Early markets for hydrogen vehicles
Bridging the gap between R&D and commercialisation

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Abstract
Early markets for hydrogen vehicles are important to bridge the gap between the phase of R&D and mass-market introduction. New technologies do not necessarily need to comply with the high demanding preference of mass-market users from the start, though they can be first deployed in protected markets where their relative advantage can be utilised most efficiently. Within the EU funded HyLights project potential early markets for hydrogen vehicles are assessed. This is done by mapping potential users of early market applications and by defining their minimal performance level. To compare this minimal performance level with the current performance level of hydrogen technologies, conclusions can be drawn about potential early markets. As hydrogen technologies will develop in time the type of early markets could change in time as well: early markets will evolve gradually towards mass-market application.

In order to describe both the requirements of the potential early market users and the performance of the technology analogously, key performance indicators are defined. These indicators describe those aspects of the technology that are of importance for the end user.

Keywords: fuel cell, hydrogen, market, vehicle performance, demonstration

1 Introduction
A limited number of hydrogen busses and cars are driving on the roads these days. Virtually all of them are being tested within a demonstration project. Although some of these vehicles, e.g. the busses that are being deployed in the CUTE project[1], are operating in regular services, a lot of effort is still needed to improve technologies and performances and to decrease the costs. In the end, hydrogen vehicles are expected to become mass-market products, able to compete with conventional vehicles. However, there are still many barriers to overcome before this stage will be reached. In order to streamline and focus the developments it is required to explore the transition pathways from first small-scale demonstration projects to mass-market introduction. To overcome the gap between R&D and commercial applications, the technology could be deployed in so called early markets. An evolution of early markets can (in theory) lead to technological improvements and cost reductions. Due to the learning effects within an early market the technology becomes more competitive and the following and more demanding (early) market can be entered. Finally, if the technology can meet the requirements of mass market users, the commercial market is reached.

To determine transition pathways, or potential series of early markets, one should know the requirements and expectations of the users in the different stages. The management of the interest of potential users and their requirements is essential to establish early markets. The different stages in the series of early markets are very important as scaling up of production will be a gradual process (see figure 1).

This paper will discuss the importance of and the way to define early markets. The aim of this study is to identify potential early markets by identifying those users that are willing and able

[1] The CUTE project (Clean Urban Transport for Europe) and its successor the HyFleet CUTE project are demonstration projects for public transport cities in several, mainly European, cities.

(costs and technology performance) to use the first series of vehicles.

The study was carried out within the HyLights project, a coordination action funded by the European Commission, which aims to accelerate the commercialisation of hydrogen and fuel cells in the field of transport in Europe (see www.HyLights.eu).

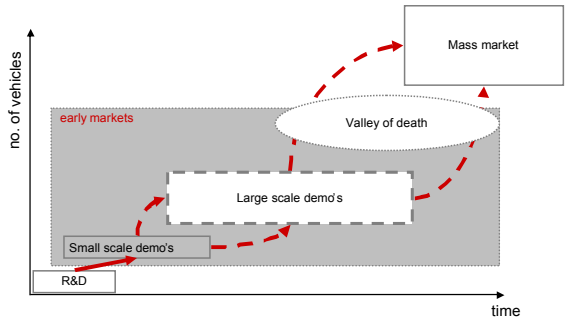

Figure 1: Pathways to come from small-scale demo's towards mass-market introduction?

2 Early markets

Early markets are highly important for introducing new technologies. This holds for almost all new technologies. The first mobile phones, for example, were extremely expensive compared to current price levels, though some users were willing to pay that price as they provide additional functionality and the costs could be balanced against personal profits. This is an example of an early market application. Although many new technologies enter the market via early markets, these early markets and the introduction of these technologies can not be compared completely. In the case of hydrogen technologies for transport applications, the case is much more complicated than, e.g., the case of the introduction of mobile phones. This is not only because hydrogen technologies have to compete with conventional technologies that are highly appreciated by their users, it is also because most users are not willing to pay more for the performance improvements (e.g. fuel efficiency and zero emission) of hydrogen vehicles and because a complete new energy infrastructure has to be set up (e.g. fuel production, fuel distribution and vehicle production).

