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Innovation; Transition management; Sustainable Mobility; Barriers

**ABSTRACT**

The transition toward a sustainable transportation system in the Netherlands takes place in the context of the Dutch “Transition management policy framework”. We study four technological routes that the “Platform Sustainable Mobility” has selected for this goal: (1) hybridization of vehicles, (2) liquid biofuels, (3) natural gas as a transportation fuel and (4) hydrogen as a transportation fuel. These technological routes all envision large-scale changes in vehicle propulsion technology and fuel infrastructure. Furthermore, they compete for the scarce resources available to invest in new (fuel) infrastructures, which implicates that these ‘transition paths’ are also interdependent at the level of the mobility system. The main outcome of the analysis is the identification of barriers that are currently blocking the transition toward sustainable mobility. Barriers are classified as being related to (1) technology and vehicle development, (2) the availability of (fuel) infrastructures, and (3) elements of the institutional infrastructure. The transition management framework currently misses guidelines for coping with (competing) technologies that each requires large infrastructural investments. We further argue that avoiding undesired lock-ins and creating a beneficial institutional context for sustainable mobility cannot be pursued at the transition path level. Therefore, we recommend that a more systemic approach should be taken to the transition to sustainable mobility, in which the interdependencies between the transition paths are critically assessed and in which the possibilities to legitimize sustainable mobility as a whole should be used.

## 1. Introduction

Our transportation system suffers from a number of serious problems, such as (greenhouse gas) emissions, congestion and accidents. Although some of these problems can, and have been, reduced in the past decades, the consensus is that our transportation system is not sustainable [1-4]. Increasing the sustainability of important socio-technical systems – such as transportation, energy and food production – requires large-scale changes and system innovation [5, 6]. In the Netherlands, such changes are pursued in the context of the Dutch "Transition management policy framework". This policy framework was initiated with the Fourth Dutch environmental policy plan [7], and is based on the transition management framework [8-11].

The Dutch energy transition activities are organized in seven sectoral 'Platforms'[1] [12], which are partnerships consisting of diverse actors[2] from government, industry, knowledge institutions and non-governmental organizations. These platforms are steering the activities in several so-called 'transition paths'. That is, each transition path consists of a number of actors that work on, and experiment with, a specific technological or organizational innovation. We focus on the Platform Sustainable Mobility (PSM). The goals of the Platform Sustainable Mobility [13] are to reduce greenhouse gas emissions of new vehicles by 50% in 2015 and greenhouse gas emissions of all vehicles in the Netherlands by 66% in 2035. We study four technological routes that the Platform Sustainable Mobility has selected to reach these goals: (1) hybridization of vehicles, (2) liquid biofuels, (3) natural gas as a transportation fuel and (4) hydrogen as a transportation fuel[3].

These four technological routes all envision large-scale changes in vehicle propulsion technology and fuel infrastructure. The large required investments and irreversibility of infrastructure development make this transition particularly difficult [14]. Furthermore, the four transition paths described above address so-called competing technologies [15]. They compete for the scarce resources available to invest in new (fuel) infrastructures. When the build-up of infrastructure is started for one of the four technologies, this may lead to a lock-out of the other technologies, implicating that the activities in each of the transition paths are also interdependent at the level of the mobility system.

In order to manage the complexity of transition processes [16], transition management [9, 11] prescribes that the activities within transition paths are organized in so-called 'transition rounds', each lasting several years. At the end of each transition round,

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[1] The seven platforms are called: 'Sustainable Mobility', 'Green Feedstock', 'Chain Efficiency', 'New Gas', 'Sustainable Electricity', 'Houses and Buildings' and 'Energy-producing Greenhouse'.

[2] We use the term 'actor' throughout this paper for all people involved in transition management activities in the Netherlands; in most cases these people can also be seen as stakeholders in the transition processes.

[3] At the time of our research, electrical vehicles were not part of the Platform Sustainable Mobility. Currently, electric vehicles are addressed as part of the hybridization transition path.

results are assessed and, if necessary, long-term and short-term targets are adapted. Furthermore, unsuccessful routes toward sustainability may be discarded, while new routes may be identified. This paper addresses the barriers within transition paths that were identified as part of the evaluation of transition paths following such a transition round.

