Development of an alternative fuel infrastructure: What H_2 can learn from LPG

The case of LPG/CNG in the Netherlands and other countries

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ECN-E--10-037

April 2010

Acknowledgement

This report is part of the THRIVE project, a study on the possible build-up of a hydrogen infrastructure in the Netherlands. The study is jointly carried out by ECN, Shell, Linde and TNO. Within ECN, the units Clean Fossil Fuels and Policy Studies contribute to the project. THRIVE is financed by Agentschap NL within the EOS-LT program under contract number EOSLT06025. The authors would like to thank Ynke Feenstra (ECN) for thoroughly reviewing earlier versions of this report and Coen Hanschke, Marcel Weeda, Pieter Kroon, Ruth Mourik (ECN) and Koos Ham (TNO) for additional comments. This project is registered by ECN under the number 7.7897. Contact person for this publication is Ingo Bunzeck, email: bunzeck@ecn.nl.

Abstract

The introduction of an alternative transport fuel always bears a challenge that is often referred to as a ‘chicken and egg’ problem: while people will only become interested in and start switching to a new fuel if sufficient refuelling stations are available, industry will only start investing in the development of a refuelling infrastructure if the market is sufficiently developed and existing stations are economically viable. Governments have a variety of, for example, fiscal or regulatory measures at hand to facilitate and support the introduction of an alternative transport fuel.

This report describes and analyses the introduction of liquefied petroleum gas (LPG) or compressed natural gas (CNG) in the Netherlands, Germany, Poland, Canada and Argentina. In particular, the report pays attention to the development of station coverage and vehicle numbers for these alternative fuels. Drivers and barriers to the introduction of LPG or CNG, such as fuel price developments, supporting policy instruments or a lack thereof were identified. Main focus are the Netherlands where LPG was introduced in the mid-1950s. A comparison of developments in the Netherlands with the other four countries reveals that well concerted efforts by policy makers and industry supporting a parallel development of vehicle uptake and refuelling station availability may lead to the firm establishment of an alternative fuel market. The report concludes with lessons learned for the introduction of hydrogen as an alternative transport fuel.

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Executive Summary

The objective of this report is to identify the drivers and barriers for the development of alternative fuels and fuel infrastructures in several countries in order to excerpt several 'lessons learned' for a future introduction of hydrogen as alternative transport fuel in the Netherlands. The report is based on research of literature and (online) statistics databases and interviews as well as shorter personal communication with experts on the topic. Main theme of this report is how refuelling station coverage advanced, stagnated or regressed, how vehicle numbers in- or decreased over time, what policy instruments were applied and what their effects were. Focus is on the introduction of liquefied petroleum gas (LPG, or auto gas) as an alternative fuel in the Netherlands. Additionally, the development of an alternative fuel in terms of infrastructure and vehicle numbers is followed in Germany (LPG) and Poland (LPG) and in Canada (Compressed Natural Gas, CNG and LPG) and Argentina (CNG).

These countries were selected for two reasons. First, data and figures for these countries were readily available to the authors of this report. Second, each of these countries presents a specific constellation of policies, context and success of the alternative fuel that allows to draw conclusions to important success factors. Policies and market introduction strategies of each of these four countries are compared to those of the Netherlands. This analysis provides useful information for a 'plausible' market introduction and refuelling infrastructure build-up of hydrogen as an alternative fuel in the Netherlands. However, it has to be emphasised that these different alternative fuels, i.e. LPG, CNG and hydrogen cannot be compared one-to-one as there are technical, economic, social and other differences associated with each of them. Additionally, times when and contexts where these fuels have been or will be implemented vary greatly. It is beyond the scope of this report to analyse differences in production and distribution systems of LPG and CNG, neither does it pay much attention to the social acceptance of a particular fuel. Instead, developments in terms of station and vehicle numbers and differences between countries are described generally. A comparison of these developments allows to produce valuable insights into the introduction of alternative fuels in general and the commercialisation of hydrogen as alternative transport fuel in the Netherlands, in particular.

History of LPG in the Netherlands

The introduction of LPG as transport fuel started in the Netherlands in 1954. The initiative came from an importer of American trucks that ran on LPG as well as petrol and that were to be introduced to the Benelux market. Refining companies, a prominent industry branch in the Netherlands, saw their chance to generate additional income by selling LPG which is a by-product in the oil refining process. The Suez Crisis of the 1950s and the oil crisis of the 1970s caused the global oil price to increase significantly. Therefore, fuel prices at the pump soared also in the Netherlands. This created a price advantage for LPG compared to other fuels and helped LPG to establish a quick foothold in the market. LPG was available at about 100 refuelling stations by the end of the 1950s, 200 (~2%) by the end of 1960s and 5500 (~50%) by the end of the 1970s. The corresponding share of vehicles driving on LPG changed from 0.5% in the 60s and peaked at 11.5% in the 1980s. In the same decade station numbers dropped to less than half - from about 5500 (~50%) to about 2400 (~30%); mainly due to the fact that the trend went from small, single-fuel stations to large, multi-fuel and multi-pump stations. Despite these promising early developments, during the 1990s a steady decline of vehicle conversions to LPG set in. Nowadays, LPG cars only have a share of about 2% of the Dutch market but 40% (1800) of all fuel stations in the Netherlands still offer LPG.

Drivers and barriers

In the Netherlands, LPG became an initial success mainly for two reasons: (1) it was supported by industry gaining additional income by selling an otherwise flared by-product of refinery processes; and (2) LPG offered clear price advantages to its users. Additionally, the two other available fuels, petrol and diesel, were still suffering from technological shortcomings in terms of fuel efficiency and environmental friendliness. At a time when about 60 stations were in operation in the Netherlands, the amount of stations offering LPG seemed to match people's requirements regarding fuel availability; vehicle conversions steeply increased from then on.

After the 1990s the use of LPG as transport fuel for Dutch passenger cars declined steadily. Several reasons for this development have been identified. The main one is the technological and environmental improvement of diesel engines which are the fiercest competitor for LPG in the high-mileage vehicle sector. Instead, LPG technology only improved in terms of its emissions, but hardly in terms of its efficiency. Maintenance costs for LPG cars also tend to be higher because they are usually driven as high mileage vehicles although they were not designed as such. Additionally, by-products of refinery processes can nowadays be transformed to fuels with higher energetic value and hence be sold at a higher price. Therefore, industry's interest to offer LPG as an end-product has declined. The only change to the advantage of LPG as transport fuel is the availability of more LPG models ex factory.

Policy measures supporting the use of LPG as transport fuel were only introduced in the 1980s but never sufficed to create cost advantages for LPG over diesel. Instead, diesel, its main competitor in the high-mileage sector, performs superior in terms of tax, fuel and maintenance cost and vehicle residual value. Therefore, also the commercial sector is hardly interested in LPG, as interviews with leasing companies and a fleet operator have shown. A detailed cost analysis revealed that the cost advantage of LPG over petrol and diesel is rather small and limited to a range of annual mileage in the range between 22000 - 24000 km per year. The Dutch LPG market could never regain its old strength and currently stagnates at about 2% for passenger vehicles.

Experiences in other countries

The case studies of Poland, Germany, Argentina and Canada show significant differences in developments following the introduction of LPG or CNG. The differences can mainly be attributed to national context, stakeholder constellations and actions, and policy measures. With a market share of over 13%, Poland currently has the largest LPG market in the European Union, mainly due to two reasons: fuel excise tax for LPG is very low in comparison to its competitors and vehicle conversions are cheap. Germany experienced a major growth of the LPG market following an industry offensive in 2004 and large infrastructure investments. These actions were supported by a long-term policy commitment in terms of vehicle tax reductions granted until 2018 and low excise tax to make LPG cost-competitive.

In Argentina over 20% of the passenger car fleet is currently driving on CNG after a steady and politically well orchestrated station and vehicle build-up commencing in the 1980s. Due to Argentinean natural gas resources a government action plan supported vehicle conversions and station construction by means of grants and still supports favourable excise taxes for CNG. Thereby, one of the worldwide most successful alternative fuel markets was established and maintained. Canada is discussed as an unsuccessful market introduction of alternative fuels as both LPG and CNG were introduced but never reached a significant market share. The Canadian LPG market developed slightly similar to the Dutch one, with an initially promising start and a steady decline to insignificancy beginning in the 1990s. The reasons, however, differ slightly: initially governmental support was rather high as conversion grants were offered to vehicle owners. By the time these grants were removed, however, petrol and diesel cars had made technological advancements and commercial fleet owners quickly switched to diesel. Excise taxes have been reduced for LPG and CNG alike, although generally low fuel excise taxes in Canada lower the effect of this measure considerably.

Discussion

Worldwide, the market share of alternative fuels varies greatly and is closely linked to policy frameworks in place. Generally, LPG or CNG only hold high market shares in countries where their main competitor diesel can only be driven less cost-efficiently or is banned completely. Cost-effectiveness of LPG or CNG can be improved by a number of means, e.g. by conversion grants, road tax reduction, or low fuel excise tax. In the Netherlands, the road tax reduction for LPG vehicles and the current excise tax on LPG as transport fuel do not render LPG competitive.

Generally, also 'softer' measures, such as awareness and education campaigns have shown to have a positive effect. These measures to improve social acceptance are only briefly touched upon in detail in this report and could not be researched and analysed in detail. Described developments show, however, that the market reacts quickly to changing policies and only long-term policy commitments in terms of low fuel excise tax help maintaining a high market share of an alternative fuel. With respect to the build-up of refuelling infrastructure and vehicle numbers policies supporting both simultaneously in order to orchestrate industry investments in stations and vehicles, seem to be most effective.

Implications for hydrogen

There are, of course, some similarities and differences that characterise LPG, CNG and hydrogen as fuels. During the 1950s, 60s and 70s private car ownership was less common than today. Additionally, the number of refuelling stations was a lot lower than nowadays and people were more accustomed to taking detours or driving extra time to reach a station. Therefore, conclusions for a market introduction of hydrogen based on experiences with LPG and CNG can only be drawn to a limited extent.

The fact that LPG and CNG are 'add-ons' to existing fuels and a vehicle conversion still allows people to drive on conventional petrol is very different to a 'one-fuel' only car that drives on the new alternative. Remaining flexible in terms of fuel and refuelling may work to the advantage of LPG and CNG. At the same time, the necessity to transform the transport sector and in the course of this transformation switch to alternative vehicles driving on hydrogen, electricity or other alternative fuels has been recognised by many governments worldwide. Issues such as climate change, security of supply and oil price volatility are higher and more persistent on current national and international agendas than they were some decades ago. Therefore, governments may be more willing to create favourable incentives schemes to support the introduction of alternative sustainable fuels.

A policy framework stimulating and helping to establish hydrogen as a transport fuel should address both, infrastructure and vehicle cost. At the same time, hydrogen can be promoted or even made obligatory along-side other zero-emission vehicles by containing or inhibiting competitors. Tighter emission regulations can help to limit the possibilities to comply for less desired competitors, such as diesel.

