



Energy research Centre of the Netherlands

Ingredients for consistent hydrogen infrastructure policy

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Abstract

Hydrogen is seen as one of the energy carriers that have the potential to enable a transition towards a sustainable energy system. Special interest for hydrogen is discernible with the car industry. Currently, barriers like the high cost of fuel cells, institutional barriers and the absence of a fine-meshed infrastructure prevent the widespread application of hydrogen technologies. Apart from commitment by the industry, the barriers for establishing a full-fledged hydrogen economy require support from governments and involvement of the general public. In this report we aim to provide effective policy support tools for the deployment of a hydrogen infrastructure in the Netherlands.

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Summary

Hydrogen is seen as one of the energy carriers that has the potential to enable a transition towards a sustainable energy system. Special interest for hydrogen is discernible with the car industry. Currently, barriers like the high cost of fuel cells, institutional barriers (e.g. limited connection between relevant actors, a lack of regulations) and the absence of a fine-meshed infrastructure prevent the widespread application of hydrogen technologies. Apart from commitment by the industry, the barriers for establishing a full-fledged hydrogen economy require support from governments and involvement of the general public. In this report we aim to provide a framework of policy support tools for the deployment of a hydrogen infrastructure. We take the approach of splitting the development and deployment pathway for hydrogen technologies in different development phases and analyse the needs and uncertainties felt by stakeholders in each of these phases. In addition we investigated the zero emission vehicle policy in California and the German Clean Energy Partnership as exemplary cases.

Hydrogen technologies may help improving air quality from day one

Effective policy support improves the attention to new technologies required to meet long-term targets over competing incumbent technologies. Such a policy should therefore start from the hydrogen production pathways available today, but also include a long-term strategy for a transition towards hydrogen that is produced in a clean manner. In the short term, deploying hydrogen technologies creates immediate local benefits in terms of reduced local air pollution. In the long term, switching to producing hydrogen from clean sources leads to other benefits as well, e.g. actual reduction of GHG emissions and resolving security of supply problems. At this moment, hydrogen based transport is being demonstrated and, in some locations, even deployed as a commercial product. However, there are still several hurdles to overcome before hydrogen vehicles are a commercial, mainstream mode of transportation. Support will be required to guide this technology through its development.

Technology phases and policy tools

A technology's development to commercialisation can be split up in five stages: R&D, small-scale demonstrations, large-scale demonstrations, early markets and commercialisation. For each stage the different set of activities takes place involving a (partially) different set of actors. Each phase has its own intricacies and shifting from one phase to the other usually involves a shift in uncertainties and actors involved. Handing over a technology from one phase to the next might give rise to some specific hurdles as activities and actors change. Policy instruments should follow these changes in order to sustain a receptive ground for this technology. This means that current policy measures should address the specific uncertainties of a technology's current phase and the policy instruments that will be introduced for the next phase should be clear to actors in the field. The available types of policy tools are reinforcing mechanisms, direct subsidies, cross subsidies, market based mechanisms, the involvement of non-profit organizations and mandates. They should be used in different compositions in each of the development stages (see Table 3.2). This approach enables the implementation of policy instruments effective for a specific development phase and by that provides best value for each euro of public money spent.

Perseverance of policy important

The successful introduction of hydrogen into the transport system will be a lengthy process. It is of critical importance that governments display a long-term vision on future transport and the role of hydrogen. To gain confidence with investors it is important to align discourse with decisions and actions.

Support schemes in California and Germany

In California, the ZEV programme suffered from underestimation of conventional technologies to meet environmental goals and the overestimation of the potential of advanced technologies to become commercial in time. The ZEV programme thus ended up relying on very clean conventional vehicles instead of the advanced (full-electric) technologies as envisioned. Changing the ZEV regulations also undermined the strong signal of creating a strong demand for zero-emission technology and created uncertainty for technology developers and investors in these advanced technologies. This led to a loss of interest and investments. Another risk of a programme like the ZEV programme is that by focusing on one technology, there is a risk of getting locked in with a path that results in high societal costs while preventing or slowing down developments in other, promising clean vehicle technology.

In contrast to the top-down approach taken in California, the German example shows a bottom-up approach of introducing H₂. Although this approach ensures better interest from stakeholders firmly attaching to H₂ technologies (instead of eroding emission or vehicle standards), this support scheme still assumes the success of an advanced technology and that in the long run, improvements of the incumbent technologies will not be sufficient to achieve GHG reduction targets. Yet, if a particular technology choice (e.g. hydrogen) is made, there is also still the risk of getting locked in with a path that may result in high societal costs while preventing or slowing down developments in other, promising clean vehicle technology (e.g. full-electric).

Current status of hydrogen technologies

Hydrogen technology has now reached the early market phase in California. This implies that hydrogen cars have become available to some customers under a lease contract with the car manufacturer. Hydrogen is commonly available at dispensing units located at regular fuelling stations and run by commercial enterprises. In Germany, large-scale demonstrations are now running under programmes like the Clean Energy Partnership. These programmes involve car manufacturers and hydrogen production and infrastructure stakeholders. It should be noted that both California and Germany have a large interest in the survival of their automobile industry and therefore a large economic incentive, justifying an extensive support scheme. In the Netherlands, hydrogen deployment has so far been limited to a small-scale demonstration of fuel cell busses including an accompanying fuelling station in Amsterdam (CUTE and HYFLEET:CUTE projects). Other local initiatives on hydrogen are set up, for example, in Arnhem where industrial partners, research institutes and the local government have joined in the Arnhems Waterstof Network.

1. Introduction

Hydrogen (H₂) is seen as one of the energy carriers that have the potential to enable a transition towards a sustainable energy system. Special interest for hydrogen is discernible with the car industry. Currently, barriers like the high cost of fuel cells, institutional barriers and the absence of a fine-meshed infrastructure prevent the widespread application of hydrogen technologies. Apart from commitment by the industry, the barriers for establishing a full-fledged hydrogen economy require support from governments and involvement of the general public. In this report we aim to provide effective policy support tools for the deployment of a hydrogen infrastructure in the Netherlands by splitting the development and deployment pathway for hydrogen technologies in different development phases and analyzing the needs and uncertainties felt by stakeholders in each of these phases. In addition we investigated the zero emission vehicle policy in California and the German Clean Energy Partnership as exemplary cases.

1.1 Policy makers' dilemmas

The priority of (national) governments is to mitigate environmental and climate change problems and secure energy supply against least possible costs. To achieve this, policy should focus on technologies with a large impact on greenhouse gas (GHG) emission reduction. Cost effectiveness of the technology options plays a major role as well. To make satisfying these conditions easier, new, clean technologies should fit well into the current energy system.