More specifically, this paper addresses the following research question: *What barriers and interdependencies are identified by actors in the transition paths toward sustainable mobility; how can these barriers be understood and classified; and what are the implications for managing the transition toward sustainable mobility in the Netherlands?*

The paper proceeds as follows. Section 2 gives a short theoretical background. Section 3 describes the data collection. In Section 4 we describe the four transition paths including a description of the barriers that were observed. In Section 5 we then classify these barriers and give an overview of the interdependencies between transition paths and their influence on the identified barriers. Section 6 concludes with an analysis and gives an overview of the implications for policymakers and other actors involved in the transition to sustainable mobility.

## 2. Transitions and Innovation Management: Theory and Practice

### *2.1. The Theory of Transition Management and Innovation Systems*

Since the beginning of this century, transition management [8-11] plays a role in Dutch policies aiming at decreasing persistent environmental and societal problems. A transition can be defined [11] as a “gradual, continuous process of change where the structural character of a society (or a complex sub-system of society) transforms”. Transition management is the approach in which long-term (societal) goals are used to steer shorter-term experiments and developments [8]. At the heart of transition management lies the idea that implementing (radically new) environmentally friendly technologies is hampered by a multitude of factors, such as e.g., technological factors, cultural factors, regulatory factors and the fact that in many cases infrastructures need to be adapted or newly established [17]. In this paper we consider infrastructures as the basic physical and institutional structures needed for the operation of the mobility system.

More specific, physical and institutional infrastructures of the current mobility system tend to favor the existing technologies and incremental change of these technologies. Influencing (more radical) technological change toward a sustainable direction does not only involve technical change but also changes in for example fuel infrastructures and institutional infrastructure (regulations, knowledge base, governance structures, etc.) [18-20]. This is particularly true for sustainable innovation where market forces alone cannot be relied upon to realize the desired transitions [21, 22].

Insight in the dynamics of such system innovation processes is necessary in order to influence technological change toward a more sustainable direction. These dynamics can in a large part be explained by looking at the technological (innovation) system, which Carlsson and Stankiewicz [23] 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". A way to understanding the dynamics of transition paths is thus through understanding the dynamics of the technological innovation systems that play a role (or are envisioned to play a role) in these transition paths.

In this research we therefore identify each transition path with an emerging technological innovation system. The different transition paths can be regarded as technological innovation systems that compete with the incumbent technological system (or 'mobility regime') and, to some extent, with each other.[4]

The literature on the dynamics of such technological innovation systems gives us important insights how these systems should function [24, 25]. This allows us to systematically evaluate system functioning for each of the transition paths and identify current barriers to the further development of these systems. Such barriers can relate to any of the components of the technological innovation system and are expressed as barriers in the generation, diffusion and utilization of the technology (technological/infrastructural barriers) or barriers related to the institutional infrastructure (institutional barriers) that provides the boundary conditions for system performance. For this study we make a distinction between: (1) barriers related to technology components and vehicles, (2) barriers related to physical infrastructures and (3) barriers related to institutional infrastructures. We treat barriers due to physical infrastructures separately from the other technological aspects because we aim to learn about the implications of infrastructural barriers for transition management practice.

Earlier research indicates that when different technological innovation systems exist as alternatives for the incumbent system, processes of legitimation may provide interactions between those systems. When successful, these processes can lead to improved system performance through processes of cumulative causation [26, 27]. Bergek et al. [28] also show that processes of legitimation and positive externalities of partially overlapping technological innovation systems can mutually reinforce each

[4] In order to stay close to the practices of transition management in the Netherlands we use the term 'transition path' throughout this paper. However, conceptually we regard the transition paths to be 'technological innovation systems'.

technological innovation system. So, besides the competition for resources between emerging technological innovation systems as mentioned in the introduction, there is also a possibility of mutual reinforcement. Both possibilities for interaction between technological innovation systems stress the interdependency between emerging innovation systems that share (part of) an institutional infrastructure (such as the four transition paths toward sustainable mobility). In order to address the barriers observed in technological innovation systems it is thus necessary to also take into account the interactions between the different systems.