For the industry, early markets could be important to deploy their first vehicles in a protected environment. While gaining experience in these protected markets, they can prepare for the next and larger markets. Besides, in the beginning the first early market users could be satisfied with relatively limited performance levels of the vehicles compared to conventional technologies.

2.1 Evolution of early markets

Early markets[2] should not be confused with niche markets. Niche markets for transportation applications are defined as oriented at specialized vehicles like scooters, forklift trucks and street-cleaning vehicles[3]. These markets are very important as well for the development and testing of technologies and to bridge barriers in legislation and infrastructure. However, due to the type of application, they hardly have the potential to become mass-market applications. Early markets on the other hand are defined as those markets that prepare for large scale deployment of the technology in a commercial mass-market (see figure 2).

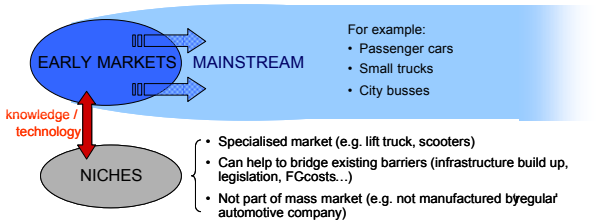

Figure 2: Early markets versus niche markets.

In general one can say that early markets exist in the period between the R&D phase and the mass-market phase. Just before the technology will have its breakthrough in the mass-market, commercial use could be feasible in market segments were the costs are outbalanced by the benefits. Before the vehicles will be used in a commercial market, their deployment will take place in demonstration projects. Within demonstration projects one can not expect that hydrogen vehicles will be deployed in a competitive way, though early markets should be established in those situations were benefits could be maximised (close to competitive).
The transition from demonstration projects towards the first commercial use is a critical moment. In this period governmental support has to decrease gradually and the technology has to prove its competitiveness. In the past this period has turned out unsuccessful for many technologies and that is why this period is called the valley of death (see figure 1). While governmental support for R&D will decrease in time, manufacturers should be able to gradually decrease the losses on the vehicles during R&D and the first deployment and should start to make a profit (see figure 3).

[2] The focus of this paper is on early markets for hydrogen and hydrogen technologies within the transportation sector. Portable applications (e.g.) could be seen as early markets of the technology as well, though they are not subject of this paper.
[3] Within social sciences, both early markets and niche markets are called niche markets. Niche market management is a common concept, where actually early market management should be read.

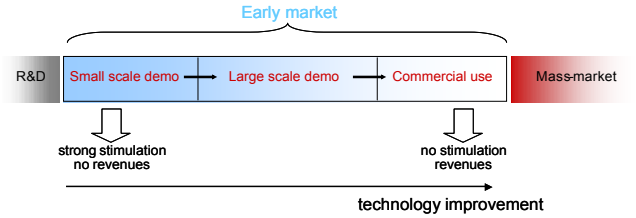

Figure 3: Different phase between R&D and mass-market.

The first early markets are those markets where barriers due to limitations (i.e. costs, performance) of the new technology can be overcome most easily since the requirements for the vehicle of early users differ from the mainstream end-user demands in a mass market. Even though the performance requirements (technical and financial) for these early markets are more flexible than for mass-market applications, still substantial financial support might be required. Since the hydrogen based technology will develop in time (infrastructure might become more widespread and in general cost may come down) the need for stimulation will decrease. While technology develops, more, larger and more demanding early markets will become interesting. In the end technologies will be used within the mainstream market. Early markets should be seen as an evolving process rather than describing a status quo. Figure 4 shows how early markets may evolve in time.