Current European emission target for 2020 is set at 20% emission reduction compared to 1990 levels, however, as the Stern Review (2007) points out, more challenging targets of a global reduction of GHG emissions by 50% are required in 2050 to keep global warming between acceptable levels, which for rich countries implies a 60-80% reduction on GHG emissions compared to 1990 emissions. For the transport sector in the Western World the King Review (2007) estimated that this comes down to a 90% CO₂ emission reduction per vehicle by 2050 compared to the technology standard of 2000. As it now shows, this long-term target can only be achieved by moving towards technologies like hydrogen fuel cells which allow for zero-emission vehicles.

On the other hand, incremental improvements of incumbent technologies enable the fulfillment of short-term targets at relatively low costs. The potential to achieve emission reductions by improving incumbent technologies is nevertheless limited and long-term emission targets may become out of reach if these currently dominant technologies become locked-in (King Review, 2007). New, clean technologies like hydrogen fuel cells and batteries are currently expensive but have a large potential for further cost reductions. Effective policy can play a crucial role in crossing this cost barrier as well as other barriers for the large-scale uptake of clean technologies like hydrogen and enable further emission reduction after 2020.

1.2 Current status of the use of hydrogen technology in transport

There has been a strong drive for developing hydrogen technologies towards commercialisation. All large car manufacturers are developing fuel cell vehicles. Development has changed from prototype testing to production of small series of cars which are tested under real-life conditions through selected customers. Test programmes are coordinated as much as possible with refueling infrastructure suppliers and operators to obtain maximum synergy between vehicle and infrastructure R&D. Concerning the refueling infrastructure, relevant learning takes place in the utilisation of stations and as a consequence, test programmes concentrate in a few areas, in particular the Los Angeles region in California, Berlin and Hamburg in Germany and the Tokyo

area in Japan. With the current rate of learning, major players in the field like Honda, Toyota and ChryslerDaimler, expect to be ready for commercialisation by 2015 with others like and General Motors, Hyundai/Kia, Nissan following soon.

Obligations for car manufacturers to sell at least a minimum amount of zero-emission vehicles (ZEV) in California have enhanced this development (ARB, 2009). Hydrogen technology has reached the early market phase in California and other states are following this example. This has resulted in hydrogen cars becoming available to any customer under a lease contract with the car manufacturer. Hydrogen is available at dispensing units located at regular fuelling stations and run by commercial enterprises.

In Germany, large scale demonstrations are running under programmes such as the Clean Energy Partnership (CEP). These programmes involve car manufacturers and hydrogen production and infrastructure stakeholders. This approach is also used in Japan and California to stimulate the uptake of hydrogen technology in transport via respectively the Japan Hydrogen & Fuel Cell Demonstration Project (JHFC) and the California Fuel Cell Partnership. In Section 2.3, the Californian ZEV regulation and the German CEP are further discussed.

In the Netherlands, hydrogen deployment has so far been limited to a small-scale demonstration of fuel cell busses including an accompanying fuelling station in Amsterdam (CUTE and HYFLEET:CUTE projects). Other local initiatives on hydrogen have been set up, for example, in Arnhem where industrial partners, research institutes, large customers and the local government have joined in the Arnhems Waterstof Netwerk.

The development status of hydrogen technologies differs in the several countries where hydrogen programmes are currently taking place. While the technology in itself is already in its early market phase due to earlier activities in e.g. California and Germany, deployment in the Netherlands has only reached the phase of small-scale demonstrations. Chapter 2 of this report provides a framework on the development stages of new technologies and describes examples of policies from California and Germany. Chapter 3 discusses the options for policy support in the Netherlands. In Chapter 4 we conclude by summarizing the findings in this report.

2. Technology deployment path

In this chapter we split up a technology's development to commercialisation in different stages. For each stage the different set of activities and (partially) different actors are described. Handing over a technology from one phase to the next, might give rise to some specific hurdles. These so-called valleys-of-death are discussed in the last section of this chapter. We distinguish between five technology development stages. They are related to technology and market developments shown in Figure 2.1.

2.1 Technology development phases

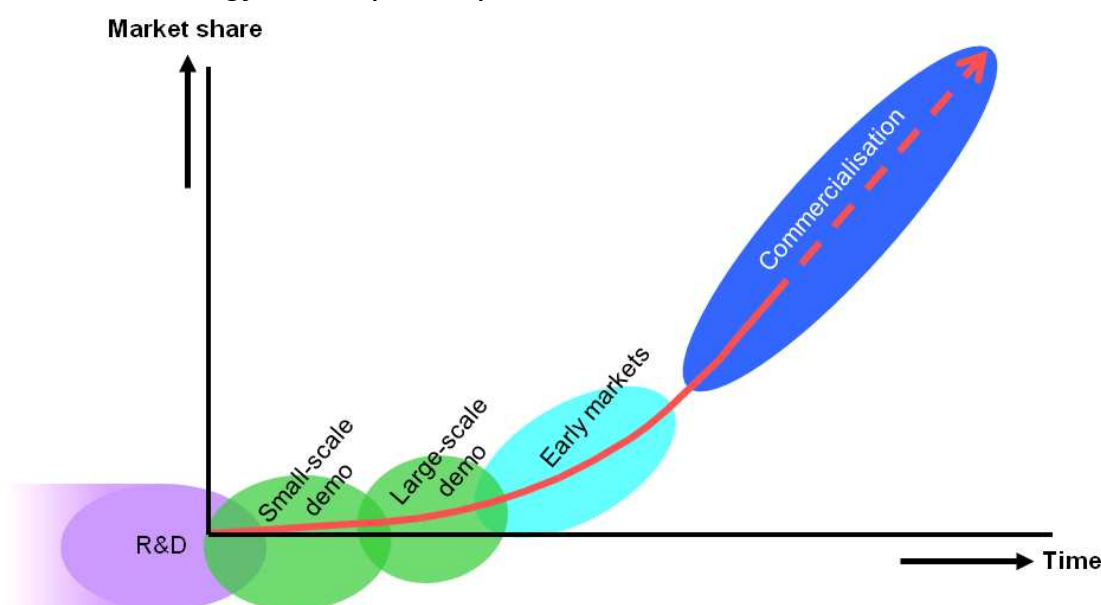


Figure 2.1 *Technology development phases*

The R&D phase occurs before any deployment of the technology takes place. This is the development stage of the technology in which typically a number of technological principles (e.g. the outcome of fundamental research) are transformed into a useful product. During this stage, the design of the technology is focused at delivering a proof-of-principle.