Supporting infrastructure policies include station construction grants or (initial) tax exemptions for station build-up. The development of a refuelling network needs to run parallel to that of vehicle penetration. Vehicle purchasing can also be supported by means of grants or tax exemptions. Most importantly, however, alternative vehicles need to be cost-effective on the road. Therefore, fuel excise taxes and vehicle road taxes need to be regulated in such a way that the desired alternative fuel outperforms conventional ones independent of distance travelled. By designing policies that support a parallel build-up of stations and vehicles, drivers' fuel availability concerns and industry's station viability concerns can be diminished. Policy plans for development of a hydrogen infrastructure should therefore be well coordinated, preferably with other (neighbouring) countries to ensure fuel availability abroad.

1. Introduction to the LPG/CNG case study

This report has been written within the THRIVE project that analyses the build-up of a possible hydrogen infrastructure in the Netherlands. The THRIVE consortium consists of ECN and TNO as research institutes as well as Shell and Linde Benelux representing the industry. It aims to provide plausible routes and technological options for a hydrogen infrastructure for refuelling of vehicles in the Netherlands. *'Plausible'* in this context does not only refer to cost and technical feasibility, but also explores other aspects, such as socio-economics, e.g. consumer behaviour with respect to the introduction of innovative technologies and other, non-technical reasons that need to be considered during the introduction process.

The project is based on the assumption that commercial roll-out of hydrogen vehicles and the development of the necessary infrastructure commence in the current decade (2010-2020). The 'plausible development' is then projected for the first 15-20 years after commercial introduction with a focus on hydrogen as a transport fuel for passenger cars and light duty vans, trucks and busses.

Part of the socio-economic research by ECN (unit Policy Studies) is a case study on the introduction of alternative fuels in different countries with a focus on the Netherlands, where LPG was introduced during the 1950s. The concept 'alternative' conveys that this case study deals with the analysis of the development of a newly introduced fuel when one or more others are already well established, also in terms of a 'mature' infrastructure. Therefore, the new, alternative fuel has to compete with a technically, economically, regulative and socially well established fuel-transport system.

This report first discusses the rationale for choosing LPG (and CNG) as the focus of this study and report (1.1), followed by the questions guiding the research (1.2), and the applied methodology (1.3). The second chapter provides a general introduction to policy incentives and their effects. The third chapter includes a historic overview of the introduction of LPG in the Netherlands and of LPG and CNG introductions in four other countries in and outside of the EU. The fourth and final chapter presents conclusions that can be drawn for hydrogen based on a comparison of more and less successful introductions of LPG and CNG and accompanying policy measures.

It is taken into account that the introduction of LPG/CNG took place in a very different setting and at a very different time than the roll-out of hydrogen will. For example, current norms and perceptions of environmental conservation and oil depletion were less regarded and of different shape five decades ago. Furthermore, the refuelling system appeared and operated very differently 50 years ago than it does nowadays. In addition, energy systems and energy as well as transport policies have undergone dramatic changes during the same period of time. In other words, conclusion made concerning LPG or CNG cannot and will not be applied to the case of hydrogen one-to-one.

1.1 Rationale for an LPG/CNG case study

Liquefied petroleum gas (LPG) and compressed natural gas (CNG) have been introduced in various countries worldwide in previous decades. The success of their introduction varies greatly between countries, however. Therefore, this report aims to show which (economic, political and social) conditions were most favourable for the introduction of LPG and CNG as alternative fuels. Due to the fact that the THRIVE project has a clear focus on the Netherlands, the introduction of liquefied petroleum gas (LPG) in the Netherlands in the mid 1950s will be handled as a show case for the introduction of an alternative fuel into an already existing driving and refuelling system. Through a comparative analyses of the introduction of alternative transport fuels, of how they were managed, and which (contextual) factors quickened or hampered their market performance, 'lessons learned' on alternative fuel introduction can be formulated for hydrogen.

The focus of this case study are LPG and CNG, since there are some parallels with hydrogen: first, they were both, LPG and CNG, alternative fuels which required the build-up and establishment of a new infrastructure. Second, both are available in liquefied and gaseous form. Third, in competition to longer established fuels, LPG and CNG are nowadays both advertised as more environmentally friendly due to lower emissions.[1]

Nevertheless, there are a number of differences between the cases of LPG and CNG, on the one hand, and hydrogen, on the other: First, while each of these fuels can be used to power an internal combustion engine, hydrogen is mainly planned to be used in fuel cell applications. Second, LPG and CNG can be used in cars retrofitted appropriately, while hydrogen will only be available as original equipment manufacturer (OEM) vehicle. Third, while vehicles running on LPG or CNG produce slightly lowered greenhouse gas and nitrous oxide emissions, hydrogen is a zero tailpipe emission solution. Fourth, LPG is a by-product of oil refinement; CNG also only requires minimal refinement of natural or biogas, while hydrogen can be produced in chemical, electrolytic, thermolytic, photolytic or biological processes (Rijswijk, 2009). Fifth, LPG and CNG are most commonly distributed by trucks, while hydrogen is planned to either be distributed by pipelines, trucks or to be produced on-site. Insights for hydrogen can be gained by studying the introduction of other, alternative gaseous fuels, while differences have to be kept in mind. This issue is revisited in the concluding section at the end of this report.

1.2 Research questions

The previous chapter concludes that a study on the introduction of LPG in the Netherlands and LPG and CNG in other countries can yield important lessons for a research on the introduction of hydrogen. LPG and CNG have now been available for several decades. It is not only possible to study the introduction of the alternative fuel as such but also to observe and come to conclusions concerning reasons for more or less successful developments. The main focus of this report is on the introduction of LPG in the Netherlands, due to the fact that the THRIVE project has the same country-specific focus. The analysis of the developments in other countries mainly serves to broaden and deepen the insights gained. The research questions guiding the report at hand can be formulated as follows:

1. How did the use of LPG as alternative fuel and its supporting infrastructure develop in the Netherlands?
2. What were the main driving and hampering factors in this development?
3. What other experiences with LPG/CNG do some other countries have?
4. What are strong supporting structures that work in favour of the introduction of an alternative fuel?
5. What can be 'lessons learned' for the development of a hydrogen infrastructure and the introduction of hydrogen powered vehicles (taking into account the shortcomings of an LPG/CNG - hydrogen comparison)?

[1] Autogas outperforms petrol and diesel as well as most alternative fuels in the majority of studies comparing environmental performance that have been conducted around the world. Autogas emissions are especially low with respect to noxious pollutants. With respect to greenhouse-gas emissions, autogas performs better than petrol and, according to some studies, outperforms diesel, when emissions are measured on a full fuel-cycle basis and when the LP Gas is sourced mainly from natural gas processing plants, World LP Gas Association

1.3 Methodology

This report is fully based on desk research and interviews. Relevant publications from the Netherlands and the rest of the world have been used as resources. In order to trace and graphically depict the developments of infrastructure and vehicle numbers, the Dutch Central Bureau of Statistics (CBS) has been consulted and experts abroad, e.g. in Germany, have been contacted. Finally, several interviews have been held over the phone or via email with experts to receive additional information, e.g. on reasons for success or failure of alternative fuels in the Netherlands, Germany, and Argentina.[2]

[2] A full overview of the organisations contacted for interviews can be found in the Appendix A to this report.

2. Introduction to policy measures and their effects

Consumers' decisions for a particular fuel and hence vehicle type depend on a number of factors. Vehicle and fuel price, but also fuel availability play a large role. Policy measures, e.g. in terms of taxation schemes can play a key role when it comes to vehicle and fuel price (WLPGA, 2005). If a vehicle is more expensive, incl. associated taxes, as e.g. diesel compared to petrol in the Netherlands, it may still be economically interesting for people travelling more kilometres by car per year, profiting from a lower fuel price of diesel per km. In other words, vehicle and fuel price together with road and excise taxes, define the break-even point of different types of fuels. With respect to the introduction of a new alternative fuel, policy measures can influence the monetary or economic point of break-even with already established fuels.

In an international comparison LPG is by far the most widely used alternative fuel worldwide. Its use is rather concentrated, however: Korea, Japan, Australia, Turkey and Poland together account for more than half of global LPG consumption. In Poland, over 16%, and in Korea, Bulgaria, Turkey and Lithuania over 10% of the cars drive on LPG. In other countries, the share of LPG is rather low, e.g. the Netherlands show a share of about 2% (CBS, 2009) and the US only 0.1% (WLPGA, 2004). The following table displays a recent overview of the globally largest LPG markets:

Table 2.1 *LPG markets 2003*

Country	Consumption [ktonne]	Vehicles [x 1000]	Refuelling sites
Korea	3 740	1 723	1 242
Japan	1 528	290	1 900
Turkey	1 260	1 000	4 000
Australia	1 213	492	3 240
Italy	1 202	1 220	2 150
Mexico	1 200	450	1 400
Poland	1 070	1 100	4 500
Russia	780	550	470
Netherlands[3]	440	289	2 150
United States	730	190	4 300
China	500	115	285
Rest of the World	3 282	2 110	14 639
World	**16 445**	**9 416**	**39 641**

Source: WLPGA, 2004.

Figures of the use of CNG as an alternative fuel are similarly varied. While CNG is available and used as fuel in over 60 countries almost 80% of the global consumption of CNG as transport fuel is distributed over only six countries: Pakistan (21%), Argentina (17%), Brazil (15%), Iran (15%), India (7%), and Italy (5%). In the Netherlands, only about 1.500 vehicles (0.01% of the total Dutch passenger car fleet) drive on CNG.

The large difference in LPG and CNG penetration rates largely depends on differences in policy incentives supporting or discouraging the use of an alternative fuel. The most effective policies are those that make LPG and/or CNG more competitive compared to already established fuel alternatives, such as petrol, diesel and thereby create a financial incentive for drivers to switch. The length of pay-back time for the vehicle conversion to an alternative fuel such as LPG or CNG is rather sensitive to governmental taxation systems for road, but even more so for fuel

[3] 2003 figures from the Netherlands retrieved from CBS (2009).

excise taxes. These dependencies are shown, for example, in the relation of pay-back times and vehicle penetration rates, which are highest in those countries with the lowest break-even points[4], e.g. Bulgaria, Korea, Lithuania, Turkey and Poland, and lowest in those where LPG is least competitive to petrol and diesel, such as Canada or the U.S. The table below provides a classification of tools and policy incentives available to governments for the promotion of alternative fuels.