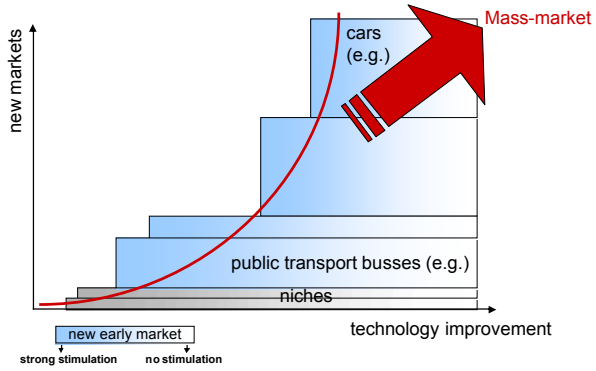

Figure 4: Evolution of early markets.

3 Market requirements

3.1 Identification of early markets

To identify potential early markets one should look for those situations where market (user) requirements and technology performance meet. Within the HyLights project a gaps analysis is performed to identify potential markets by assessing the needs and requirements of potential users and by assessing the current performance level of hydrogen technologies (see figure 5).

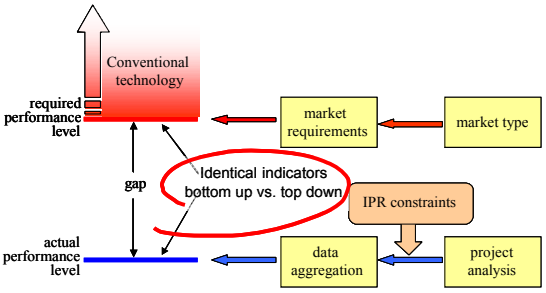

Figure 5: Overview of the gaps analysis.

3.2 Current state of technology

The current state of hydrogen technologies for application in the transportation sector is not on the same performance level as conventional internal combustion engine technologies. For example fuel cell vehicles are still more expensive, driving ranges are limited, (sufficient) hydrogen storage is difficult and besides infrastructure, refuelling facilities and large scale production plants are lacking. On the other hand hydrogen vehicles do have a number of advantages compared to conventional engines: mainly the environmental performances (no polluting emissions (locally) for fuel cells, low noise emissions and - if hydrogen from renewable sources is used - low impact on climate change) and the increase of security of supply (diversification of energy sources and the possibility to use renewable energy sources).
First applications in early markets of hydrogen technologies should be able to cope with the (vehicle/driving) limitations of the current state of technology and should be able to outweigh these down sides by the benefits as much as possible. Besides, these early markets could obtain an advantage by making use of existing hydrogen production and infrastructure like at refineries, chlorine production plants and dedicated chemical plants. Furthermore the vehicles should have an operation distance in line with the current performance level and preferably a central refuelling point. Since the costs of the first vehicles will be relatively high, users should be able and willing to cover them (support of motivated local or national government will be helpful in this).

To define the current performance level of hydrogen technologies a list of key performance indicators is drawn up. These indicators are based on the Monitoring and Assessment Framework [1]; a framework for identifying the performance of demonstration projects that has been developed within the HyLights project. The key performance indicators (KPI's) describe those aspects of the technology that are of main importance for the end-user. And so they do not focus on pure technical issues like stack performance, but only on issues that are relevant and measurable for the end-user (like driving range). Key performance indicators have been defined respectively for passenger cars, vans,

busses and infrastructure. The KPI's for passenger vehicles are formulated in the text box below as an example.

Key performance indicators for passenger vehicles

- maximum speed – km/h
- driving range – km/tank
- vehicles costs – euro
- efficiency – km / kg H_2
- number of passengers – #
- load – m^3 and kg
- annual maintenance costs – euro/year
- refuelling rate – kg H_2 / min
- acceleration (0-100km/h) – seconds
- availability – %

Text box 1: An example of the key performance indicators for a passenger vehicle.

The KPI's for passenger vehicles and vans are equal, while the KPI's for busses have been modified in acceleration (0-50km/h) to account for the special characteristics of this vehicles class. Infrastructure KPI's include annual maintenance costs, refuelling rate, fuel cost, availability and consecutive refuelling.

In order to identify the minimal performance level that is set by the end-users the key performance indicators are discussed with potential users of early market applications (see next section). The potential users are also asked to define the performance level they would set for new conventional vehicles.