R&D

The origin of new technologies usually lies in older principles and concepts which were found out by doing fundamental research. It is hard to determine when the R&D phase starts. After basic principles are discovered or understood, it can take up to several decades before it is applied in a new technology. During this stage, typically a number of technological principles (e.g. the outcome of fundamental research) are formed into a useful product. The design efforts are more focused at delivering a proof-of-principle rather than delivering a product which is ready for mass markets.

As application of a technology does not yet take place, it usually takes the shape of a laboratory set-up which may differ considerable from a usable product. In this stage the use of exotic materials or production processes is fairly common in order to prove that the technology in principle works. Later, in the development stage, the first steps are made to view a technology as an actual product. During the development stage, user-friendliness and the ability to produce the technology in larger numbers becomes an issue. At the end of this stage, the first small scale demonstration projects are carried out.

Small scale demonstration

The small scale demonstration phase mainly focuses on validating a new technology. Some of the technological uncertainties are resolved and much attention goes to integrating the technology in existing systems (e.g. integrating fuel cells in cars) and reducing the complexity of the technology. The first attempts for technology standardisation takes place and a better indication of the potential of the technology on GHG emissions, costs and scalability emerges.

Funding focuses on R&D, but also on investments required for demonstration projects. The core of funding for projects initially lies with local and/or national governments, but as the potential becomes clearer private parties start to contribute as well.

Large-scale demonstrations

If small scale demonstrations are successful, the scale of demonstration projects will gradually increase. We distinguish between small-scale and large-scale demonstration phase as the latter emphasises the interaction with end-users rather than validation of the technology. With the scale of projects, also the financial risks increase, especially because the future prospects of the technology may still be unclear.

During large-scale demonstrations, R&D efforts are not supported by government, but carried out and funded by private parties. Still, the high financial risks necessitates government support for the investments required for large-scale demonstration projects.

Early markets

After demonstration, a technology moves into its early markets. The technology now starts to be of commercial interest for a specialised set of users, willing to take on a novel beneficial technology at slightly higher costs. These markets are also referred to as niche markets. In the classification of Rogers (1962), the customer base (but also producers, investors, etc.) consists of early adopters. In order to convince interested parties, the technology may be supported via incentives like investment support, tax exemptions or consumer rebates. During the early market phase, the deployment of a technology generally takes off. Together with set standards, cost reductions through learning-by-doing effects start to play a role.

The main uncertainties are the perception of demand with consumers and their demand behaviour for the medium to long term. Actors will compare the new technology with other options. A new uncertainty arises on the front of availability of resources (although this may already be considered by actors in an earlier phase) and the ability of suppliers to deliver e.g. fuel and components. When the technology starts to become successful, markets for fuel and technology components may become more strained.

Commercialisation

The final phase from the conception of a technology towards commercialisation is the commercialisation phase itself. In order to enter this phase, the technology needs to be attractive to a different type of customers that have higher demands on matters like costs, user-friendliness and do not necessarily care for novelties. The technology still has to compete with other options and resource and supplier availability remains an issue as well. In order to leave the niches and enter the mass markets, the technology has to bridge gaps on these issues. Technological uncertainties described in the three earliest phases are now resolved, which leaves room to generate market pull via covenants and obligations. Increasing cost reductions through R&D efforts, learning effects and economies-of-scale reduce the need for incentives, which at this stage can be phased out. After this phase, the technology's market share may still increase and eventually the technology may become one of the incumbents, coexisting with, or pushing out regime technologies. At that stage, the use of the old technology might be phased out by prohibiting its use.

2.2 Valleys-of-death in-between technology phases

Before a technology moves from one phase to the next, it has to be clear that it could ‘survive’ the economic circumstances of the next phase and should address the needs and expectations of actors in this next phase. As the conditions, economic circumstances and actors are not necessarily the same as in the current phase, and the technology might not directly appeal to stakeholders in the next phase, there is a large probability that the technology is not taken up in the next phase. A technology gets sort of lost between the two development phases and this barrier is referred to as a ‘valley of death’. For illustration, different end-user technology adopter categories as defined by Rogers (1962) are indicated as well. Valleys of death occur e.g. when a new adopter category is to be addressed. In literature, the valley of death is usually associated with this barrier between the early markets and commercialization. However, using a similar line of reasoning the same type of barriers can be found between each development phase, i.e. each transition between development phases has its own valley of death. In Figure 2.2 the valleys of death are indicated between the technology phases as mentioned in Figure 2.1. Below, we will elaborate on the specific barriers between technology phases.