Table 2.2 *Typology of government policies and measures to promote alternative fuels*

Fiscal/financial	Regulatory	Other
Excise-duty exemption or rebate	Mandatory sales/purchase requirements for public and/or private fleets (with enforcement)	Government own-use of alternative fuel vehicles (AFVs)
Road/registration-tax exemption or rebate	Standards to harmonise refuelling facilities	Information dissemination and public awareness campaigns
Vehicle sales-tax exemption or income/profit tax credit (purchasers and OEMs)	Vehicle conversion standards	Voluntary agreements with OEMs to develop and market AFV technologies
Tax credits for investment in distribution infrastructure and R&D	Coherent and appropriate health and safety regulations	Direct funding for research, development, demonstration and deployment of AFVs
Grants/tax credits for AFV conversion/acquisition	Exemptions from city-driving restrictions	
Rapid depreciation for commercial purchasers of LPG vehicles and owners of distribution infrastructure	Environmental restrictions (e.g. emission regulations)[5]	
Exemption from parking/road-use charges		

Source: WLPGA, 2004.

A long-term policy commitment to a certain fuel is beneficial in several ways: It creates a sense of price security, comparatively competitive costs and hence also commitment by consumers. How closely consumer and policy commitment are related and how swiftly consumers react to policy changes became obvious by a sudden decrease in vehicle conversions and LPG consumption in Australia six years ago when the government proposed an excise duty on LPG.

There are also other factors than current or projected price competitiveness that play a role in people's decision to opt for LPG or CNG as fuel or not. Some of these factors are policy related and have proven to be successful, as for instance public awareness and education campaigns in the U.K. or mandates and public transportation fleet conversion programmes in China and the U.S.. An important boost to the LPG industry has been (environmental) restriction on the use of diesel cars, as for example in Korea or Japan. Other important factors that can contribute to or hinder the establishment of a strong LPG market are of course the availability of cars and vehicles. Additionally, the LPG market in some countries, including the Netherlands, suffers from a

4 The break-even point refers to the specific distance that needs to be covered in order to drive one car as cost effective as a similar car driving on another fuel. This distance is different in every country, due to the fact that vehicle cost, road, vehicle purchasing and fuel excise taxes vary across countries.

5 This table does not provide an exhaustive list of policy measures but a general overview of the main (most widely used) measures. 'Environmental restrictions' was added by the authors to the table developed by the WLPGA.

negative public image of LPG related to safety and reliability of vehicles and the decrease of trunk space due to the LPG installation.

Overall, the role of policy measures is crucial for achieving critical mass and a stable alternative fuel market in a country. Appropriate measures depend on national context. In case of LPG, however, a tax policy favouring LPG over conventional fuels seems to be the most effective measure, independent of national context. Beyond strategic policy measures, the efforts of other stakeholders such as vehicle manufacturers, converters and fuel suppliers are needed to convince consumers of LPG as a safe, reliable and cost-effective alternative to conventional fuels.[6] In the following, case studies of several countries are described: First, the Netherlands are discussed as the main focus of this report. In the EU, Poland currently has the largest share of LPG vehicles. The other European example discussed is Germany that experienced a sudden surge in the LPG market following successful industry initiatives in 2004. The other two cases analysed are Argentina as an example of a very successful and strongly policy driven alternative fuel market and Canada as a country were both, CNG and LPG could not gain ground as alternative fuels. Each of these five cases is briefly outlined, in order to allow a comparison in types and effectiveness of different policy measures and other factors contributing to or hampering a successful introduction of an alternative fuel. Thereby, recommendations concerning the introduction of an alternative fuel in the Netherlands, such as hydrogen, can be made.

[6] World LP Gas Association and Menecon Ltd. (2005) Autogas Incentive Policies - A country-by-country analysis of why & how governments promote autogas and what works. Paris: World LP Gas Association SARL.

3. Lessons learned from gas powered vehicles

3.1 LPG in the Netherlands

3.1.1 1950s

The introduction of LPG as transport fuel started in the Netherlands in 1954. The initiative came from an importer of American trucks that were to be introduced to the Benelux market and able to run on LPG. Most parts required to install LPG refuelling stations were imported from the USA or Germany. The the Dutch company BK-Gas became the first importer and supplier of LPG in the Netherlands (De Jong, 1994). The first two years take-up was slow, but then gained significant momentum with the Suez Canal Crisis which caused a sudden increase in petrol prices. Due to the crisis, LPG was a lot cheaper at the fuel pump and hence a lot more cost-effective than previously. During these first years, LPG stations numbers increased from 13 in 1954, to 25 in 1955 and to 50 in 1956. The initial 13 stations[7] were located in: The Hague (2), Amsterdam (2), Groningen, Venlo, Breda, Alkmaar, Hengelo, Geleen, Beverwijk, Barneveld and one in the province of Zeeland. The following figure provides an overview of their spatial distribution:

Figure 3.1 *Geographical distribution of the first 13 LPG stations in the Netherlands in 1954*

One major obstacle during the first decade after introduction was a lack of support by larger oil companies. Only in the aftermaths of the blockage of the Suez Canal three large oil companies (i.e. Shell, Esso and Caltex) showed interested in introducing LPG to their portfolio (De Jong, 1994). A lot of oil, gas and refinery industry is located in the Netherlands and the surrounding waters of the North Sea. Due to the fact that LPG is a by-product of refinery processes which

[7] An indication of how this number relates to the total amount of refuelling stations available in the Netherlands at that time would have presented a helpful reference. However, this information cannot be provided due to a lack of data. Whenever possible percentages are included in the following.

previously had been flared, the opening of a market for LPG as transport fuel meant additional profit for a readily available product (Rijkeboer, 1982).

1956 brought the first break-through for LPG in the market for delivery trucks and vans due to first sufficient infrastructure coverage (Rijswijk, 2009). Since cars fitted with LPG systems are still also able to run on regular petrol, delivery services and holiday travellers were still able to drive abroad despite a lack of LPG refuelling infrastructure (Rijkeboer, 1982). Of course, the investment for retrofitting petrol engines with LPG installations only pays off if the vehicle is mostly driven on LPG. Initially, sufficient stations could only be found in the Benelux countries. Considering the increasing growth of the passenger car market at the time, numbers of LPG vehicles increased only slightly in what can be considered a niche market (Rijswijk, 2009).

One reason why LPG initially remained a niche market was the lack of policy incentives for station build-up or for vehicles. On the contrary, the incumbent fuel leaded petrol was favoured over LPG by means of a road tax based on the weight of a car. Vehicles equipped with an LPG system are heavier than the same model without such a system and hence had to pay a higher road tax (Rijswijk, 2009). However, some political movement took place during this first decade: a propane commission was established to develop (safety) guidelines for LPG stations. This first regulatory framework with station safety guidelines facilitated infrastructure build-up in the following decade (De Jong, 1994).

By the end of the decade 100 LPG stations were in operation in the Netherlands. BK Gas had understood the importance of fast infrastructure development and initiated an ‘early bird’ incentive by making those who join the refuelling network early ‘key dealer’ of a region. As a consequence another station was only allowed to open in the same region with approval of the already existing one and was required to pay fl. 0.01 per litre to the regional ‘key dealer’.

3.1.2 1960s

The Dutch passenger car market experienced a major boom during the 1960s. Although LPG cars remained a fraction of the overall market, vehicle uptake in the Netherlands was viewed as success in comparison to those in Germany, Belgium, or Sweden. Passenger cars remained a niche market with a share at the end of the decade of about 1.5% (CBS, 2008). Focus of LPG activities was on light trucks, forklifts and vans, while heavy trucks increasingly drove on diesel. The number of LPG system or component producers and suppliers also increased, while the number of LPG distributors stabilised (De Jong, 1994).

On a regulatory level first guidelines for LPG stations were published based on a proposal made by the propane commission. Additionally, the Liquid Gas Association (VVG - Vereniging Vloeibaar Gas) was founded as a Dutch intermediary organisation and on European level the Association European LP Gas (AEGPL) was set up. Both organisations aimed at advancing the use of LPG, e.g. by providing policy advice on a national and international level (Rijswijk, 2009).

3.1.3 1970s

The 1970s bring the big break-through of LPG on the passenger car market. Generally, the number of privately owned vehicles again increased in the Netherlands with the share of LPG cars rising significantly, from only 1.5% in the beginning to 7.5% by the end of the decade (CBS, 2008). Reasons for this increase in market share may be, on the one hand, rising environmental awareness during the 1970s among the public and, on the other hand, favourable price conditions at the pump. Following the first oil crisis, the price for petrol and diesel increased significantly, rendering LPG a financially attractive alternative. Following the increase in demand, a steep increase of station numbers could be observed: The number of LPG stations increases from 220 in 1970[8], to 580 in 1975, to approximately 1350 in 1977. In 1980 there are already 5500 LPG stations in the Netherlands (CBS, 2008).[9]

The suspension of a law that did not allow selling LPG and other fuels at the same station facilitated station build-up. From then on stations were allowed to offer the complete fuel portfolio. Following increasing demand and improved regulatory framework, the number of LPG distributors and suppliers increased alongside the number of LPG system or component producers and suppliers. A propane sub-commission to advice the government on LPG safety issues was created. Additionally, at the end of this decade, the Dutch Organisation for Applied Scientific Research (TNO) was authorised to conduct a fundamental risk analysis on LPG as a transport fuel (Rijswijk, 2009). In other words, LPG became more accepted as transport fuel in policy circles, and measures were taken to govern developments safer and more strategically in the future.

3.1.4 1980s

In the beginning of the 1980s, the Dutch LPG industry agreed to make large investments (~75 million €) in safety measures while the government aimed to make these investments cost-effective by ensuring continuity of the LPG market segment in the Netherlands. The increase of the vehicle road tax for LPG cars in 1982 (BP nieuwsbrief) was accompanied by a 'gentlemen's agreement' between industry and government to keep the break-even point[10] of LPG with petrol at mid-80s levels (~18300 km) in the coming years. However, vehicle conversion costs increased, due to more complex motor and electronic technology of cars. At the same time, petrol engines made great advancements in terms of fuel efficiency. Therefore, the break-even point of LPG with petrol increased to 23300 km despite the earlier made 'gentlemen's agreement' (De Wit, n.d.b). Related to the issue of decreased cost-efficiency, LPG could not profit as much from the growth of the Dutch passenger car park as it could during previous decades. Besides, diesel developed to a serious competitor, offering economic driving to people who travel many kilometres by car. With unleaded petrol a new competitor in terms of environmental performance entered the market (Rijswijk, 2009) and petrol engines equipped with a three-way-catalyst provided better emission values than cars without catalyst, but also than cars running on LPG. These developments called for technical improvements of LPG systems if the market was to be kept alive. New '3rd generation' LPG technology was developed by two Dutch companies, with financial contributions from BK Gas, LP Gas, the Dutch Ministry of Economics and some EU funding. The new systems with computer-controlled direct injection of liquid or gaseous LPG created higher conversion cost, but provided better fuel efficiency and emission values. Nevertheless, the break-even-point of LPG with petrol remained above 23000 km. Therefore, the Dutch LPG industry, world-leading in LPG equipment for vehicles at the time, demanded a new fiscal treatment of LPG in the Netherlands (De Wit, n.d.a), also referring to the earlier made 'gentlemen's agreement'.

