020 and 2050 while a longer time-span lowers the maximum achievable diffusion percentage. Final, it may be expected that the time-span with regard to alternative fuels is somewhat lower compared to drivetrain technologies since alternative fuels do not involve drastic changes to the currently used infrastructure.

According to UNFCCC, the CO_2 emission from aviation and sea shipping are not attributed to individual countries. Therefore, the Netherlands is not formally accountable for any emission by these sectors (Hoen et al., 2009). It should be noted, however, that the CO_2 emissions from these sectors are far from negligible (Hoen et al., 2009). In the near future, the introduction of an emission trading scheme is expected to regulate the CO_2 emission of these sector. An emission trading scheme may form a driver for these sectors to investigate the possibilities of drivetrain technologies and alternative fuels or other measures to lower the CO_2 emissions.

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Appendix I: Diagnostic questions per function.

The diagnostic questions per function are derived from Hekkert et al. (2007b).

Function 1: Entrepreneurial activities.

- Are sufficient entrepreneurs active?
- What is the quality of the entrepreneurship?
- What type of entrepreneurs is present/ what is the product?
- Which part of the entrepreneurial activities occurs? (dedicated or not)
- To what extent do entrepreneurs experiment?
- What is the variety in the number of the technological options
- Are entrepreneurs entering or leaving the sector?
- Are the entrepreneurs incumbent companies with new activities or new entrants?

Function 2: Knowledge development.

- How can the knowledge base be assessed in terms of quality and quantity?
    - Quantity: Are there many projects, researchers, patents, articles.
    - Quality: Leading international position, many cited patents
- Which actors are active in knowledge development? /Who finances the knowledge development?
- Does the technology receive attention in knowledge projects?
- Is the created knowledge fundamental or of an applied character?
- Is sufficient user knowledge generated? In which way?
- What are the main problems/knowledge gaps?

Function 3: Knowledge diffusion through networks.

- Do actors cooperate with each other?
    - In the domain of research
    - Between knowledge institutes, entrepreneurs and users
- Is the knowledge development demand-oriented?
- Are sufficient opportunities, where the diffusion of knowledge can occur, arranged?
- Can we speak of competition in a way that secrecy becomes necessary?
- Does the developed knowledge satisfies the IS needs?
- Are licenses permitted to certain actors?

Function 4: Guidance of the search

- Is a certain vision of the transition path shared by actors?
- Did the government set any targets?
- Is this a generic or specific target for the transition path?
- Are targets supported by projects/policy?
- Is the trajectory supported by champions?
- How is the technological change affected by the technological expectations?
- Is the shared vision compatible with the incumbent policies?
- Are there any negative expectations with respect to the technology? By whom?

Function 5: Market formation.

- How does the current market look like?
    - Who are the users? (current and potential consumers)
    - Size of the market? (niche - large)
    - Who is the prime consumer/user? (Public or private parties)
- Are institutional stimuli/barriers present for the formation of a market?
    - How do these affect the transition path?
- Does the technology create new markets or will they become vested in incumbent markets?