### *2.2. The Practice of Transition Management*

An important task for transition management is thus to address the barriers within the transition paths. Transition management activities start with making collective visions of a sustainable far-away future, like e.g. for sustainable mobility [4, 29]. The long-term societal goals in these visions should become clear enough to select short-term activities: transition experiments with specific innovations. The transition experiments are aimed at learning, cost reduction and the gradual build-up of a technology-specific innovation system. Technologies can be in specific phases of development. Transition management identifies a pre-development, take-off, acceleration and stabilization phase. Barriers may be different in each phase, therefore it is important to identify the specific development phase in order to understand the barriers that are encountered.

The means that the actors in the Dutch transition paths have at their disposal for overcoming these barriers are mainly communication, lobbying and the execution of experiments. Small-scale experiments can be supported financially with subsidies from the transition policy framework. Furthermore, communication activities, like e.g. conferences, help to diffuse knowledge and align expectations. Lobbying is an important activity for the transition path actors to raise the expectations of the technology, to stimulate entrepreneurs and local governments to take actions, and to generate funds and stimulate a supportive institutional environment for the transition path. Large budgets to initiate (niche) markets and infrastructural development are lacking. However, strong signals from transition path actors and from the platforms may induce the national government to change specific institutional settings and support developments financially.

## 3. Data Collection

The data, on which this analysis is based, were originally collected for an evaluation/assessment of 35 transition paths which are part of the seven transition management platforms in the Netherlands. In this paper we use the data on four transition paths that belong to the Platform Sustainable Mobility. The current status and barriers for each transition path were identified in interview sessions that took three to four hours. In each interview session at least four relevant actors were present from government, industry and knowledge institutes. Occasionally we augmented the information from the interview sessions with data from documents of the Platform Sustainable Mobility.

The interview sessions were structured on the basis of an interview strategy that consists of six steps. These steps are designed to reveal the functioning of the transition paths, based on our previous research on systems of innovation [24, 25] and related to the approach by Bergek et al. [30]. The six steps in the interview sessions are: (1) identify the technologies and markets that belong to the transition path – make system boundaries explicit; (2) describe and give argumentation for the development phase(s) of the technologies considered, based on the phases identified in transition management; (3) describe and evaluate the presence of innovation system components: supply, demand, intermediary organizations, governmental actors and knowledge institutes; (4) evaluate and give argumentation for the presence (or absence) of seven innovation system functions [24, 25]; (5) describe cumulative causal patterns of technology development [27]; (6) identify possible intervention strategies that may solve (some of) the problems identified in steps (1-5).

The interview strategy made it possible to get uniform data for each transition path. After the interview sessions, the interview reports were sent to four to six other actors/experts who had not been present at the interview session. These actors could not change the original report, but they were asked to add their views wherever they disagreed with the data from the interview session. Diverging views between actors thus remained visible.

One output of the expert interviews is thus an overview of the barriers observed in the technological innovation system associated with each transition path. In this paper we classify these barriers according to the theoretical framework described in Section 2 as (1) barriers related to technology components and vehicles, (2) barriers related to physical infrastructures and (3) barriers related to institutional infrastructures.

Furthermore we observe the interdependencies between the different transition paths under investigation, as these interdependencies can have an important influence on the transition paths, as explained before.

## 4. Transition Paths toward Sustainable Mobility

### *4.1. Introduction*

In this section we describe the four transition paths toward sustainable mobility, based on the expert interviews and relevant documents. We start by presenting the technology characteristics and relevant activities in a narrative manner. At the end of each section, we summarize the barriers that we discerned.

### *4.2. Biofuels*

The transition path 'Biofuels' relates to the use of biogenic liquid fuels to replace the current fuels derived from fossil origin. Different types of biofuels are discerned: currently available biofuels, which include 'pure vegetable oil' and other first generation (1G) biofuels, and advanced or second generation (2G) biofuels.

Actors in the transition path indicate that first generation biofuels are in a late take-off or early acceleration phase. The use of pure vegetable oil for fuel purposes is not widespread in The Netherlands. Second generation biofuels are currently not available on the market; these are considered to be in the pre-development phase.