An important development for the Dutch LPG infrastructure was the establishment of a law ('Besluit LPG-tankstations Hinderwet') on standardised technical requirements of LPG stations based on results of the TNO risk analysis (De Jong, 1994). In order to decrease risks to the public, safety distances of 80 metres were between the fuelling station and nearby houses and other objects. In some cases where infrastructural modifications were not feasible shorter distances (to 25 m) were tolerated. In urban areas it became mandatory for station owners to move LPG storage tanks underground.[11] Generally, an infrastructure trend can be observed away from many small and very locally operating stations to larger ones positioned at strategic places. The number of refuelling stations offering LPG decreased during that time from 5500 in 1980 to 2400 in

8 For comparison, the total amount of stations in the same year was 13 000.

9 In 1980, the Dutch refuelling infrastructure consisted of 10 500 stations in total.

10 The break-even point describes the moment when cost or investments and savings or revenues are even. With respect to the comparison of petrol and LPG cars it refers to the amount of km one needs to drive on LPG in order to have recovered the increased purchasing and maintenance (and often also tax) costs.

11 Personal communication, Koos Ham, TNO

1985. Additionally, standards for LPG vehicles and systems were set on European level (ECE, 2008). At the end of the decade, the percentage of LPG cars to the total amount of privately owned passenger cars was around 11.5% (CBS, 2008) while the infrastructure of refuelling stations and LPG system manufacturers and equipment suppliers and retro-fitters regressed (De Jong, 1994).

3.1.5 1990s

In the early 1990s LPG prices increased dramatically due to a number of reasons: due to necessary maintenance work at gas fields in the North Sea European production decreased and the Netherlands were forced to import more LPG from the Middle-East. This source almost ran dry for the duration of the Gulf-war (1990/91) while European gas demand for heating purposes was unusually high due to a cold winter in 1990/91. Although these developments caused price increases for all fuels, LPG prices experienced a stronger increase than other ones. As an almost immediate response, LPG conversions dropped by 25% in the first quarter of 1991. All events leading up to the price increase ended at a similar time, and as soon as the First Gulf war, gas field maintenance work in the North Sea and the cold winter in Europe were over, fuel prices relaxed. An increased vehicle road tax was implemented for all vehicles in the Netherlands. Following the ‘gentlemen’s agreement’ made in the early 80s and the cost increase for vehicle conversions with 3rd generation technology (De Wit, n.d.a), the new vehicle road tax for LPG cars was set to allow for a break-even point at 20.000 km (De Wit, n.d.b). This political change can partly be accredited to successful lobbying by the Dutch LPG industry who made clear that the only way to keep the strong position of LPG technology developed in the Netherlands worldwide was to ensure a strong home market (De Wit, n.d.a).

The downward trend of LPG as car fuel continued throughout this decade, however, despite fuel price relaxation, rising sales of passenger vehicles and growing environmental concerns. Main competitors (and market winners) were the two new types of unleaded petrol Euro 95 and Super Plus 98 and diesel with a low sulphur value (Rijswijk, 2009). These fuels have much lower emission values than their predecessors and hence met political and social demand for more environmentally friendly driving. Most long-distance drivers and frequent commuters opted for diesel in this decade, causing the overall market share of LPG to recede. At the end of this decade the percentage of LPG passenger cars has dropped to 5.2% (CBS, 2008).

The system of infrastructure and vehicle system producers and suppliers remained stable. However, fundamental research to strengthen the knowledge base on LPG was carried out by several Dutch institutes, such as TNO, NOVEM (Dutch governmental agency for energy and innovation) and the Technical University Eindhoven. Furthermore, a law (‘Wet Vervoer Gevaarlijke Stoffen’) was passed concerning safe trucking of LPG on Dutch roads, including technical standards and requirements (Rijswijk, 2009).

3.1.6 2000s

After 2000, the downward trend of LPG as fuel for passenger cars in the Netherlands continued and seems to have now stabilised at about 2%. In terms of infrastructure the earlier observed downward trend also continued. A law was passed by Dutch government that no longer tolerated safety distance exceptions that were still allowed in the 1980s.[12] This concerned about 250 stations which had to close down in the following years. 113 of these stations already removed LPG from their portfolio in the first year after this law was passed, causing the amount of stations to drop from 2150 in 2003 to 2037 in the following year. The number of LPG stations decreased slightly to 1900 in 2007 and 1800 in 2008. More than 40% of all stations in the Netherlands offer LPG by the end of this decade.

[12] Personal communication, Koos Ham, TNO.

However, in the same decade other political measures were taken to the advantage of LPG, e.g. a lowering of road taxes for LPG vehicles following the introduction of third generation LPG systems (G3 LPG) who produce lower emissions. Nevertheless, competitiveness of LPG was hardly increased by this change in taxation schemes as the following chapter on cost-effectiveness demonstrates.
Only during the past decade policy schemes changed for LPG with the introduction of two main tax incentives:

- The excise tax on LPG was reduced in 2002 and 2003 and has only marginally increased since then. For a comparison of excise taxes for LPG compared to the two other main fuels see Table 3.1.
- For LPG cars that have a third generation (G3) LPG installation (available since 1997) on board and adhere to the Euro 2 emission levels (in vehicles produced 1995 or later), the 'motorrijtuigenbelasting' (MRB), or road tax is lowered by € 317 per year while that of diesel is much higher.[13]

These two factors contribute to a lowered break-even distance compared to petrol. The following section deals with a detailed cost analysis, comparing the use of petrol, diesel and LPG under current policy and price conditions. Table 3.1 depicts the development of fuel excise taxation in the Netherlands over the last years. For each fuel the table shows in the first row the amount of excise tax consumers have to pay per kg or per litre at the pump and the second row displays how this translates into euro per km driven. Overall, fuel excise tax has only increased slightly over the past five years while the cost in terms of taxes paid per km are highest for petrol and lowest for LPG.

Table 3.1 *Comparison of fuel excise taxes in the Netherlands*[14]

Fuel	Excise tax	2005	2006	2007	2008	2009	2010
LPG	[€/kg]	0.10	0.10	0.10	0.13	0.13	0.15
	[€/km]	0.01	0.01	0.01	0.01	0.01	0.01
Petrol	[€/l]	0.68	0.68	0.69	0.70	0.71	0.72
	[€/km]	0.04	0.04	0.04	0.05	0.05	0.05
Diesel	[€/l]	0.37	0.37	0.38	0.41	0.42	0.43
	[€/km]	0.02	0.02	0.02	0.02	0.02	0.02

Interviews conducted with a small random sample of three players operating commercially used passenger vehicles in the Netherlands already indicate that the tax advantages do not suffice to convince people of switching to LPG. Two lease companies and one commercial car fleet owner were contacted in order to get first insights into the uptake of LPG for commercially used vehicles and the reasons they identify for and against using it.[15]

The commercial fleet user stated that an internal policy has been in place since 2004 that prohibited LPG cars in their fleet. The reason for this was a variety of reoccurring technical problems with LPG cars and related higher maintenance cost. Petrol cars work with spark ignition and suffer more material abrasion if LPG is burnt instead.[16] Currently, despite of possible technological advancements that might have solved some of these problems, there are no internal discussions to change that 'anti-LPG' policy.

13 Information from the Ministry of Housing, Spatial Planning and the Environment.
14 Source: CBS, The Netherlands.
15 See Appendix A for a full list of all people and companies contacted.
16 Based on information attained from TNO.

One Dutch lease company that has about 30000 cars under contract, of which 3% are driving on LPG reports no additional (technical) problems when comparing LPG to other fuels. For them it does not matter which fuel their customers opt for since they simply adjust the leasing rate based on the lower residual value of LPG vehicles and the extra cost of installing an LPG system.

The share of LPG vehicles at the second lease company contacted is about 5%. Here the lease rate for LPG vehicles is higher due to the initial extra investment for the LPG unit and an add-on for higher maintenance and repair costs. The residual value of an LPG vehicle is set even to that of the same car driving on regular fuel at the start of the contract. In other words, the initial investment in the LPG system is lost. It is admittedly always problematic to put a figure on the residual value of a vehicle after so many years, since the demand and price varies significantly depending on fuel price developments.

As a first guess why LPG is not well accepted among drivers, despite possible economic advantages, explanations given were the safety issues and negative technical image people often still attach to LPG.

3.1.7 An example of the current competitiveness of LPG with petrol/diesel in the Netherlands

Expected purchase, maintenance and operation cost of a vehicle are decisive factors for people when buying a car. It is often assumed that LPG cars in the Netherlands have a relative cost advantage compared to conventional fuels due to lower fuel cost and road tax. Although the retrofit of an LPG car is currently estimated to cost between €1500-3000, the lower operating cost due to decreased vehicle road and fuel excise tax should be able to recover the initial higher cost if a certain mileage is driven annually.

However, only a detailed cost comparison of an LPG, petrol and diesel powered car allow drawing conclusions concerning the most cost efficient annual mileage of a car. For this purpose, a calculation model has been created that considers all occurring costs during purchase and operation of three identical vehicles running on the three different types of fuel. The model operates on a total cost of ownership (TCO) basis that calculates all cost during a vehicle lifetime and divides it by its mileage.[17] The calculation model can be fed with different figures for the purchasing price, run-time and residual value of a vehicle as well as with a range of annual mileages. Thereby, the model can be used to calculate the break-even points for the different fuels based on different parameters. Input for the model is taken from the most recent available public sources. Taxation and official governmental tariffs have been checked with the respective authorities. Vehicle resale values have been estimated by means of online resale platforms. Of course, not all figures included are immune to error and in practice other costs differences than found can be encountered, e.g. due to variations in sales and resale price that may depend on the respective dealership. The outcomes presented here are, however, deemed rather realistic as they are well in line with current sources and comments made by interview partners in the context of this study.

For the comparison, an average medium-sized car, a Volkswagen Golf (model 09) has been chosen. Volkswagen also offers an LPG version directly ex factory which therefore excludes any additional LPG retrofit cost. In the official pricelist of Volkswagen Netherlands, the LPG version is only €200 more expensive than the petrol model. More details about some input parameters for the comparison can be found in Table 3.2.

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[17] For more information about the used calculation model, see Appendix B to this report.

Table 3.2 *Technical data for cost comparison VW Golf*[18]

		Volkswagen Golf , Version Trendline		
Model		Bluemotion 1.6. BiFuel LPG	Bluemotion 1.2 TSI	Bluemotion 1.6 TDI
Power	[kW]	75	77	77
Weight	[kg]	1222	1134	1214
Emissions	[gCO_2/km]	149	121	99
Tank capacity	[l]	Petrol: 55 LPG: 40	55	55
Sales price incl. taxes[19]	[€]	22850	22650	25450
Road tax[20]	[€]	764	472	1.096
Insurance premium p.a.	[€]	200	200	200
Maintenance p.a.[21]	[€]	1200	1000	1000

The comparison also assumes a theoretical vehicle lifetime of seven years and slightly higher (20%) maintenance cost for an LPG vehicle, e.g. due to valve damage.