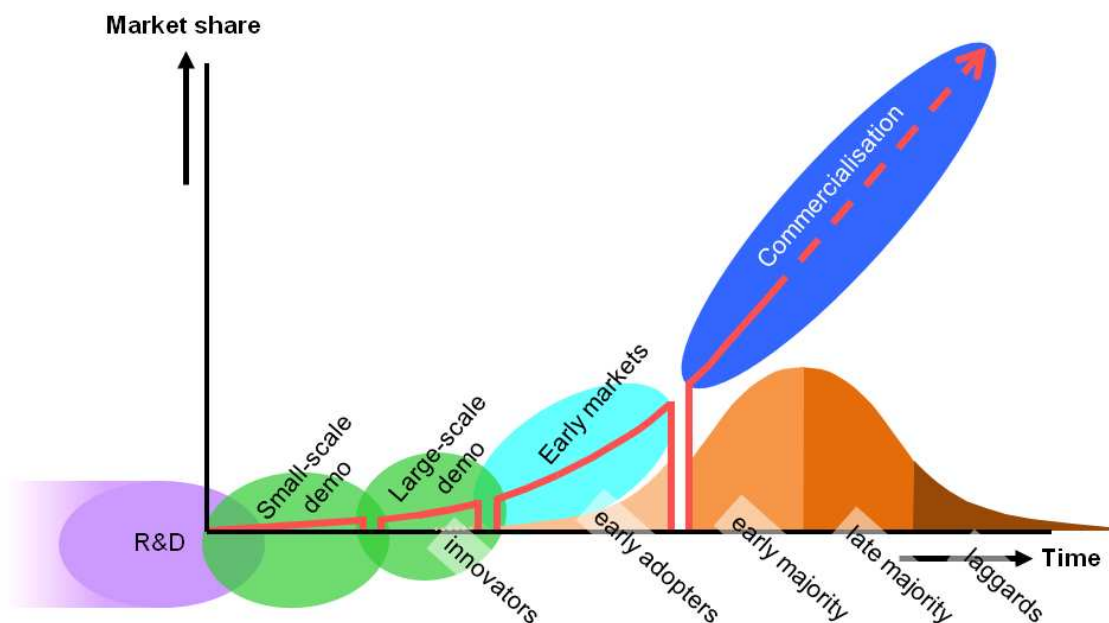


Figure 2.2 Indication of valleys of death

2.2.1 R&D → small-scale demonstrations

During the early R&D phase generally a mainly academic interest drives research efforts in, e.g. the mechanism behind certain basic principles. As soon as much of these principles are known, academic research moves to other, unexplored fields. For the next phase, a different type of research activities is required in applying certain principles into a useful device. However, actors in this field need to be convinced that a certain principle is useful for their goal or the future technology gets delayed or even stranded between the fundamental and the applied R&D stages. This might be the reason why some fundamental principles take such a long time to get integrated in crucial technologies¹. The applied R&D phase may be classified as the development phase of a technology. The aim of this phase is to deliver a proof-of-principle, i.e. show the capability of a (set of) principles and concepts to solve a particular problem. Towards the end of the R&D phase when the first prototype is constructed, the emergent technology is scarcely ‘out of the egg’.

¹ For example electrochemistry was discovered by Michael Faraday in 1832 leading to the first rudimentary fuel cell by William Grove in 1839, however, it took until 1955 before the development of practical fuel cells started.

For the use of hydrogen the applied R&D phase took place in the 1960's when the first fuel cells were applied in vehicles. Investments in the next small scale demonstrations phase are only justified when the technology has good market prospect. For H₂ technologies in transport the following barriers can be identified which could have prevented from entering small-scale demonstration phase.

- Technological uncertainties exist on:
 - Potential for cost reductions
 - Efficiency,
 - Complexity i.e. performance changes are harder to predict for radical innovations than for incremental changes in current technologies
 - Comfort and other characteristics
 - Scalability of production
- Does the technology have enough potential, e.g. to reduce GHG? If the technology has to be implemented in a complex system, judgments on its potentials are hard.
- Will there be sufficient market share e.g. to recover investments in developing the technology and to realise significant GHG reduction? This issue strongly depends on information on experience with the technology's deployment
- Will other crucial components related to the technology develop sufficiently for the technology to become viable? For developing a H₂ infrastructure fuel cells and on-board H₂ storage needs further development while H₂ production is already well known.
- Will there be enough political and societal support to bring the technology to market.
 - Will the current political view on reducing GHG and the role of this new technology sustain in the future.
 - Will there be a consistent regulatory framework preventing e.g. market failure and balancing collective benefits and costs to further develop the new technology into a marketable product.
 - How do the state of the economy and oil and gas prices influence government actions.
 - Trust in credibility of the government: does government align discourse with actions? To what extent is commitment delayed? What happens when government changes?

As with many other emergent technologies, the characteristics of H₂ technologies are subject to change and constantly improving (although not necessarily on all fronts). Therefore, especially in the R&D and early demonstration phases of H₂ technology much of the information investors and other stakeholder get is either incomplete or outdated. This stimulates the uncertainties for private investors and holds them back from moving into small-scale demonstrations. Government actions which could lower these barriers are discussed in Section 3.

2.2.2 Small-scale demonstration → large-scale demonstrations

Uncertainties on the technology and its potential still exist in between these phases, but are reduced to some extent. Policy support remains a major issue, as developing an emerging technology towards the market usually takes more than a government period, while stable political and societal support are required up to commercialisation. A new barrier that arises during the small-scale demonstration phase is the increasing sunk costs of demonstration projects. These make investors extra sensitive to uncertainties like choosing the wrong standard, future costs and prices and consumer demand (i.e. economic viability). As the form and application of a new technology becomes more clear, its competing technologies also emerge. In principle there are two types of competing technologies: incumbent technologies which deliver the same service at lower costs, but could have environmental disadvantages, and new technologies that offer the same service, are clean, but based on a different concept.

Uncertainty on standards specially plays a role in the development of H₂ infrastructure where choosing the wrong standards require early replacement of equipment. Investors observe this as a high risk which make them reluctant to invest before standards are set. The complication is

that the small scale demonstrations are required to set these standards. Investors need the assurance that H₂ is going to be an economically viable fuel in the long run. Because the technology now starts to take the form of a usable product e.g. in FCEVs and H₂ dispensing stations, its competing technologies also become clearer. For H₂ these technologies are e.g. plug-in hybrids which compete at range, BEVs which compete at emissions and conventional ICE and fuelling technologies based on petrol and biofuels. An emerging technology like hydrogen has both advantages and disadvantages over its competing technologies and consumer demand also plays a role in determining which technologies may 'win'. However, in this early phase consumers are unaware of a possible need for the new technology, and accordingly their needs for the future are also uncertain.

In the Netherlands, the *deployment* of hydrogen technologies are now moving out of the small-scale demonstration phase with projects like HYFLEET CUTE and now need to move into the large scale demonstrations like those now taking place in Germany, Japan and the USA. In Germany, under the Clean Energy Partnership (CEP) hydrogen technologies are deployed in large-scale demonstrations. A development along similar lines is taking place under the Japan Hydrogen en Fuel Cell Project (JHFC). In California, Hydrogen vehicles are commercially available for the general public via lease contracts. Vehicles have moved out of the laboratory scale production and for example the Honda FCX Clarity is manufactured on a production line.

2.2.3 Large-scale demonstration → early markets

The main barrier between these phases is the uncertainty on whether technology choices at that moment will be the future standards. Irreversible investments in large projects make this issue of key importance for investors and have a strong influence on their expectations on return on investment. Another barrier that is still present but now more pronounced is the competition with other technologies, i.e. the question whether the new technology under demonstration has any future prospects? Will its position be taken by other new technologies? Are instruments in place to make incumbent technologies less attractive? In the case of H₂, the prospects on oil, gas and CO₂ prices influence the cost difference between incumbent and H₂ technologies (or any other zero-emission technology). For scaling up the new technology, the availability of resources (raw materials for vehicle and infrastructure construction, human capital, etc.) starts to become an issue. Limitations in the availability of resources could have a strong impact on the prospects of mass deployment. Although the visibility of the technology for the general public could increase, there may still be a lack of perception of demand with these potential end-users, also their future demand behaviour on the mid and long term is uncertain.