First generation biofuels are food crop based and are stimulated by the EU directive on biofuels [31] and Dutch legislation [32]. Oil companies in the Netherlands have the obligation to sell biofuels in an increasing share of their fossil fuel sales; from 2% (on an energy basis) in 2007 to 5.75% in 2010[5]. This national legislation has led to investments in biofuel plants and biofuel import facilities near Rotterdam harbor. Currently, oil firms meet their biofuel obligation by importing biofuels, for instance from Brazil and Ukraine. The obligation does not stimulate the blending of higher percentages of biofuels (than strictly needed) or the further development of advanced biofuels. Thus, the position of the incumbents (large oil companies) seems to be strengthened, leaving little room for innovative entrepreneurs. High feedstock prices and difficulties to find locations and get permits for biofuel plants prevent large-scale (advanced) biofuel investments in the Netherlands.

Higher percentages of blended biodiesel (>5%) are not compatible with the guarantee restrictions of most car manufacturers [33]. High ethanol blends in gasoline (15-85%) also require specially adapted ('bi-fuel' or 'flexi-fuel') vehicles. Such vehicles are available in other countries from a limited number of car manufacturers. According to the transition path actors, a separate fueling infrastructure for higher percentage blends might stimulate the transition; only a limited number of such filling stations are available in the Netherlands [33]. The use of pure vegetable oil for fuel purposes is limited to a few projects (supported by a lower fuel excise) and a few small pure vegetable oil producing mills.

Competition between food and fuel feedstock is recognized by the transition path actors to be a potential (sustainability) problem for first generation biofuels. The

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[5] Recently, the Dutch government reduced the obligatory biofuel share to 4% in 2010.

development of sustainability criteria for biofuels may possibly reduce adverse interactions between the food and biofuel markets.

Second generation biofuels are currently not available on the market, and they are expected to be more expensive than currently available biofuels when they will arrive on the market [34]. Second generation biofuels are mainly cellulose-derived ethanol and Fischer-Tropsch diesel from biological origin. Second generation biofuels are expected to show lower well-to-wheel greenhouse gas emissions, and to require less arable land for growing feedstock, relative to first generation biofuels. The development of the Second generation biofuels may thus decrease the direct market interactions between food and fuel. However, indirect interactions through cropland use is not excluded when the market share of second generation biofuels would increase (which is expected to be no sooner than 2010-2015; [35]).

In summary, the main technological and vehicle barriers in this transition path relate to the (knowledge) development of second generation biofuels' production processes and the low number of flexi-fuel vehicles. Barriers related to physical infrastructures are the low number of fuel stations with high biofuel blends, the small size of the (international) fuel distribution system (in the Netherlands) and the non-existence of second generation biofuels production. Institutional barriers identified are the uncertainties regarding future (feedstock) prices and the sustainability performance of biofuels. Furthermore, difficulties to build biofuel production plants and the large role of incumbents in the current biofuels market pose institutional barriers.

### *4.3. Hybridization of Vehicles*

The 'Hybridization' transition path relates to vehicles that combine an internal combustion engine with an electric engine. Hybrid vehicles are more energy efficient than vehicles with an internal combustion engine and thus contribute to lowering $CO_2$ emissions and reaching local air quality targets.

The phase of development of the hybridization path was assessed as the beginning of the acceleration phase. However, supply and demand of hybrid vehicles are currently low when related to the total car market. At this moment, only a limited number of personal car models are commercially available from Toyota, Lexus and Honda; several additional models are expected to enter the (Dutch) market in 2009.

Several developments are envisioned for hybrid cars. First, further diffusion of hybrid vehicles is expected as more vehicles become commercially available. One outcome of the expert interviews was that the current tax schemes that stimulate the purchase of hybrid vehicles should be kept in place in order to facilitate this development. Second, the transition path actors envision the development of more advanced hybrid vehicles with longer all-electric ranges. An advantage of such vehicles is their potential contribution to local air quality improvement in urban environments. A third development that is envisioned for hybrid vehicles in the Netherlands is the use of (advanced) biofuels (see previous Section) as a replacement for fossil fuels in hybrid vehicles. Because of the efficient fuel use in hybrids, the (initially) higher costs of advanced biofuels would hinder adoption of biofuels to a lesser extent in hybrids than in regular cars, which would position hybrids as a potential niche market for these advanced biofuels[6].