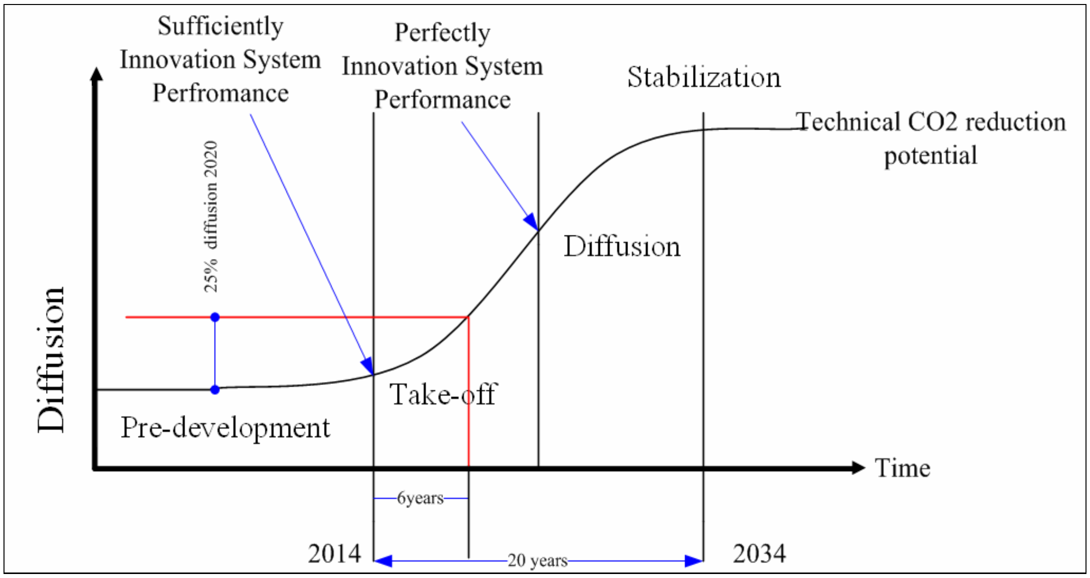
Function 6: Resources mobilization.

- Are the financial resources sufficient enough?
- Are the human resources sufficient enough? (Both quality as quantity)
- Are the resources pre-dominantly used for reaearch or manufacturing?
- Are governmental resources sufficient enough?
    - Which do exist?
    - What is there purpose?

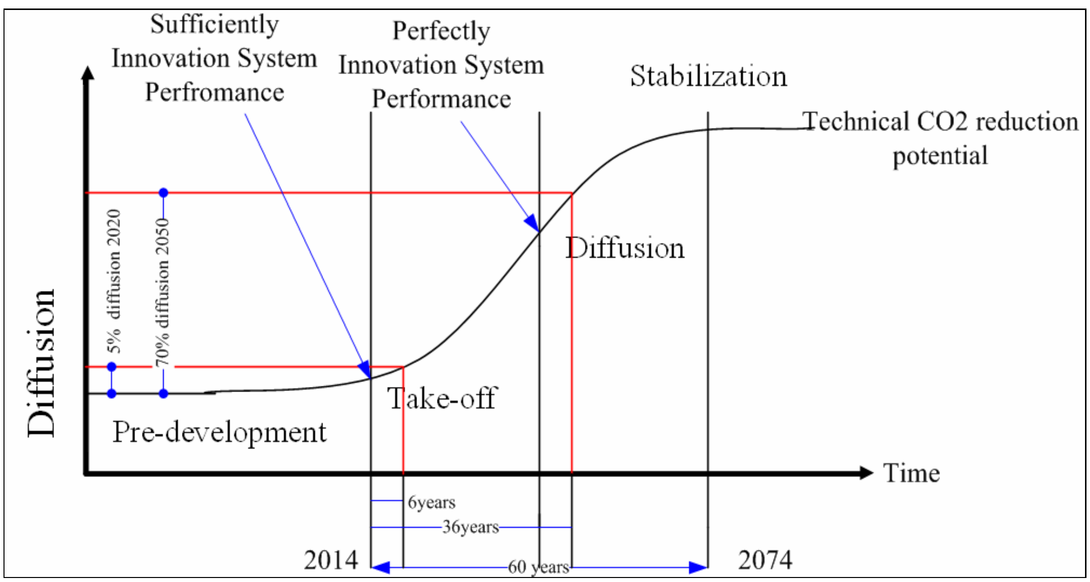
Function 7: Creation of legitimacy/counteract resistance to change

- Are investments in this technology seen as a legitimate investments decision?
- Who is resisting to this technological change and in what way is this expressed?
- To what extent is the lobby power of actors capable of overruling this resistance to change?
- Does the formation of coalitions occur?

Appendix II: Diffusion time-span sensitivity



Diffusion percentage for 2020 with a time span of 20 years for the period between take-off and stabilization. Since the stabilization phase is reached in 2034 it is assumed that the diffusion in 2050 is 100%.



Diffusion percentage for 2020 and 2050 with a time span of 60 years for the period between take-off and stabilization.