Until an annual mileage of about 20300 km the model shows the lowest cost for the petrol car. In the considerably small window of an annual mileage between about 22300 and 24600 km LPG is the cheapest option. If a mileage above 24600 km is driven per year diesel turns out to be the cheapest fuel type. The calculation therefore shows that LPG is not the cheapest fuel for high mileage vehicles despite decreased road and fuel excise taxes in the Netherlands.

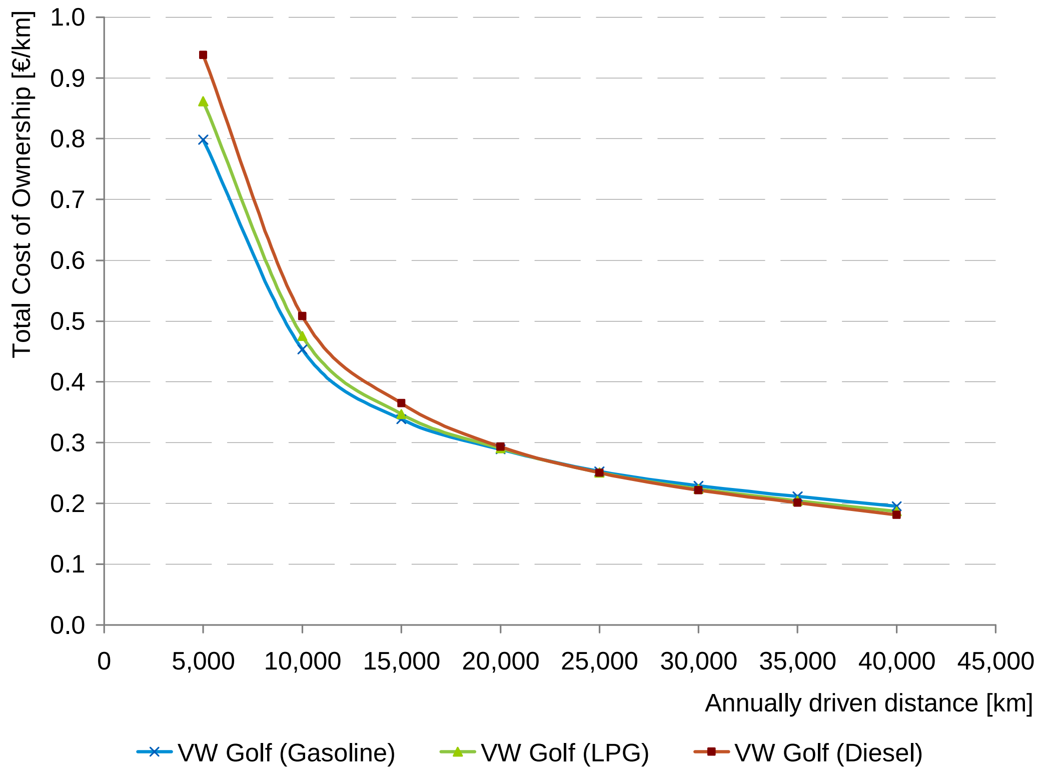

Figure 3.2 *Total cost of ownership of three VW Golf models (comparing petrol, LPG and diesel)*

18 Source: http://www.volkswagen.nl.
19 BTW (VAT) & BPM (Belasting op Personenauto's en Motorrijwielen = tax on passenger vehicles & motor bikes)
20 2010 figures
21 Estimated amounts

The calculation of total cost of ownership in €/km shows that the real cost advantage of LPG cars in the Netherlands is rather small. Only in a rather confined window of about 2000 km between 22000 and 24000 km/year is driving an LPG car the most cost-effective option. There are several factors that hamper the cost-effectiveness of LPG in comparison to its two competitors. In comparison to petrol, LPG cars are only slightly more expensive and require slightly higher maintenance investments, but they consume at least 10-20% more fuel due to the lower calorific value of LPG. The same reason diminishes the cost advantage of LPG over diesel, as diesel just like petrol engines have improved in terms of fuel efficiency in recent decades. Most importantly, the calculation has shown that current financial incentives that are in place in the Netherlands (lowered road and fuel excise tax for LPG cars) are insufficient to make LPG truly cost effective in comparison to diesel, its main competitor in the high-mileage sector.

It is unlikely that the 'average consumer' would conduct such a detailed cost analysis as this chapter is based on. Furthermore, the shown price advantage between LPG and diesel is rather small. Therefore, other factors which were not taken into account for this analysis such as image or the perception of risks linked to the use of LPG as car fuel might play a role in people's decision-making when deciding which car to buy, i.e. which fuel to drive on.

3.2 Summary and conclusions of the Dutch LPG case study - Implications for hydrogen

The initial start of LPG during the 1950s and 60s was hardly promising, despite the fact that the Dutch oil industry was interested in opening a new market for LPG, a by-product of refinery processes, as transport fuel. The oil crisis of the 1970s gave strong impetus to the use of LPG in the Netherlands as it created great price advantages for LPG over other fuels - no policy support was required. Starting in the 80s, however, the use of LPG slowly declined to a rather low market share, while diesel became the big market winner of the time. This development can, on the one hand, be accredited to the technical advancement of diesel engines. On the other hand, new industry processes allowing the conversion of LPG into motor spirits with higher energy content made the direct selling of LPG as end-product less attractive from a production point of view.

In the first decades after the introduction of LPG as transport fuel for passenger cars, policy measures were mostly concerned with safety issues and consequences for spatial planning. In the 1980s a loose agreement between industry and policy makers aimed to keep the break-even point of LPG with petrol in the same range as in the beginning of the decade. However, all measures taken in the following decades, such as reduced vehicles road tax and fuel excise tax for LPG failed to make LPG more cost-attractive for users. The hampered success of LPG at the market may (according to the fleet owner and leasing companies interviewed for this report) also be related the users safety concerns and the resulting negative image of LPG. Currently, LPG holds a share of only 2% of Dutch passenger vehicles. The following graphs and tables depict the history of LPG in the Netherlands described in detail earlier:

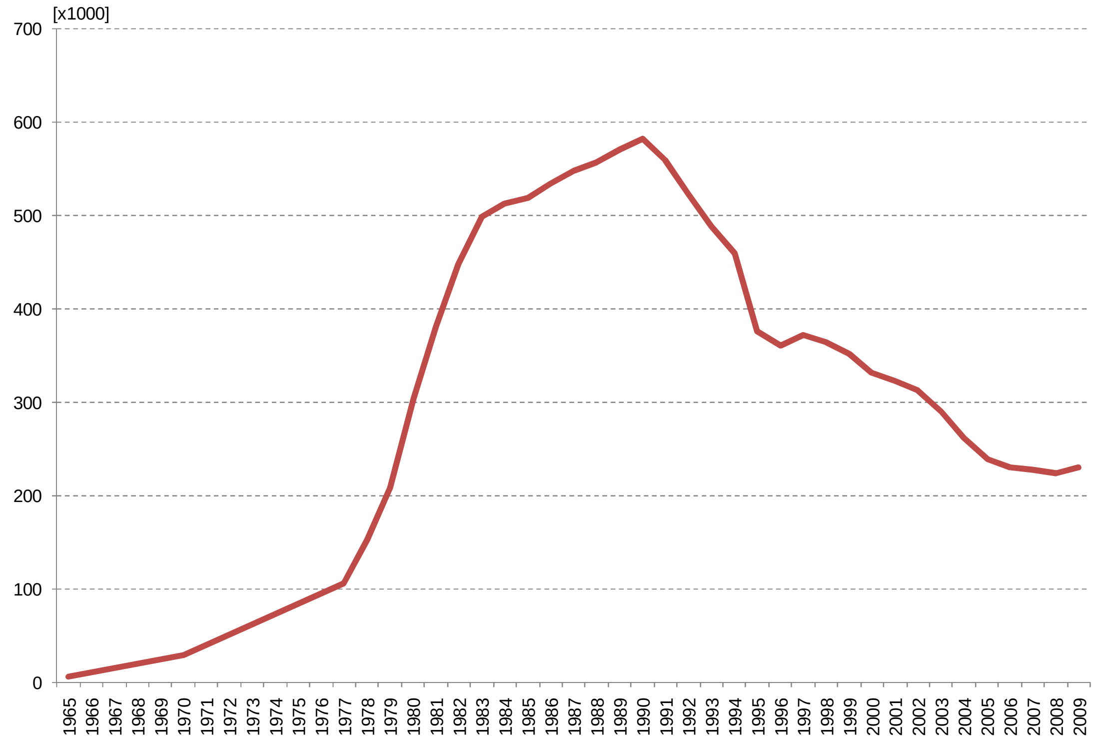

Figure 3.3 *Amount of LPG cars in the Netherlands 1965-2009*[22]
Source: CBS 2009.

Table 3.3 Development of LPG passenger cars and stations in the Netherlands (VRI23)

Year	LPG cars	LPG stations	Ratio cars/station	VRI
1956	105	50	2	0.002
1970	28860	220	131	0.131
1980	333000	5500	60	0.061
1985	524000	2400	218	0.218
2004	262000	2037	134	0.134
2008	224000	1800	119	0.124

[22] For some years (1966-1969; 1971-1976) data could not be retrieved.
[23] VRI refers to the vehicle-to-refuelling-station index and is defined as number of vehicles (in thousands)/number of refuelling stations. It is an indicator of the spatial density of a refueling infrastructure, the profitability of refuelling stations and therefore also the success of governmental policies. A VRI of 1 (1000 vehicles per refueling stations) stands for a mature infrastructure, profitable for its operators and supported by a suitable policy framework. A VRI below 0.2 can be measured in countries that continue to struggle with the alternative fuel (Yeh, 2007).

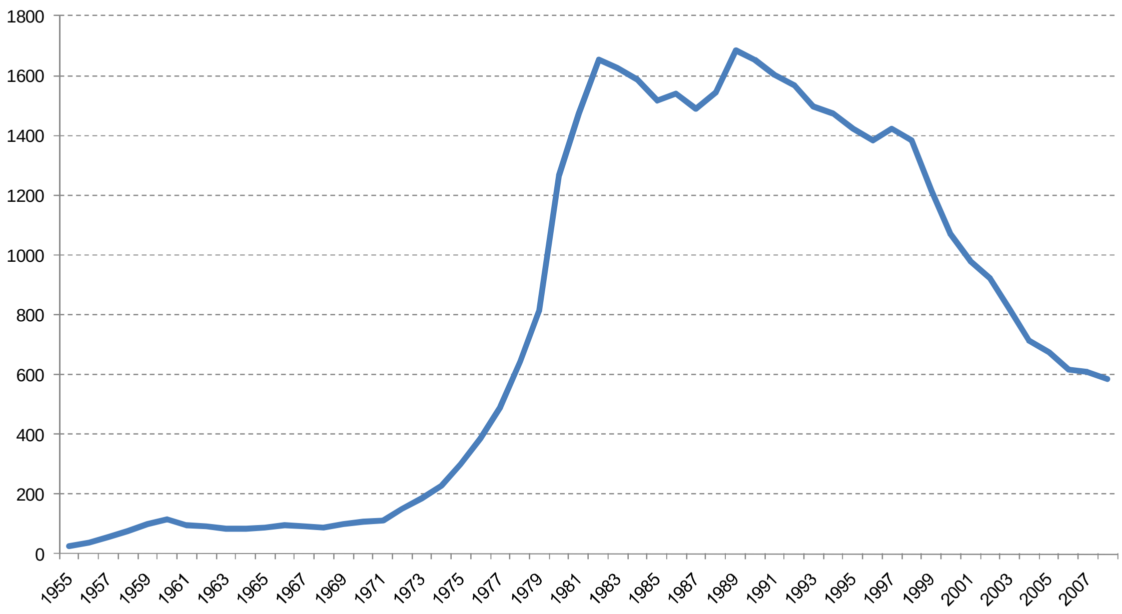

Figure 3.4 *LPG delivered to (and sold by) Dutch stations[mln l] 1955-2008*
Source: CBS 2009.