Finally, the actors in the transition path regard the development of ‘plug-in’ hybrid vehicles as an important step. Plug-in hybrid vehicles can charge their batteries like normal hybrid cars (by using the internal combustion engine), but can also be charged by plugging into an electricity socket. The latter charging method would increase the use of electricity and decrease the (direct) use of fossil fuels in hybrid vehicles. Currently, plug-in kits are available for retrofitting hybrid vehicles, but commercial plug-in hybrid vehicles are not yet available from car manufacturers, which hinders the adoption of plug-in technology. Also battery technology should be improved for this purpose.

Increasing the use of plug-in hybrids will require an electricity refueling infrastructure with recharging points near car parking places. Expectations exist that a large amount of plug-in hybrids can help to balance the electricity load curve. For this purpose hybrids should recharge during periods of low electricity demand and should be able to feed electricity back into the grid during peak demand. Studies are performed to see if this can be done technically, and how it might work out. The well-to-wheel emission benefits and lifecycle environmental benefits of extending the electric range of hybrid vehicles are uncertain and disputed by some actors.

Because there is no car manufacturing industry in the Netherlands, several projects within this transition path focus on the adoption of commercial hybrid vehicles by fleet owners.

For the farther future, the actors see hybridization as a stepping stone technology toward all-electric vehicles (without the internal combustion engine) for urban use and toward the fuel cell electric vehicle (FCV), because the development of hybrid vehicles leads to the development of electronic parts that can also be used in fuel cell electric vehicles.

Summarizing, the technological and vehicle barriers that we identified relate to the small number of hybrid models on the market, battery performance and the absence of plug-in technology on the market. Physical infrastructural barriers in the

[6] For hybrid vehicles to use second generation (cellulose-derived) ethanol, the internal combustion engines should be adapted; second generation biodiesel can be used in diesel-hybrid vehicles without special adaptations.

Hybridization transition path relate to and the absence of a recharging infrastructure for plug-ins and the absence of knowledge regarding the influence of plug-in hybrids on the electricity grid. Institutional barriers identified relate to the fiscal benefits presently needed for marketing hybrid vehicles, the large influence of incumbent car manufacturers and uncertainty about (future) environmental benefits of hybrid vehicles and plug-in hybrid vehicles.

### *4.4. Natural gas and Biogas*

Natural gas can be used to propel cars. The natural gas transition path aims at stimulating the development of a natural gas fueling infrastructure and a natural gas fleet. Driving on natural gas leads to lower emissions of $CO_2$[7] and to lower emissions that affect local air quality, when compared to gasoline or diesel. According to the transition path actors, natural gas for mobility is currently in the take-off phase.

Natural gas is also positioned as a possible ‘stepping stone’ toward other technologies. Natural gas produced from biomass (biogas or methane) is one development route envisioned within this transition path. Natural gas as a stepping stone technology toward a hydrogen economy is another possibility [36, 37].

Biogas can be produced from digestion of biomass. However, the potential of this route is limited in the Netherlands [37]. Production of biogas after gasification of biomass has a larger potential (in terms of available biomass resources), but this route has a higher technological complexity and is not fully developed yet. Biogas can be cleaned to meet natural gas specifications and can then be mixed with natural gas in any ratio.

Currently, two routes are available for transporting and storing natural gas: compressed natural gas (CNG) at 200 bar pressure, or liquefied natural gas (LNG). Approximately ten CNG filling stations are currently present in the Netherlands. Also, rather expensive home-fill compressors can be bought for overnight gas fueling at home. A limited number of bi-fuel cars for gasoline and CNG (with two tanks) are available from several car manufacturers, but at higher prices than the gasoline models [33]. Fiscal policies, among which a relatively low excise rate are currently favorable for driving on natural gas, but the actors in the transition path are uncertain if such favorable conditions will remain in the future.

The driving range of cars that run on natural gas only is low when compared to gasoline cars. With regard to the refueling infrastructure that is being built up, the

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[7] Although natural gas has a lower carbon content per unit of energy than oil-derived fuels, the well-to-wheel reduction of $CO_2$ by driving on natural gas is contested.

choice seems to have been made for CNG because of the market availability of CNG cars. The build-up of a natural gas vehicle fleet and infrastructure is mainly pursued by the transition path actors through stimulating large fleet owners. However, the higher costs (of vehicles) and uncertain (policy) future of natural gas in transportation – which also affects the residual value of cars that run on natural gas – are seen as important barriers.