For H₂ it is critical that standards on e.g. fuelling and safety are set as well as regulation that prevents the use of incumbent (i.e. less efficient or polluting) technologies. On the other hand, the expected high oil prices may partially cover the cost gap between petrol and H₂ technologies. Depending on whether the production method of H₂ is based on renewable energy sources or not, the CO₂ price may respectively reduce or increase the cost gap with petrol. The increasing visibility of the technology, as well as the majority of people not convinced of its need, makes public acceptance of H₂ technology and its infrastructure an increasingly important issue. The first movers might also experience first mover advantages and disadvantages compared to competitors moving in later. For example, for car manufactures moving into the new technology early puts them ahead of competition in experience with H₂ and gives them more time to build an image or brand. On the other hand, if the H₂ technology does not take off, car manufacturers are left with sunken investments in the development of H₂ vehicles. For fuel suppliers, the advantage of moving in early is that the number of competitors is still low enabling them to take a large share in the initial market. This may have continued benefits for the share when the market expands. Moving in early has disadvantages for fuel suppliers in that it reduces their ability to amortise earlier investments in conventional fuel infrastructure and the initially low H₂ demand results in a low utilisation of new infrastructure making it an unattractive investment on the short term.

2.2.4 Early markets → commercialisation

The main uncertainties for H₂ technologies in this phase are the perception of demand with consumers and their demand behaviour for the medium to long term. Actors will compare using H₂ with other options like BEV or vehicles based on ICEs and fuelled with petrol or diesel. The key source of the consumer related uncertainties in this phase are that a different type of consumer needs to be addressed. In the commercialisation phase, the early majority, late majority and laggards become the key consumer groups. These customer groups base their choices on a different set of needs and benefits and these types of customers perceive disadvantages differently from innovators and early adopters. If H₂ manages to also fulfill the needs of these customer groups, it may establish itself as a regime technology and autonomously increase and, after stabilisation, maintain a market share. Availability of resources as defined in Section 2.2.3 remains a concern but is now accompanied by for example the ability of suppliers to provide fuel. When the technology starts to become successful, markets for fuel and technology components may become more strained.

2.3 Current international developments

2.3.1 USA (California's zero-emission vehicle programme)

California has the worst air quality problems within the USA. In response, this state has developed aggressive policies to reduce emissions, making it one of the international leaders in environmental policy, particularly in air pollution from vehicles. Instruments for mitigating emissions from transport have mainly focussed on reducing emissions from vehicles and not at upstream emissions from e.g. extraction, refining and distribution of fuels. The Federal Air Quality Act of 1967 gave California an instrument to set its own emission standards for vehicles. Since the 1970, California has achieved significant reductions of emissions from new passenger vehicles, particularly in smog-forming emissions. The California Air Resource Board (CARB) is responsible for the regulations concerning air pollution. Over time, their regulations have evolved from specific technology mandates via performance standards for vehicles which were subsequently updated and revised. In 1990 CARB launched the Zero-Emission Vehicle (ZEV) programme as part of the Low-emission Vehicle (LEV) regulation (Wells Bedsworth & Taylor, 2007). The programme intended to achieve significant emission reductions from the passenger vehicle fleet. The basic instrument CARB used was to link a performance standard with a sales mandate. The change in LEV compared to previous regulations was that instead of establishing a single performance standard, a number of emission categories for cars and light-duty trucks (SUVs, minivans and pickup trucks) with varying levels of stringency were established to which manufacturers could certify new vehicles. There was no requirement placed on the number of vehicles that had to be sold in any one emission category, but per manufacturer the mix of sold vehicles (i.e. the mix of emission categories) was constrained by the level of the emission performance standard. The emission standard included nitrous oxides, non-methane organic gasses (NMOG) and carbon monoxide. Although regulators anticipated that clean-burning fuels were required to reach the most stringent emission levels, in principle they let the industry decide how to achieve the targets. However, in the early 1990's, the only technology option by which the zero-emission standard could be achieved at some production level were Battery Electric Vehicles (BEV). By introducing the ZEV programme, CARB de facto supported this specific technology and moved away from making regulation more flexible.

The ZEV programme was meant to overcome barriers for deployment and development of Zero-emission vehicle technology and spur innovations in this field. By moving towards choosing a particular vehicle technology the authorities also took a risk of choosing the wrong technology and getting locked in with a suboptimal technology. At first, BEV appeared to be technologically and economically feasible within reasonable time from the initiation of the ZEV

programme. Manufacturers also seemed to be moving their development efforts towards this technology. GM introduced its first commercially available BEV, named EV1 in 1990 and a larger development programme was intended, based on the by then upcoming ZEV mandate by CARB. Other partnerships between domestic automobile manufacturers and government, like the US Advanced Battery Consortium (USABC) or the Partnership for a New Generation of Vehicles (PNGV) were established aiming for developing BEVs.

Around 1993 it became clear that BEVs were not meeting cost and performance goals. Batteries remained expensive and the range of vehicles could not compete with the range of conventional cars. The ZEV programme was reviewed biannually and during the review at this time, the ZEV programme was altered by changing the time frame at which the ZEV mandate needed to be met and by broadening the scope of the programme such that other vehicle types could also apply. Because battery performance kept lagging behind, in response to the 1996 review, CARB decided to eliminate the ZEV vehicle-fleet requirements for 1998 and 2001, but kept a 10% fleet requirement for 2003. Deployment of ZEVs was further stimulated by memorandum of agreement to introduce LEVs nationwide. In 1998 new vehicle categories were introduced like Partial zero-emission vehicles (PZEV) and super ultra low emission vehicles (SULEV) to provide additional flexibility. These extra technology options were not received well by car manufacturers as they claimed the standards and required sales volumes to be unachievable. The new categories were not credited at the same level as true ZEVs. During the 2000 review it became clear that the BEV remained much more expensive than estimated at the beginning of the programme, but also that car manufacturers were moving towards other technologies like hydrogen FCEVs. This review also led to the introduction of another category of vehicles Advanced Technology PZEVs (AT-PZEVs) which incorporated technologies like electric drive systems or high pressure gas storage.

As the other vehicle categories were not accounted at the same level as ZEVs and the 2003 fleet requirement still was in place, the car industry challenged these regulations in court. This led to the alternative compliance path which enabled the compliance of the ZEV vehicle-fleet requirement through the sales of ZEVs, PZEVs, and AT PZEVs.

Apart from making the programme rather complicated, the various changes in the ZEV regulations led to much less deployment of advanced technology than originally envisioned. Still, the environmental benefits of the programme are significant. Although the additional vehicle categories introduced later on were not zero-emission, they were much cleaner than conventional vehicles under the rest of the LEV regulation.