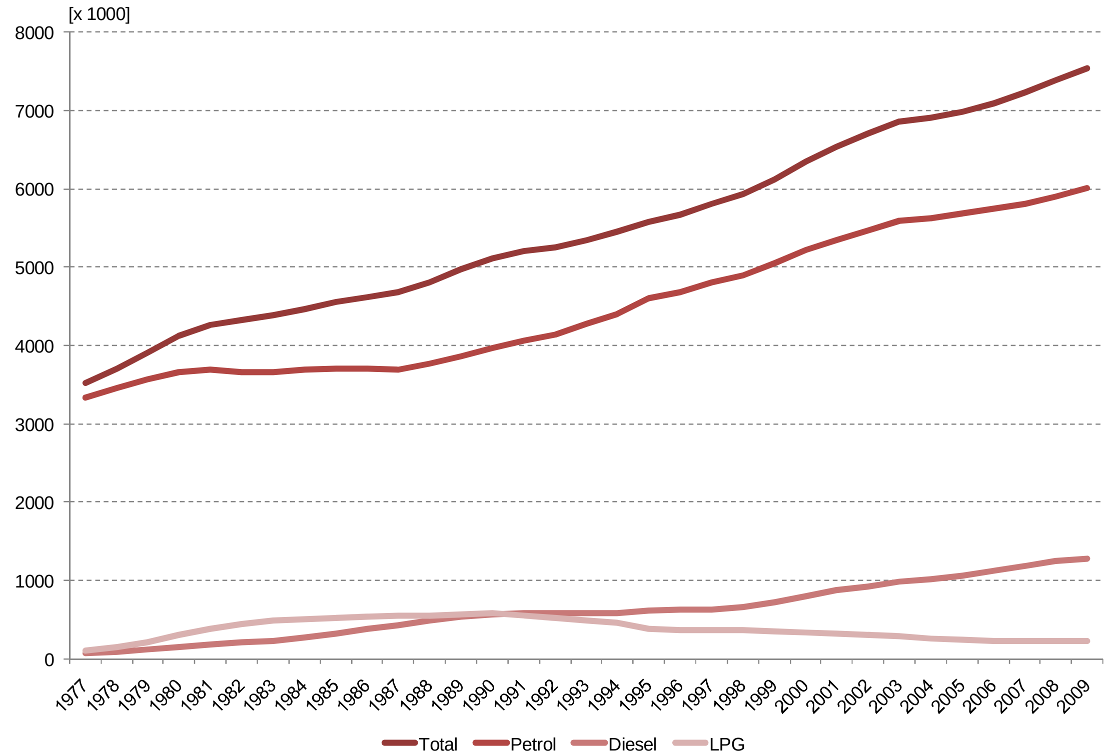

Figure 3.5 *Number of passenger cars in the Netherlands by fuel type 1977-2009*
Source: CBS, 2010.

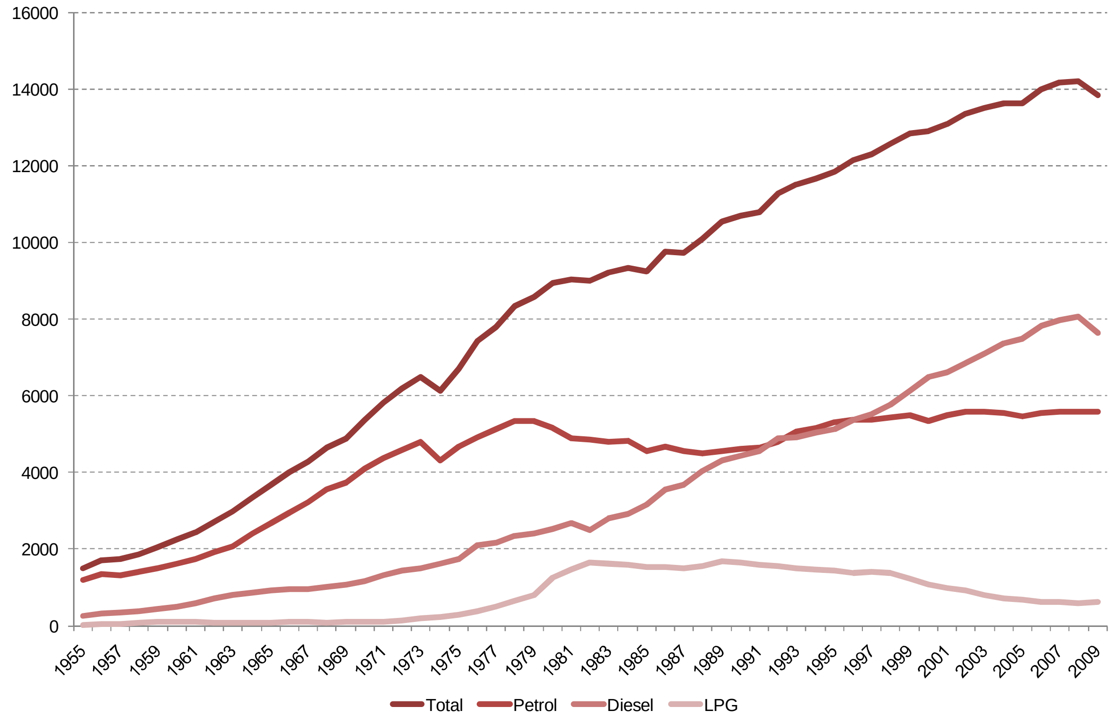

Figure 3.6 *Fuel consumption [mln l] of road traffic in the Netherlands 1955-2009*
Source: CBS, 2010.

Table 3.4 *Overview of changes relevant to the Dutch LPG case after the introduction of LPG regarding vehicle numbers and infrastructure, policy and external developments*

Decade	Vehicles	Infrastructure	Policy	Other Developments
1950s	Slow but steady take-up	Slow but steady development (0 - 100 stations)	No incentives (higher road tax due to higher vehicle weight)	Suez Crisis
1960s	Continued slow but steady take-up (~0.5 - 1% LPG cars)	Continued slow but steady development (100 - 220 stations)	No incentives (higher road tax due to higher vehicle weight)	
1970s	Sudden significant increase (~1 - 10% LPG cars)	Sudden significant increase (220 - 5500 stations)	No incentives for vehicles; regulative incentives for stations: LPG allowed in combination with other fuels	Oil crisis, increased awareness of environmental issues and limited availability of oil
1980s	Early 80s: slow increase; Mid-80s: levelling off; Late 80s: first slight decrease (~10 - 11 - 10% LPG cars)	Significant decrease: trend to less but bigger stations (5500 - 2500 stations)	Increase of vehicle road tax, but 'gentlemen's agreement' between industry and government to keep break-even point of LPG with petrol at level of early 80s	'Gentlemen's agreement' not kept due to technological developments: increase of conversion cost and improved efficiency of driving on petrol, introduction of unleaded petrol
1990s	Steady decrease (~10 - 5% LPG cars)	Slow decrease	Early 90s: Increase of fuel excise tax ('Kok's quarter'[24]) for all fuels; following industry lobbying and introduction of 3rd generation LPG systems → lowered increase of vehicle road tax for LPG compared to other fuels	Gulf war I, price for LPG increases even more than prices for other fuels (related to high demand for LPG for heating in winter 90/91), improved efficiency and emissions for diesel and gasoline vehicles, some technological advancement of LPG vehicles (G3)
2000s	Continued decrease (~5 - 3% LPG cars)	Steady decrease, slightly accelerated by change in regulations (causing closure of ~200 stations) Currently: ~1800 LPG stations in NL	Incentives for vehicles: decrease of vehicle road tax and fuel excise tax; Restraint for stations: safety distance exceptions were no longer tolerated	Further technological advances of gasoline and diesel driven engines, little technological advancement of LPG systems

[24] De Wit, n.d.a

Lessons learned for the introduction of hydrogen after 2010 that can be derived from the introduction of LPG several decades ago are of course limited. Pre-conditions, circumstances, and approach to their introduction vary greatly. A number of main differences are captured in the following table:

Table 3.5 *Comparison of barriers and drivers of the introduction of LPG and hydrogen*

LPG	Hydrogen
• 1950s: Very small-scale introduction by one company importing LPG and LPG refuelling as well as conversion systems from abroad; competition with oil companies • Development of infrastructure learning by doing • Retro-fitted cars drive on LPG and petrol → less dependence on LPG availability • 1960s: Interest of industry to sell LPG, a cheap residual product from refineries, as transport fuel (i.e. new market), large infrastructure investments • Before 1990s: Government stimulation not yet necessary (LPG price low; petrol and diesel engines not very efficient yet) • Concerns with and regulation for emissions not yet acute	• Oil companies likely to invest in hydrogen as future fuel • Extensive theoretical R&D and planning precedes introduction of hydrogen • Hydrogen vehicles are 'single-fuel' vehicles → strong dependence on sufficiently developed hydrogen refuelling infrastructure • Increased competition at start of introduction: efficient petrol and diesel cars, biofuels and electric vehicles • Increased environmental concern of public and government (emission targets) • Zero tailpipe emission • Climate change concerns add urgency to development and implementation

Despite these fundamental differences, this case study of the introduction of LPG in the Netherlands provides insights into some factors that support the introduction of an alternative fuel to the market. Certain policy measures contributed to a speed-up of developments from first introduction to firm establishment:

- The setting of fuel excise and road taxes helps establishing a crucial competitive advantage for the alternative fuel over its competitors. A low fuel price at the pump but also the total cost of ownership (i.e. break-even point with other fuels) are decisive factors for consumers.
- Early set and long-term policy commitments turn the above listed incentives into reliable factors for users to base their purchasing decision on and provide a stimulating environment for an alternative fuel.
- Financial advantages for early movers in infrastructure development support initial station build-up. (In the case of LPG this advantage was created by industry who created an 'early bird incentive' for early movers in a region.)