In summary, technological and vehicle barriers are numerous. These relate to the choice to be made between CNG and LNG, the short driving range, the small number of available natural gas/flexi-fuel cars and the fact that technology development is mainly based abroad. Infrastructural barriers relate to the low number of fuel stations and the very limited capacity for biogas production. Institutional barriers relate to uncertainties about favorable taxing policies and environmental performance, and the absence of a second-hand market for cars that run on natural gas.

### *4.5. Hydrogen for Transport*

Hydrogen is considered an important fuel option in a sustainable energy and mobility system. Hydrogen can be produced from many different energy sources, which increases the diversity and flexibility of the energy system. When used in fuel cell systems, mobile and stationary application of hydrogen is possible. An energy system based on hydrogen is expected to be more energy efficient than the current system – thus leading to a decrease in $CO_2$ emissions. Furthermore, the emission of nitrogen oxides and fine particles can be reduced to zero-emission levels.

The transition path actors position hydrogen in the pre-development phase and see that many technological barriers still need to be overcome. These barriers relate to the fuel cell itself (cost reduction, lifetime increase) and to hydrogen storage solutions (cost reduction, energy density of storage). With regard to hydrogen storage and distribution, more knowledge is also demanded regarding safety issues and user acceptance.

Furthermore, integration of fuel cells, hydrogen storage and auxiliary system components into a volume and weight that would fit easily into cars is still seen as a barrier for mass production. Activities are shifting toward the construction of prototypes and demonstration projects, but commercial applications in transportation are non-existent. Most projects depend on subsidies and are technology-driven. Without subsidies it is difficult to involve market parties in this early innovation phase. Mass production of fuel cell vehicles is expected around 2015-2020 [13]. The necessity to build up a network of hydrogen fuel stations and a hydrogen distribution system is identified as a barrier in this transition path.

Although hydrogen is often depicted as the 'end-state fuel' for a sustainable mobility system, according to the actors in the transition path, policy articulation of hydrogen goals has been weak for over a decade.

Summarizing, there are large technological/vehicle barriers in the Hydrogen transition path. These relate to fuel cell development as well as hydrogen storage technology and result in the fact that hydrogen cars are not commercially available. A refueling infrastructure is lacking, which is seen as a barrier related to the physical infrastructure. Institutional barriers found relate to the fact that it is difficult to involve market parties in the transition path activities and to uncertainties about the acceptance of hydrogen and safety issues.

## 5. Barriers and Interdependencies

### *5.1. Barriers Identified in the Transition Paths*

In the previous section a description of the individual transition paths was given, based on the expert interviews, augmented with information in documents from the Platform Sustainable Mobility. In this section we give a categorized overview of the main barriers and extend our analysis to the system level by identifying the interactions between the transition paths that were articulated in the expert interviews. Table 1 gives an overview of the barriers that we identified in the four transition paths.

INSERT TABLE 1 AROUND HERE

A few observations can be made on the basis of Table 1. First, we see that technology development is in an early stage for hydrogen, relative to the three other transition paths. Commercial vehicles are not yet available and technological barriers relate mainly to fuel cell and hydrogen storage components. This is in line with the classification that hydrogen still is in the pre-development phase. In the *biofuels* and *hybridization* transition paths we see that the identified technological barriers are mainly related to 'next generation' technologies like advanced biofuels and plug-in technology – which are also in the pre-development phase. The lack of commercially available vehicles for the transition paths (and the higher costs of these vehicles) is an important barrier in all four transition paths. Because there are no car manufacturers in the Netherlands, it is difficult for the actors in the transition paths to join forces with car manufacturers. This creates a dependency of the Dutch transition paths on technological and vehicle developments abroad.

With regard to physical infrastructural barriers it is clear that each transition path requires its own type of fuel infrastructure (with the exception of blending low percentages of liquid biofuels in current fossil fuels; and with the exception of hybrid vehicles, which can use current fuels). The fuel infrastructural barrier can be explained from the fact that developing fuel infrastructures – even in smaller experiments – requires large investments. As we described before, the transition paths do not have the financial means for such investments.