In hindsight, the ZEV programme suffered from underestimation of conventional technologies to meet environmental goals and the overestimation of the potential of advanced technologies to become commercial in time. The ZEV programme thus ended up relying on very clean conventional vehicles instead of the advanced (full-electric) technologies as envisioned. Changing the ZEV regulations also undermined the strong signal of creating a strong demand for zero-emission technology and by that created uncertainty for technology developers and investors in these advanced technologies. This led to a loss of interest and investments. Another risk of a programme like the ZEV programme is that by focusing on one technology, there is a risk of getting locked in with a path that results in high societal costs while preventing or slowing down developments in other, promising clean vehicle technology.

2.3.2 Germany (Clean Energy Partnership)

The Clean Energy Partnership (CEP) is an international cooperation of BMW Group, Berliner Verkehrsbetriebe BVG, Daimler, Ford, GM/Opel, Hamburger Hochbahn, Linde, Shell, Statoil, TOTAL, Toyota, Vattenfall Europe and Volkswagen and was founded in 2002. The Clean Energy Partnership roots in the Economic Energy Strategy (EES) and has set the goal to show the possibilities for safe use hydrogen for road transportation by normal customers and the op-

tions for renewable hydrogen production methods. The deployment of the Partnership is divided in three phases (CEP, 2010).

The first phase

CEP launched its demonstration project in November 2004 in Berlin by bringing two hydrogen filling stations in operation as well as a fleet of approximately 25 hydrogen cars and other H₂ technologies e.g. decentralised production of hydrogen (either by electrolysis or by LPG-reforming) centralised hydrogen production by natural gas reforming and liquefaction, distribution and storage, supply at the filling station and use in fuel cell propulsion systems or in internal combustion engines.

The first phase of the Clean Energy Partnership was completed on June 30th, 2008. Essential results are:

- Forward-looking hydrogen drive systems and fuelling technologies have been successfully demonstrated over a period of several years.
- The technical and economic conditions for using hydrogen in road transportation have been identified and initial obstacles have been removed.
- Evidence has been provided, that the production and supply technologies are compatible.
- Evidence has been provided, that vehicles can be fuelled with compressed gaseous and liquid hydrogen fast and in a safe mode.
- It has been proven, that efficient hydrogen-powered vehicles with fuel cells and with hydrogen-powered internal combustion engines can be operated reliably.

The second phase

In May 2008 CEP started its second phase by establish the hydrogen region Hamburg-Berlin. This phase runs until 2010. The aim is to validate H₂ technology in everyday conditions and in particular to push ahead with the further development of technologies that are essential for hydrogen's market entry at a later date. The concrete steps taken in this phase are the increase of the vehicle fleet up to 40 cars, the expansion of the fleet of public busses in Hamburg and Berlin and the opening of three new filling stations in Berlin and in Hamburg HafenCity. A first major milestone is the enlargement of the Berlin vehicle fleet by ten GM/Opel HydroGen4s equipped with an onboard 700bar-vessel H₂ storage system.

At this moment the CEP is supported by the National Hydrogen and Fuel Cell Technology Innovation Programme (NIP) in which it is categorised as a lighthouse project aiming to contribute to establishing hydrogen as the fuel of the future.

The third phase

The third phase is planned to start in 2011 and should run until 2016. The main focus of this phase is on market preparation. The technical, political and organisational or logistic goals of the partnership will be outlined, targeting the preparation of the market for commercial hydrogen-powered vehicles by 2016. Special attention is paid to the sustainable production, processing and distribution of hydrogen which at that time will not be a regional issue, but rather an international challenge. An overall infrastructure of hydrogen production and fuelling with relevant shares of renewable energy still has to be developed.

In contrast to the top-down approach taken in California, the German example shows a bottom-up approach of introducing H₂. Although this ensures better interest from stakeholders firmly attaching to H₂ technologies (instead of eroding emission or vehicle standards), this support scheme still assumes the success of an advanced technology and bets that in the long run, improvements of the incumbent technologies will not be sufficient to achieve GHG reduction targets. Still, if a particular technology choice (e.g. hydrogen) is made, there is also still the risk of getting locked in with a path that may results in high societal costs while preventing or slowing down developments in other, promising clean vehicle technology (e.g. full-electric).

2.4 Considerations for the Netherlands on H₂ technologies

In relation to the development of H₂ in transport and given the current status of the technology, the Netherlands may consider a few lines of action. First, it may leave the development to other countries and import all technology later. The advantage is that investments in R&D and learning are not required. However, if other regions display the same behaviour, the global critical mass needed to achieve cost reductions might not materialise and the costs of meeting more stringent targets in the transport sector may become expensive after all. Second, it may join the current efforts, gain experience with the technology in an early phase. This requires R&D and learning investments, but also stimulates economic activities within the Dutch borders. The question that we address in the remainder of this report is which measures could be taken to stimulate the uptake of H₂ in transport until it is a commercially viable technology. Third, it could take the 'wait-and-see' approach. The Netherlands does not have a large impact on the global developments in the automobile industry. Because there is no large car manufacturer, nor a supplier of key engine components present, so the Dutch economy is unlikely to profit from pursuing a leading role in hydrogen development and deployment. Still it is worthwhile to remain alert on the global developments in this field. The latter line of action, taking a wait-and-see position and look for specific added value, seems the most logical way to go.

3. Options for policy support in the Netherlands

3.1 Introduction

In the framework of deploying new technologies like hydrogen technologies, policy support aims to create a level playing field for new and incumbent technologies and prevent market failure. Apart from high vehicle and fuel costs, an important aspect which requires policy support for hydrogen infrastructure is the high risk perceived by investors. These risks involve amongst others technological uncertainties, what will become the standard, consumer behaviour and (potential) demand. Policy support can be instrumental in reducing these risks and evening out barriers for actors involved in hydrogen technologies, e.g. by introducing R&D programmes on H₂ storage and fuel cell technologies, setting H₂ vehicle and infrastructure standards, and use the (local) governments' captive fleets to ensure a certain level of demand for H₂. These public investments are justifiable as they contribute to societal benefits like reducing CO₂ emissions local air pollution, public health and creation or shifting of jobs.