3.3 Developments in two EU and two non-EU countries

3.3.1 LPG in Poland

In Poland LPG has a large tax advantage over conventional fuels which caused a rapid growth of the market during the previous two decades. Despite the fact that excise duty on LPG has tripled after 2000 it is still much below the tax on petrol and diesel and its pump price is about half that of conventional fuels. Additionally, car conversions are much cheaper in Poland than they are in other European countries for a number of reasons: a) the cars to be converted are older and costs rise for newer models, b) conversions are of poorer quality and c) labour costs are lower than, e.g. in Western Europe. Due to the price advantage of fuel and conversion the break-even distance, depending on the age of the vehicle is between 16000 - 30000 km (i.e. about 1-2 years of car use for a private owner). The much higher buying and running costs of diesel vehicles mean that diesel at no point in time or distance travelled, breaks even with LPG in Poland (WLPGA, 2004).

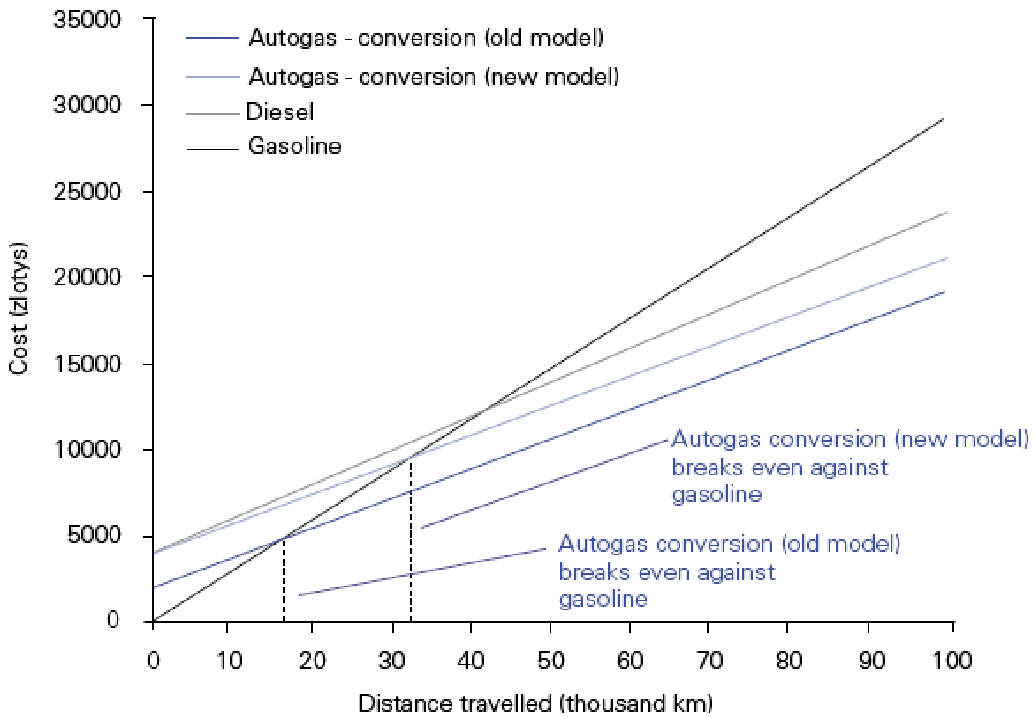

Figure 3.7 *Break-even points of old and new converted car models with petrol in Poland, 2004*
Source: WLPGA, 2004.

There are no other policy incentives for LPG in place in Poland which may point to the importance of the fuel excise tax for an alternative transport fuel market and users' decision making. A large rise in vehicle numbers followed Poland's EU accession in 2004 when a large number of second-hand vehicles, mainly from Germany, came on the market. Many of these second-hand cars were subsequently converted (WLPGA, 2004). The same year, LPG vehicle numbers increased from about 850 000 to 1.3 million (Eurostat, 2009) and Poland overtook Italy as the largest consumer of LPG as personal transport fuel in the EU (IEA, 2009). It now holds the highest vehicle share in the EU with over 13% (Eurostat, 2009). In 2007 over 1.9 million LPG vehicles were registered in Poland. Most of these are private and commercial light duty vehicles, but also about 80% of the Polish taxis have been converted to LPG (WLPGA, 2004).[25]

[25] Unfortunately, the source does not provide information as to why this may be the case.

3.3.2 LPG in Germany

In Germany the upward trend of LPG started in 2004. At the time the German refuelling infrastructure was still underdeveloped and the DVFG (Deutscher Verband Flüssiggas - German Association of Liquid Gas) motivated its members to invest in LPG stations. This association is composed of liquid gas utilities as well as industry and their suppliers. Main argument for the development of the fuel market was to compensate for the decreasing gas use for heating. The gas demand in the heating sector decreased (and continues doing so) because of improved efficiency of heating systems (e.g. extra heat exchanger) and housing insulation. Several members of the association became interested and decided to invest in stations and thereby capture the profits of a different gas sector. In 2006/07 the investments agreed upon came through and the refuelling infrastructure started to expand. Those members who joined have managed to keep their sales constant despite decreasing demand from the heating sector. The following table displays the rising number of refuelling stations, LPG vehicles and sales since then until 2009.

Table 3.6 *German LPG market 2004-2009*

Year	LPG stations	LPG vehicles	LPG cars per station	LPG vehicles [%]	LPG sales in tonnes (of DVFG members)
2004	600	30 000	50	0.07	26 467
2005	1 000	65 000	65	0.14	50 961
2006	2 300	125 000	55	0.27	86 917
2007	3 200	200 000	63	0.49	152 498
2008	4 400	300 000	69	0.73	247 000
08/2009	5 050	370 000	73	0.90	380 000

Source: DVFG, Eurostat.

The LPG price in Germany remained relatively stable for that period and only rose from about 0.60 €/l in 2005 to a peak at about 0.67 €/l in 2008 and dropped again to about 0.63 €/l in 2009. The price for LPG has always been a little higher in Germany compared to the Netherlands; only in 2008 Dutch LPG users had to pay slightly more for their fuel:

Table 3.7 *Comparison of LPG prices [€/l] in Germany and the Netherlands, 2005-2008*

Year	LPG Germany [€/l - yearly average]	LPG Netherlands [€/l - yearly average]
2005	0.59	0.51
2006	0.62	0.56
2007	0.64	0.59
2008	0.66	0.67

However, vehicle and road taxes make LPG less attractive in the Netherlands than in Germany. In Germany, CNG and LPG were equalised in terms of taxes, and the tax reduction for LPG vehicles compared to petrol has been granted until 2018 with no immanent plans to change this arrangement. These policy incentives provide planning (price) dependability for vehicle users and partially explain the increasing demand for LPG and rising LPG vehicle numbers.

The greatest impulse to the German LPG market came, however, in 2007 with large increases of prices of other fuels. Since then it kept growing steadily with 1.5 million LPG vehicles expected to drive on German streets by 2015.[26]

[26] Interview R. Schneiderbanger, managing director Deutscher Verband Flüssiggas (DVFG).

3.3.3 CNG in Argentina

For Argentina, CNG is considered as an alternative fuel. The introduction of this gaseous fuel is an additional example of the challenges in station build-up and vehicle roll out for new alternative fuels and provides a possible approach. In 2009, about 20-25% of the Argentinean passenger car fleet is running on CNG and 30% of all refuelling stations supply CNG. In absolute numbers, there are about 1.8 million CNG vehicles and about 1800 refuelling stations (Prensa Vehicular, 2009). This constellation leads to the perfect VRI of 1[27] and therefore profitable operation of refuelling stations. The following table shows the still increasing CNG sales of Argentina in recent years:

Table 3.8 *Annual sales of CNG in Argentina 2001-2008*

Year	Amount of CNG vehicles	Total annual sales of CNG [m^3]	Change compared to previous year [%]
2001	755 671	16 887 465	-5.58
2002	879 587	15 799 858	-6.44
2003	1 164 839	16 605 191	5.10
2004	1 348 126	17 881 905	8.52
2005	1 496 440	18 916 745	5.79
2006	1 607 110	20 258 930	7.10
2007	1 750 339	21 697 102	7.10
2008	1 786 989	22 110 848	1.91

Source: Prensa Vehicular, 2009.

The success of CNG in Argentina can be attributed to a number of reasons (presentation 2009):

- Argentina could rely on rather large resources of natural gas and in 1984 an initiative by the government aimed at coordinated build-up of infrastructure and introduction of CNG vehicles.
- A continuous build-up of CNG refuelling stations ran parallel to increasing vehicle sales. Therefore, infrastructure investments made were able to meet increasing fuel demand and users profited from a growing fuel supply network.
- The pump price of CNG (~0.18 €/l) is lower than those of diesel and petrol than (~0.36 €/l and ~0.47 €/l respectively) (Prensa Vehicular, 2009).

3.3.4 LPG and CNG in Canada

In Canada the LPG market developed well initially. In the early 80s, the Canadian government set up a grant programme for vehicle conversions to alternative fuels due to security of supply concerns. The industry therefore developed a refuelling network with over 5000 stations across Canada. Other arguments in favour of LPG were rising environmental concerns and the governmental programmes continuously favouring alternative fuels, including LPG, in the taxation system. However, due to the fact that fuel taxes are generally quite low in Canada, the differences in prices of different fuels at the pump were not very large, with LPG being about 26% cheaper than diesel and 31% cheaper than petrol. This difference decreases significantly and has little impact on the total cost of ownership of a vehicle due to the additional consumption of 10-20% of LPG compared to the other fuels.

[27] VRI is the abbreviation of Vehicle to Retail station Index. It is calculated as the ratio of vehicles driving on a particular fuel in thousands and the number of refuelling stations of a particular region. The VRI therefore also serves as index for fuel availability. A VRI of about one is seen as ideal, while a VRI above one speaks for insufficient fuel availability and a VRI of below 0.2 is an indication of insufficient demand for available resources.

Canadian LPG use for transport peaked in 1992 and has been in steady decline since then. Several factors have contributed to this development: removal of governmental conversion grants for LPG, efficiency and environmental improvements of petrol and diesel engines, lack of OEM vehicles and declining LPG conversions in commercial car fleets. Most commercial fleets switched to diesel after the governmental grant removal. Since this change in governmental support schemes, subsidies are insufficient to make LPG financially attractive: even in the province Ontario which is the only province were some tax rebates are still in place, LPG is competitive with petrol only above 124 000 km and with diesel only until 83 000 travelled distance per year. In 2004 there were an estimated 92 000 LPG vehicles in Canada, two-thirds of which were commercially run. At the end of 2003 there were still only about 3000 LPG stations in Canada.[28]

Although the conversion grant for LPG was removed, governmental support for CNG remains in the form of conversion grants and reduced fuel excise tax. There are even funds available for the construction of CNG refuelling stations. The situation looked quite different for CNG during the 1980s. What started as a promising alternative has never reached mass market (despite continuous governmental support) due to the following reasons identified by the author: a lack of refuelling stations could not be compensated since existing ones provided too little profitability to trigger further investment. The industry requested excessive prices for vehicle conversions which in turn hampered demand. In other words, while one part of the infrastructure - namely refuelling - did not reach sufficient revenue, another part - namely production of vehicles running on natural gas - overcharged and customers were put off. These developments could not be or have not been counteracted with policy measures. Furthermore, claims with respect to economic and environmental savings were exaggerated and promotion of gas powered vehicles was poorly designed. Additionally, oil and gas prices shifted to the disadvantage of CNG technology. When vehicle conversions did not achieve profitability, major players exited the market and condemned gas vehicles to persisting niche market existence (Flynn, 2002).