The institutional barriers involved in the four transition paths are mainly related to financial uncertainty and uncertainty about the well-to-wheel environmental performance of the technologies in question. These uncertainties are so large that entrepreneurs hesitate to take first steps. For instance, fleet owners which may have the means to build up a vehicle fleet adapted to a specific fuel, and oil companies which may have the means to create a new fuel infrastructure, are hesitant because of these institutional barriers. This finding confirms previous research which states that entrepreneurs need (at least some) stability to make cost/benefit calculations of strategic investments [18]. The transition path actors indicate that the national government plays an important role in decreasing these institutional barriers.

The last observation also shows the interrelatedness of the three types of barriers distinguished. Institutional barriers hamper possible actions of entrepreneurs to decrease other barriers related to technology and vehicles, and related to fuel infrastructures.

### *5.2. Interdependencies and System Level Interaction*

The expert interviews and the documents from the Platform Sustainable Mobility also provide insights regarding possible interdependencies between the four described transition paths. An overview of these interdependencies is depicted in Figure 1.

INSERT FIGURE 1 AROUND HERE

In the current view of the Platform Sustainable Mobility, we see that after 2030 there is only room for second generation biofuels and for fuel cell vehicles. The other transition paths are expected to support this envisioned development, but do not fit in the ultimate view of a sustainable transportation sector with low greenhouse gas emissions. This implies that first generation biofuels mainly have a function in starting up a biofuel niche which leads to learning and the building of institutions for second generation biofuels (see arrow 1 in Fig. 1). First generation biofuels are thus seen as a stepping stone technology toward second generation biofuels.

Hybrid vehicles also have a function in the transition toward sustainable mobility, but are not considered a desirable end-state option. The arrows in Figure 1 (indicated with nr. 2) express the idea that hybrid vehicles may support the development of second generation biofuels because 1) hybrid vehicles are more fuel-efficient and their drivers could therefore be willing to pay the premium prices of 2G biofuels, and 2) second generation biofuels could further increase the emission reduction already achieved by hybrid technology. In a similar way, the possible mutual benefits of hybrid vehicles and natural gas/biogas are articulated.

Arrow 3 in Figure 1 indicates the idea that the development of hybrid cars leads to technological learning which will (also) support the development of fuel cell vehicles, because of similarity in (electric) components.

The natural gas/biogas transition path is also expected to support the future use of hydrogen. Arrow 4 in Figure 1 indicates that natural gas/biogas is seen as a stepping stone technology toward hydrogen. Experimenting with natural gas should lead to learning to use gaseous fuels (technologically and with respect to user acceptance). Furthermore, when natural gas and especially biogas have been developed as energy sources for mobility, they can become the feedstock for hydrogen production.

Hybrid vehicles and vehicles running on natural gas/biogas (which do have environmental advantages over the currently used fossil fuels), are thus considered *stepping stone* technologies toward a hydrogen-based transportation system. This creates interdependencies between these paths. Progress on the hybridization and natural gas/biogas transition paths is considered to stimulate the hydrogen transition path, which at this moment creates legitimacy for the further development of the hybridization and natural gas/biogas paths. This legitimacy is important for these two transition paths, because hybridization and natural gas as standalone technologies do not fit within the stringent long-term greenhouse gas emission goals of the Platform Sustainable Mobility (see Section 1). Similarly, the articulated interdependence between first and second generation biofuels (Arrow 1 in Fig. 1) provides legitimacy to further develop first generation biofuels.

From the point of view of the individual transition path actors these interdependencies are considered stimulating forces, because they legitimize the actions in these paths. However, at the system level they may induce risks as well. These risks relate to possible lock-ins in the first generation biofuel, hybridization and natural gas/biogas transition paths, which are not considered desirable end-states by the Platform Sustainable Mobility [13].

## 6. Analysis and Implications for Transition Management

The transition to sustainable mobility is currently advanced by stimulating activities in specific transition paths, which are partnerships between government actors and market parties. We described the main barriers that are identified by the actors of the transition paths, and the interdependencies which they articulated.

Regarding the technology and vehicle-related barriers we observed that the transition paths are to a large extent dependent on international developments in technology and on the choices of (foreign) car manufacturers. This implies that selection processes are (partly) out of reach of the transition path actors. The transition management framework offers no clear advices on how to deal with such dependencies on developments abroad. Further research on this subject is advised.