As has been shown in the previous chapter, a new technology goes through different phases during its development. Each phase has its own intricacies and shifting from one phase to the other usually involves a shift in uncertainties and actors involved. The aim of policy on H₂ is to reduce these uncertainties and policy instruments should follow these changes in order to remain optimal. This means that current policy measures should address the specific uncertainties of a technology's current phase and the policy for the next phase should be clear to actors in the field. For H₂ technologies we assume that in 2015 the stage between large-scale demonstration and early markets is reached.

3.2 Policy instruments

The instruments available for policy makers to stimulate the use of clean technologies can be categorised under financial support and flanking measures. In the case of hydrogen, financial support may come in the form of investment support on vehicles or infrastructure, price benefits on fuels and tax exemptions. In the Dutch context, tax benefits do not only apply to the registration tax, excise duties and VAT, but could also be expressed in a reduced income addition for lease drivers choosing zero-emission cars. Policy makers may address different target groups by installing support measures on different technology components (e.g. vehicles, fuel, and infrastructure).

Table 3.1 gives an overview of which support measures may be used for stimulating the uptake of hydrogen technologies to address different target groups and technology components. The period over which the introduction of a new energy technology like hydrogen needs government support usually extends over several government periods. In order to make support systems more robust against government changes (and the change of focus that may come with them), financial support systems could be decoupled from government budgets by obtaining the required support funds from undesirable technologies, for example by taxing conventional fuel higher than H₂ or electricity used for transportation.

Table 3.1 *Financial support measures for hydrogen*

	Support	Vehicles	Fuel	Infrastructure
Target group				
Private consumers	-	Investment support	Price benefits (also	
	-	Energy labels	improve detour	
	-	Tax exemption (This	willingness)	
		includes drivers of		
		vehicles owned by		
		lease companies)		
Fleet owners	-	Investment support	- Fuel support	
		(aimed at resale	- Tax exemption	
		value)		
Infrastructure	-	Hydrogen in	- Fuel support (aimed	- Investment support
stakeholders	-	public transport	at level playing field	
	-	captive fleets	with competing	
	-	(also improves	technologies)	
		visibility of		
		hydrogen)		

Flanking measures include regulations and permitting procedures. By streamlining procedures for e.g. permitting and by extending the validity of permits for fuelling stations, authorities could reduce barriers for investors and stimulate the uptake of H₂ infrastructure.

In Table 3.2 we have indicated several policy tools which could be used by policy makers to stimulate the build-up of a hydrogen infrastructure. Because of the high investments that are required, a hydrogen infrastructure will probably not develop by relying on market-based mechanisms only (i.e. by itself). The main aim of these tools is to influence the flow of capital from private/public sources and enhance market-based mechanisms. We can distinguish six types of policy tools each of which addresses a specific technology development phase. Between brackets we indicate the source of funding (California 2010 Hydrogen Highway Network, 2005). In Appendix A examples of specific policy instruments are given for each of the mentioned types of policy tools.

Table 3.2 *Types of policy tools*

Phase	Type of policy tool
R&D	• <i>Reinforcing mechanisms</i> e.g. awards and incentives contributing (but not fully funding) to broader goal of accelerating development of H₂ economy (public and private resources) • <i>Direct subsidies</i> which are taxes/revenue sources for enabling programme (public resources)
Small scale demo	• <i>Reinforcing mechanisms</i> e.g. awards and incentives contributing (but not fully funding) to broader goal of accelerating development of H₂ economy (public and private resources) • <i>Direct subsidies</i> which are taxes/revenue sources for enabling programme (public resources)
Large scale demo	• <i>Direct subsidies</i> which are taxes/revenue sources for enabling programme (public resources) • <i>Cross subsidies</i> transferring some benefit of current subsidy programme from existing recipients to new recipients (i.e. participating service providers for H₂ infrastructure (public resources) • <i>Market based mechanisms</i> influencing financial attractiveness of investments (private resources)
Early markets	• <i>Cross subsidies</i> transferring some benefit of current subsidy programme from existing recipients to new recipients (i.e. participating service providers for H₂ infrastructure (public resources) • <i>Market based mechanisms</i> influencing financial attractiveness of investments (private resources) • <i>Involving Non-profit organisations</i> with public service or embracing environmental/energy sustainability or economic development goals (private resources)
Commercialisation	• <i>Involving Non-profit organisations</i> with public service or embracing environmental/energy sustainability or economic development goals (private resources) • <i>Mandates</i> actively affecting behaviours of various private and public actors (private and public resources)

For a policy maker it is important to determine in which development phase a technology is in and adjust policy instruments accordingly. In order to gain trust and market prospect, it is important for governments to express a long term policy vision and aligning discourse with government actions. Given the large scale and the fact that transport doesn't end at the Dutch border, it is important to adhere to European policy and follow the developments set out in the rest of Europe, e.g. the actions taken in the FCH-JTI. In this programme, H₂ technology use in transport is scaled up to the level of large-scale demonstrations.

4. Conclusion

Effective policy support for the use of H₂ in the transport sector addresses financial uncertainties in three ways:

First it improves the attention to new technologies required to meet long term targets over competing incumbent technologies. It should therefore include a strategy for a transition towards clean produced hydrogen. In the short term, deploying hydrogen technologies creates local benefits in terms of reduced air pollution. Local air quality improves regardless of how the hydrogen is (centrally) produced. In the long term, switching to producing hydrogen from clean sources leads to benefits as actual reduction of GHG emissions and resolving security of supply problems.

Second, an optimal support scheme acknowledges the development phase a technology is in and adjusts accordingly when the technology moves into the next phase. A possible evolution of the policy instruments for hydrogen is indicated in Table 4.1. This also implies a proactive attitude of governments which should continuously monitor the developments and take actions *before* a next phase starts or problems arise.

Table 4.1 *Types of policy tools*

Phase	Type of policy tool
R&D	• <i>Reinforcing mechanisms</i> e.g. awards and incentives contributing (but not fully funding) to broader goal of accelerating development of H₂ economy (public and private resources) • <i>Direct subsidies</i> which are taxes/revenue sources for enabling programme (public resources)
Small scale demo	• <i>Reinforcing mechanisms</i> e.g. awards and incentives contributing (but not fully funding) to broader goal of accelerating development of H₂ economy (public and private resources) • <i>Direct subsidies</i> which are taxes/revenue sources for enabling programme (public resources)
Large scale demo	• <i>Direct subsidies</i> which are taxes/revenue sources for enabling programme (public resources) • <i>Cross subsidies</i> transferring some benefit of current subsidy programme from existing recipients to new recipients (i.e. participating service providers for H₂ infrastructure (public resources) • <i>Market based mechanisms</i> influencing financial attractiveness of investments (private resources)
Early markets	• <i>Cross subsidies</i> transferring some benefit of current subsidy programme from existing recipients to new recipients (i.e. participating service providers for H₂ infrastructure (public resources) • <i>Market based mechanisms</i> influencing financial attractiveness of investments (private resources) • <i>Involving Non-profit organisations</i> with public service or embracing environmental/energy sustainability or economic development goals (private resources)
Commercialisation	• <i>Involving Non-profit organisations</i> with public service or embracing environmental/energy sustainability or economic development goals (private resources) • <i>Mandates</i> actively affecting behaviours of various private and public actors (private and public resources)

Third, it addresses vehicles, fuel and infrastructure all at the same time and distinguishes between different target groups. Table 4.2 shows how financial support instruments should be arranged to fulfill this condition.