The lack of a well developed refuelling infrastructure may have been the main factor hampering further development. Especially the build up of profitability at the first stations offering gas and the following reluctance to invest further into the development of public gas refuelling stations is seen as the most significant factor to blame. Of 80 stations in total at the time, 34 offered gas for the public. There is, however, no information on their geographical dispersion. In short, this is a prime example of the ‘chicken-and-egg problem’ of alternative fuels in their early infrastructure development. Therefore, extra marketing strategies for alternative vehicles in local areas surrounding a refuelling station and even considering moving the offered refuelling point to a more profitable area in case it does not ‘kick off’ are proposed (Flynn, 2002).

3.4 Comparison and conclusions of LPG/CNG experiences in other countries

The previous chapters show that policy measures play a crucial role in the establishment of a stable and viable market for an alternative fuel. Effective measures depend on national context and other policy measures active in the transport sector. The total cost of ownership play a central role in this respect. If they are lower for the new alternative fuel in a certain (sufficiently large) range compared to conventional alternatives, a financial incentive to switch can be created. This can either be achieved by tax exemptions for the new alternative or by tax additions for conventional fuels that are still in use; both has been seen to be successful. The length of pay-back time for the vehicle conversion to LPG is rather sensitive to governmental taxation systems for road, but even more so for fuel excise taxes. A long-term policy commitment is beneficial and creates a sense of price security and hence also fuel commitment in consumers. Public awareness and education campaigns or mandates and public transportation fleet conver-

[28] All information taken from WLPGA/Menecon Consulting (2004)

sion programmes can also be effective in image and demand building but have not been the focus of this report.

The Polish case study exemplifies that a low vehicle price (in this case vehicle plus conversion) and low fuel excise tax are key to the success of an alternative fuel. The case study of Germany shows that industry-push approaches in form of infrastructure investments can be supported by long-term policy commitments, for example in the form of a road tax reduction. At this point in time successfulness of these efforts is difficult to judge. The Argentinean case demonstrates the most successful efforts of governmental action. An initiative supporting CNG as an alternative fuel by means of grants for vehicle conversion, station construction and favourable excise tax conditions succeeded in parallel building up of demand and supporting infrastructure. In the Netherlands, such vehicle grants as well as large enough excise tax advantages are lacking. The reduction in road tax for LPG vehicles also does not suffice in making LPG economically interesting compared to other fuels, especially diesel. The case study of Canada is exemplary for mistakes made or ineffective policy measures due to wrong timing or insufficient strength: the grant system for vehicle conversions to LPG initially worked well. However, as soon as this system was stopped, the market collapsed. This can partially be attributed to technical advancement of competitors, but also to the lack of favourable taxation schemes. Therefore, the Canadian case is similar to the Dutch case, as LPG lacks policy induced competitiveness. Note, however, that the Dutch station infrastructure is much better developed than the Canadian.

In summary, this section clearly emphasises the importance of policy instruments and the necessity to tailor them to existing policies in the energy and transport system, national context in general and in reaction to external factors influencing the market. Thereby, efforts by industry and demand increase can be orchestrated to succeed in building viable stations and meeting consumers’ station availability demands.

4. Conclusions and implications for hydrogen

Based on the analysis of drivers and barriers for the introductions of LPG and CNG in different countries, some lessons can be drawn for the future introduction of hydrogen as transport fuel. The history of LPG in the Netherlands reveals several crucial issues to be taken into account for the introduction of hydrogen: infrastructure development, competition to existing fuels and policy support of an alternative fuel.

Refuelling practices were very different several decades ago than they are today. During the 1950s and 60s when LPG was brought to the Dutch market, the few people driving a car were used to driving larger distances for refuelling as there were only few stations available. In the following years a very dense network of small stations developed. From then on the trend went from small single fuel and single pump stations to fewer stations offering more fuels at several pumps, similar to the situation today. Regarding refuelling practices and fuel availability, it is important to note that cars retrofitted with LPG systems are still also able to drive on petrol. This gives their users some flexibility and independence from fuel availability, also abroad.

Cars driving on hydrogen, on the other hand, will provide their users no flexibility. Therefore, refuelling options need to be available abroad early on, especially in neighbouring countries. Eventually, it will have to be available in the whole of Europe in order to offer a similar level of convenience to its users as they are currently used to. Trans-national mobility for business and holidays has increased significantly compared to the introduction of LPG in the 50s. For the introduction of a new fuel current refuelling practices need to be analysed in detail. Meeting users' current refuelling habits and requirements can facilitate the process of switching fuels.[29] Furthermore, efforts for infrastructure development are best coordinated across a number of countries.

Concerning successful competition with other fuels at the time of introduction of an alternative, all case studies presented in this report show that cost-efficiency is key. In the Netherlands, LPG was successful as long as it had competitive advantages over petrol and diesel. These advantages were not policy induced but based on the comparatively low price of LPG due to its very low production cost and increased cost of its competitors during the oil crisis in the 1970s. When the price advantage of LPG diminished due to the decreasing oil price and increased fuel efficiency of petrol and diesel engines, the amount of LPG vehicles dropped. Especially diesel, the high-mileage competitor of LPG, could convince consumers with improved efficiency and performance (e.g. acceleration, range), lower emissions, lower maintenance cost and, despite a higher road tax, a higher cost-efficiency overall. Policy measures in place, such as reductions in vehicle road and fuel excise tax for LPG cars are apparently not sufficiently large to create a sufficient cost-advantage that convinces users to drive on LPG. In other words, the total cost of ownership for LPG vehicles may not be low enough in comparison to other fuels or may be low in too small a window to convince people to invest in LPG conversions. The lack of financial incentives may be the main reason for the low share (~2%) of LPG of the Dutch passenger vehicle market as fuel availability is rather high.[30] The four other case studies of Poland, Germany, Canada and Argentina show that long-term government commitment and either strong industry

[29] The ECN report 'Analysis of refuelling and purchasing behaviour of intended end-users' deals with this topic in more detail. It argues based on a large survey among Dutch car drivers that people currently mostly choose for a station en-route to their destination and are only willing to take short detours to reach a certain station. This report will also be published in the course of the THRIVE project.

[30] The Dutch government has commissioned an analysis of possibilities to substitute LPG by other fuels, possibly due its low share of the vehicle market and its inability to perform better at the market without financial support. Reference of the resulting report (in Dutch): Beumer, L., van Bork, G, van de Velde, I., & Verster, N. (2004) Ketenstudies amnoniak, chloor en LPG: kosten en baten van LPG als autobrandstof [Supply chain studies ammoniac, chlorine and LPG: cost and benefits of LPG as vehicle fuel], ECORYS-NEI

push, strong demand surge or gradual policy-supported infrastructure build-up can help establishing and maintaining an alternative fuel at the market.

These insights call for strategically set policy measures that create a situation for a newly introduced fuel such as hydrogen in which it can compete on the level of total cost of ownership with other fuels. This can be achieved by lower fuel cost, but also by means of purchasing grants, tax exemptions or road tax reductions. Another policy measure which has not occurred in any of the five cases discussed in this report but which has a strong effect on the competition of different fuels is a tight emission regulation. If levels are set sufficiently low, petrol and diesel cars will have little to no chance to remain competitive on the market because there are technical limits to emission reduction of internal combustion engines. Of course, in the context of a tight emission regulation other competitors, such as electric vehicles, emerge as competitors to hydrogen.

The issues raised in this report call for long-term policy commitments (see also Melaina, McQueen & Brinch, 2008) across national borders in order to create an environment inviting industry investments and users' trust and support of hydrogen as new transport fuel. Regulatory restrictions on existing fuels may aid transition to and implementation of hydrogen. Sufficient refuelling infrastructure matching Dutch car drivers' refuelling requirements within the Netherlands and abroad are just as important as sufficient financial and regulatory incentives rendering driving on hydrogen attractive and cost-efficient compared to other fuels.

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CBS, Centraal Bureau voor de Statistiek: http://statline.cbs.nl/statweb/?LA=nl

Eurostat: http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search_database

Appendix A List of contacts

Name of Organisation	Type of Organisation	Contact(s)
BOVAG	Large Dutch company for mobility research and customer services in the fields of insurances, sales support and information	Jan Bessembinders, Rutger de Wit
TNO	Scientific advice for government and business	René van Asch, Koos Ham
KPN	Dutch telecommunications company operating a large car fleet	Cees van der Want
Leaseplan	Dutch branch of an internationally operating leasing company, largest leasing company in the Netherlands	Derk van Rossem
Arval	Dutch branch of an internationally operating leasing company	Call to general information hotline
DVFG	Deutscher Verband Flüssiggas e.V.	Robert Schneiderbanger, Cordelia Huhn
CBS	Dutch Central Bureau of Statistics	Ferry Lapré

Appendix B Description of the calculation tool for cost analysis of LPG, petrol and diesel[31]

The calculation model for a cost comparison of LPG, petrol and diesel takes into account all costs during the lifetime of a newly bought vehicle - the total cost of ownership (TCO). The total time the vehicle is used before it is sold again is taken to be 7 years. The figures used concern a Dutch private vehicle owner and are based on car models as similar as possible - the only parts that differ are the engines and all related necessary equipment (e.g. tanks). The costs included in the model are:

- Vehicle cost = [vehicle purchasing price (incl. VAT and private motor vehicle and motorcycle tax (BPM))] - [estimated residual value]
- Fuel cost = [price/L * distance travelled]
- Maintenance and service cost = [insurance cost + maintenance cost + road tax (MRB)]

All input, such as the fuel price or taxes is based on actual, current figures and regulation. Maintenance cost, however, is taken as a rough estimation kept mostly constant across fuels and years. Only maintenance for LPG cars is taken to be 20% higher due to reported increased maintenance cost based on the use of a vehicle constructed for medium annual mileage as a high mileage car.[32]

The total cost is calculated for several annual mileages (and thus different total distances travelled over the time of ownership), namely five-, ten-, fifteen-, twenty-, twenty-five-, thirty- and forty thousand driven kilometres per year. Based on the TCO for several annual distances the break-even-points (BEP) can be calculated. They are given as the annual distance above which one type of car/fuel is more cost-efficient than the other. In other words, this model indicates which fuel option becomes cheapest in dependency of annual usage.

[31] This tool was developed by Paul Lebutsch, ECN Hydrogen and Clean Fossil Fuels.
[32] Indications have been found in online user discussion forums as well as during an interview with Mr. Schneider-banger, DVFG.