The transition management idea to execute small-scale experiments which can be developed into mass markets, seems to be rather difficult for transition paths in which the build-up of new physical infrastructures plays an important role. One reason is the need for large and typically irreversible investments, even for small-scale experiments. This seems to hinder the involvement of small entrepreneurs and newcomers. Indeed, the role of incumbents in the mobility transition paths turns out to be quite large. Another difficulty relates to the selection of promising transition paths. As soon as transition paths have developed beyond the take-off phase, investments in the (fuel) infrastructure may have accumulated to the extent that (strong) vested interests and irreversibilities appear. At such a point the selection of that transition path may *de facto* already have been made. The question for the transition management framework is therefore how to experiment with such technologies without risking an early lock-in. The transition management framework currently misses guidelines for coping with (competing) technologies that each require large infrastructural investments.

Following Bergek et al. [28] we can distinguish two views on the transition paths of the Platform Sustainable Mobility. The first view is that these transition paths have a competitive relationship; they compete for resources and markets in order to become *the* sustainable mobility technology of the future. The second view (see [28, 38, 39]) implies that different transition paths may mutually reinforce one another if they destabilize the current (mobility) regime or if they share structural elements like actors, networks, technologies or institutions.

It has become clear that the first view – competition between the transition paths – certainly applies to the transition paths which require expensive new (fuel) infrastructures. This is something that should get ample attention at the system level. The second view – in which the transition paths reinforce one another – may be worthwhile to strive after. The stepping stone theories which are articulated by the transition path actors can be regarded as an attempt to strengthen and legitimize each transition path by linking it to the other transition paths. However, linkages are currently only poorly established because only few structural elements (actors, networks, technologies or institutions) are actually shared between the transition paths.

Based on this observation we advise the transition management actors to look at possibilities to destabilize the mobility regime by combining the merits of various transition paths; thus by looking at possibilities to share structural factors: actors, networks, technology or institutions. Some routes may especially be worthwhile, e.g. the possibility to influence the preferences of car drivers (toward lower $CO_2$ emissions), or the possibility to diminish (institutional) constraints that hinder all transition paths.

We conclude that avoiding undesired lock-ins and creating a beneficial institutional context for sustainable mobility as a whole, cannot be done at the transition path level. Therefore, our main recommendation to Dutch transition management actors is that – besides the activities at the transition path level – a systemic approach should be taken, in which the interdependencies between the transition paths are critically taken into account and in which possibilities to legitimize sustainable mobility as a whole are exploited.

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**Table 1** Technological, infrastructural and institutional barriers identified in four sustainable mobility transition paths

| | Barriers | | |
|---|---|---|---|
| **Transition path** | **Technology components and vehicles** | **Physical infrastructure** | **Institutional infrastructure** |
| Biofuels | • Technology development second generation biofuels<br>• Availability of flexi-fuel vehicles | • Fuel stations with higher biofuel blends<br>• Fuel distribution system (also internationally with Rotterdam harbour)<br>• Second generation biofuel production plants | • High / uncertain feedstock prices<br>• Uncertainty sustainability criteria and performance biofuels (incl. competition with food production)<br>• Difficult to get locations and permits for biofuel plants<br>• High impact of incumbents on market development |
| Hybridization | • Availability of (more models) hybrid cars<br>• Battery performance<br>• Development and marketing of plug-in technology | • Recharging infrastructure (plug-in)<br>• Knowledge about balancing electricity load curve with plug-in hybrids | • Favorable taxing scheme needed<br>• High impact of incumbents on market development<br>• Uncertainty well-to-wheel emission and lifecycle environmental bene-fits |
| Natural gas & biogas | • Availability of a wide range of natural gas / flexi-fuel vehicles<br>• Choice CNG or LNG<br>• Vehicle driving range<br>• Technology development mainly abroad | • Low number of fuel stations<br>• Biogas production | • Uncertainty about favorable policies and excise<br>• Uncertainty sustainability performance of natural gas/biogas<br>• Residual value vehicles / second hand market |
| Hydrogen | • Fuel cell development (cost reduction and lifetime extension)<br>• Storage technology (cost reduction and energy density)<br>• System integration with acceptable volume/weigth for automobiles | • Fuel stations and fuel distribution | • Difficult to involve market parties at early stage<br>• Acceptance / safety issues |

**Figure 1** Overview of the anticipated development of the Sustainable Mobility transition paths (Arrows indicate articulated interdependencies between transition paths)