The minimal required performance level will be compared with the current performance level of hydrogen technologies. This will be done by assessing past and ongoing demonstration projects and by identifying the key performances of the technologies that are used in these projects. By describing the current performance level and the minimal required performance level with the same indicators (the key performance indicators) the gap can be defined. In those situations that the required performance level and the current performance level are equal, early markets could be established.

3.3 Potential users of hydrogen early market applications

Not only technology performance (or market supply) is important in relation to early markets, also market demand is necessary. What do (future) users set as minimal performance level and what are they able and willing to pay for that? In order to define which actors might be interested to use hydrogen technologies as early market application the relevant actors in the transport field are mapped.

Within the field of hydrogen technologies numerous actors are interacting with each other. On the one hand manufacturers of hydrogen technology systems (car and fuel cell stack manufacturers) and producers of hydrogen are developing new technologies and products with the (final) aim to develop a mass-market product. On the other hand governments try to stimulate the development of technologies that can help to attain their policy goals. Potential users weigh carefully the pro's and cons of a certain product before they will buy or use one. As all actors are operating more or less within their own framework, it is likely that they will have different expectations and prerequisites. However, early markets should be established in those cases were different actors can cooperate in a way that all interests are served. That is why it is very important to map the relevant stakeholders and to get a clear view on their considerations in order to find common ground (see figure 6).

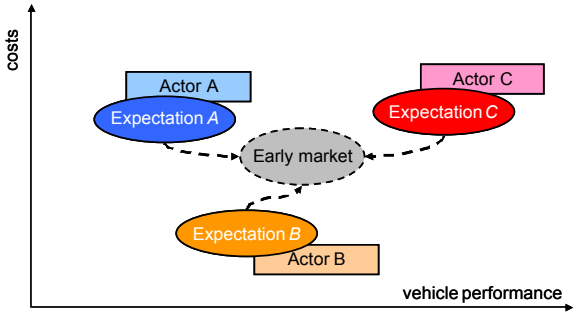

Figure 6: Expectation of different actors.

As early markets can be seen as an evolving process the kind of early markets will change in time. Due to that more and more actors might get involved. The first step while mapping the actors is to define those actors that might play an important role in the deployment of the first early markets.

In general two types of users can be identified 1) actors that are focussed on solving societal problems (mainly governments) and 2) actors that are mainly focussed on maximising their profits and increasing/maintaining their market share by bringing down their costs (mainly companies and private car owners). Governments might be users in the way that they can use hydrogen technologies themselves or that they subsidise the use of it in other sectors (e.g. public transport). They are responsible for solving problems related to climate change, local air quality and security of supply. In theory, they operate under suitable market conditions to create an early market (protected monopolistic market). In a competitive economy commercial companies try to minimise costs in order to maximise profits and are probably only willing to invest in new and more expensive technologies if it will bring them a competitive advantage (e.g. more appreciated by clients - image) or if governmental law forces them to do so (emissions caps, limited city centre access for polluting vehicles, obligations etc).

To identify actors' expectations and requirement levels, potential users (governments and private companies) will be interviewed. These users will be selected within 4 different kinds of stakeholder groups. These groups are based on the technical potential to use the first generations of hydrogen vehicles and their potential interest. The following 4 groups are defined:

- Governments; because of their public responsibility, the market characteristics (they operate on a more or less monopolistic market) and as owner of large governmental fleets.
- Bus companies; as busses are seen as one of the first viable applications of hydrogen technologies in the transport sector.
- Mail delivery companies; as these companies generally own large vehicle fleets with sometimes suitable operation conditions (central refuelling, limited mileage and often urban traffic).
- Energy companies; because of their potential interest in this issue (image and market opportunities).

By discussing the key performance indicators, insight is gained in prerequisites of potential users to switch to hydrogen technologies in the (nearby) future.

4 Conclusions

The first interviews with relevant stakeholders have been conducted and more interviews are planned for the coming months. The interviews will be hold with organisations throughout Europe. So far the activities have been focussed on The Netherlands, Germany and the United Kingdom but other countries will follow. The first results of this study are expected to be ready in summer 2007.

Acknowledgments

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