Table 4.2 *Financial support measures for hydrogen*

	Support	Vehicles	Fuel	Infrastructure
Target group				
Private consumers	-	Investment support	Price benefits (also	
	-	Energy labels	improve detour	
	-	Tax exemption (This includes drivers of vehicles owned by lease companies)	willingness)	
Fleet owners	-	Investment support (aimed at resale value)	- Fuel support	
			- Tax exemption	
Infrastructure stakeholders		Hydrogen in	- Fuel support (aimed at level playing field with competing technologies)	- Investment support
		- public transport		
		- captive fleets		
		- (also improves visibility of hydrogen)		

Finally, it is of critical importance that governments display a long term vision on future transport and the role of hydrogen within this. To gain confidence with investors it is important to align discourse with decisions and actions.

Because there is no large car manufacturer, nor a supplier of key engine components present in the Netherlands, the Dutch economy is unlikely to gain significant profit from pursuing a leading role in hydrogen development and deployment. Germany is a more logical market for hydrogen introduction, which is already taking place in current initiatives such as CEP. Still, there are Dutch players active in the automotive industry, especially as suppliers of car manufacturers. If hydrogen becomes successful in Germany, this market will extend over its borders into the Netherlands and offer opportunities for Dutch industry. This is also relevant because the uptake of zero-emission vehicles contributes to important policy themes like security of supply, local air quality and innovation.

For these reasons it is worthwhile to remain alert on global and European developments in this field. Developing and disseminating a clear vision on the Dutch government's position on supporting opportunities for Dutch players in this market and connecting to developments elsewhere in Europe and in the rest of the world, seems a logical way to go. This may take shape by a proactive and attentive attitude in recognizing and supporting innovations that could play a significant future role in the transport sector. Furthermore, it is important to look for specific added value, align policies with developments in Europe and establish a dedicated regulatory framework which addresses the specific uncertainties with stakeholders.

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Appendix A Specific Policy instruments

Based on these six categories defined in Paragraph 3.2 and the information provided in California 2010 Hydrogen Highway Network (2005) we can list a number of policy instruments.

Reinforcing mechanisms

- Monetary awards for technical accomplishments
- Streamlined and simplified codes and standards
- Recognition awards (e.g. from high level politician) for practical accomplishment

Direct Subsidies

- Long term borrowing by the government
- Interim financing, short term tax exempts, commercial paper or other short term negotiable instruments
- Tax on CO₂ produced in fuel consumption (and eventually CO₂ produced from other sources as well)
- Increase fuel excise duty
- Increase in vehicle registration tax for all vehicles or differentiating according to emissions.
- Direct funding of H₂ infrastructure projects
- Tax credits on investment to encourage more R&D, VAT credits or refunds providing flexibility for creating consumer demand or infrastructure construction in clean transport technologies
- Tax credits aimed at rental and/or lease car fleets

Cross subsidies

- Redirecting a share of tax revenues towards H₂ technologies e.g.:
 - Fuel excise duties
 - Charges used to fund energy efficiency and/or other types of public goods research programmes
 - Funding for local air quality programmes (e.g. in busses, retrofits, scrappage)
 - Penalty revenues from violating air quality laws

Market based mechanisms

- Franchise concept
The franchise concept of distributing products from large fuel companies via smaller, independent third party operators could be established when the pace of hydrogen fuelling demand is large enough so that returns, relative to costs, are seen as competitive against other, more conventional investment opportunities. An auctioning mechanism limiting strategic access to the infrastructure might raise enough capital *if* large energy companies see early stage participation as a strategic necessity.
- Investigating alternative business concepts
- Managing Strategic Business Relationships
This sensitive measure creates mandates and/or inducements for parties in incumbent technologies (conventional fuel) to accommodate and encourage smaller companies with admittedly disruptive (against vested interests) ambitions.

Non-profit

- Financing from non-profit organisations and private corporations engaged in public benefit projects
- Give these organisations tax exemptions or other incentives to move towards investing in H₂ infrastructure
- Public-Private partnerships (already there at EU-level)

Mandates relying on private resources

- Incumbent supplier mandates
Force investments by energy companies and fuel suppliers into H₂ supply infrastructure. Mandates could also be applied to fuel suppliers, industrial gas companies. Examples:
 - Require incumbent fuel suppliers to increase the number of H₂ fuelling stations as vehicle penetration reaches a certain level
 - Require fuel suppliers to add H₂ fuelling capability as a condition of obtaining new or renewed permits for their fuelling facilities
 - Mandates could focus on geographical areas lagging behind
- Private Fleet Operator Mandates
Require private fleet owners to purchase or operate a certain amount of H₂ vehicles.

Mandates relying on public resources

- State and/or Local Agency Mandates
 - Require public captive fleet owners to purchase H₂ vehicles and deploy infrastructure with public access
 - Government fleet or fuel procurement standards might be employed

Reinforcing mechanisms also include measures in case a particular policy goal cannot be made on a voluntary basis or by introducing incentives. In that case the following ‘kill or cure’ remedies may need to be established.

- Mandates for H₂ use and fuelling capability at high volume sites: airports, seaports, mail facilities. Mandates for use of H₂ in busses and specialty vehicles.
- Require all H₂ fueling facilities in The Netherlands to be available to all safety certified users.
- Include H₂ vehicles in renewable portfolio standard (obligation system)
- Eliminate all taxes/fees/restrictions for H₂-fueled vehicles and fuels, e.g. fuel excise and sales tax, registration tax, tolls, parking fees
- Require electric utilities to provide discounted rates for power used in H₂ production
- Create H₂/renewable energy infrastructure development fund
- Buy out certain levels or types of liability claims for H₂ equipment suppliers, vehicle OEMs and/or fuelling stations
- Participation of the state in vehicle development programme with OEMs.