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Hydrogen Vehicle Deployment and Required Policy Support for Roll-out Scenarios in the Dutch THRIVE Project

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Abstract

The work presented is part of the Dutch THRIVE project which centers on dynamic simulation of joint roll-out of a hydrogen refuelling infrastructure and a hydrogen vehicle fleet. The simulation tool enables modelling of fuel supplier and car manufacturer strategies, and consumer attitude towards hydrogen. A car cost model is used in the THRIVE project for the post-processing of roll-out simulation results to determine type and level of possible policy support necessary that make FCEVs cost-competitive.

1 Introduction

The Dutch THRIVE project addresses the use of hydrogen as a fuel for passenger cars in the Netherlands during the commercialisation phase. Its objective thereby is the identification of plausible rollout scenarios for both a hydrogen refuelling infrastructure as well as for a hydrogen car fleet. Attention was paid to the preferences of the motorists and the influence of the availability and visibility of both hydrogen cars as hydrogen refuelling opportunities. The methodology applied in the THRIVE project consists mainly of two steps. The first step consist of running model-simulations that generate plausible roll out scenarios for both hydrogen cars and an hydrogen infrastructure, under the assumption of level playing field conditions. The input data is bounded by coherent sets of assumptions around different levels of policy ambition regarding the stimulation of hydrogen fuelled auto mobility. During the second step, the output of the model-simulations is analysed in terms of quantitative market development, well-to-wheel efficiency and emissions and effects of policy measures. In this report, particular focus is on the analysis of the consequences of the level playing field assumption in terms of required policy support for vehicle retail prices.

2 Cost Gap Analysis

The objective of the cost gap analysis is to come to sound estimations on the amount of investment that is required to ensure the level playing fields condition. We applied the learning curve methodology which describes the fuel cell car costs as a function of the cumulative number of produced of fuel cell vehicles.

2.1 Methodology: scaling

The roll out simulations realised in the THRIVE project generate, among others, fuel cell car sales numbers in the Netherlands. Sales numbers can be translated to cumulative production numbers. Yet, the cumulative production numbers required for estimating fuel cell car cost developments should be global and not national. To estimate global cumulative production numbers, a straightforward multiplication factor of 100 has been determined which indicates

the scale of the Dutch car-fleet compared to the global car-fleet. History has shown that the introduction of new drive-train technology doesn't necessarily pick up at the constant same rate in the Netherlands as it may do in the rest of the world: after 10 years, the penetration of the ICE-hybrid in the Dutch car-fleet accelerated to a rate double to that of the global average. The general interpretation of this shift of rates is explained here by the fact that the Netherlands are generally progressive when it comes to cleaner energy technologies, yet since they do not have their own car-industry, it takes a while before the trend gains momentum. It is assumed this mechanism holds for FCEVs too. The global cumulative production numbers as derived from the simulated penetration of hydrogen vehicles in the Dutch national car fleet, for the three scenarios low, medium and high, are given in figure 1. Also the global cumulative production curve as it was estimated by the European HyWays project is plotted in the same graph.

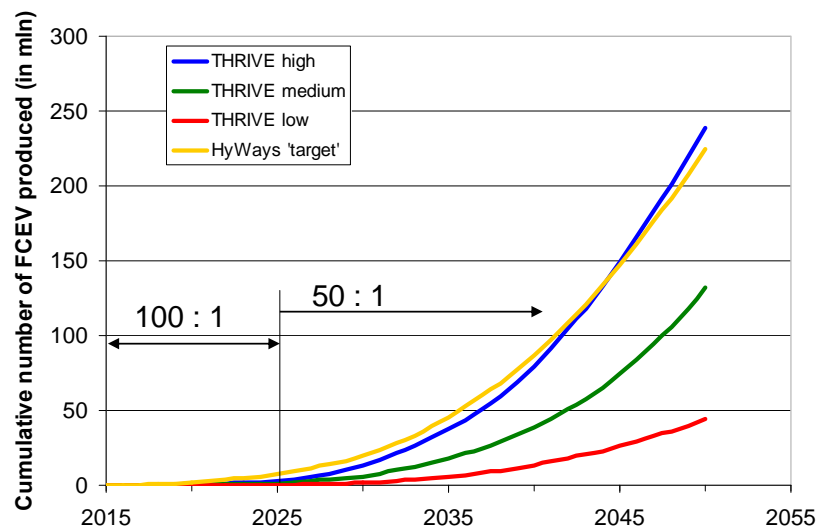


Figure 1: Global cumulative hydrogen car production numbers as derived form the THRIVE simulation results. The "high" scenario does not deviate very much from the HyWays estimations. The arrows with the ratio's indicate the interval in time over which a certain ratio is assumed.

2.2 Methodology: learning curve methodology

To estimate the future price development of hydrogen cars, a learning curve approach is applied which describes the relation between cost price and total cumulative number of units produced:

$$I(C) = I_0 * (C/C_0)^{-\ln(pr)/\ln(2)}$$

With I = cost price fuel cell vehicle, C = cumulative number of vehicles produced,

I_0 = cost price fuel cell vehicle at $t = 0$, C_0 = cumulative number of vehicles produced at $t = 0$,

Pr = progress ratio.

We assume here that the cost price of hydrogen vehicles equals the cost price of conventional ICE vehicles minus the costs of an ICE drive-train plus the costs of a fuel cell drive-train. The drive-train consists of a fuel cell system, a hydrogen storage tank, an electromotor and a battery-pack. These three subparts differ in technological maturity. Furthermore it is assumed that learning will flatten out at a bottom cost price after 1 million vehicles produced. The values of the progress ratio for each of the subparts are given in table 1. Progress ratio **pr** is here assumed to represent the lumped sum of learning by doing, learning by searching and economy of scale. [1].

Table 1: Progress ratios, initial costs and production numbers for the subparts of a fuel cell drive-train system [2,3,4].

$C_0 = 2000$ (in 2013)	80 kW FC system	H ₂ tank	E-motor	Battery
I_0 (€)	28 000	7 000	4 000	2 750
pr	0.80	0.90	0.90	0.90
pr after 1 mln cars	0.90	0.95	0.95	0.95

2.3 Methodology: reference car

The ICE hybrid is chosen as the benchmark for the FCEV in terms of cost price. In contrast to the fuel cell drive train, the ICE drive train will increase in price as a result of technological changes that are required to meet emission legislations, reaching it's maximum increase at around 2800,-euro [5]. The forecasted development of the cost-price of both the ICE hybrid drivetrain as well as the FC drivetrain is plotted in figure 3.

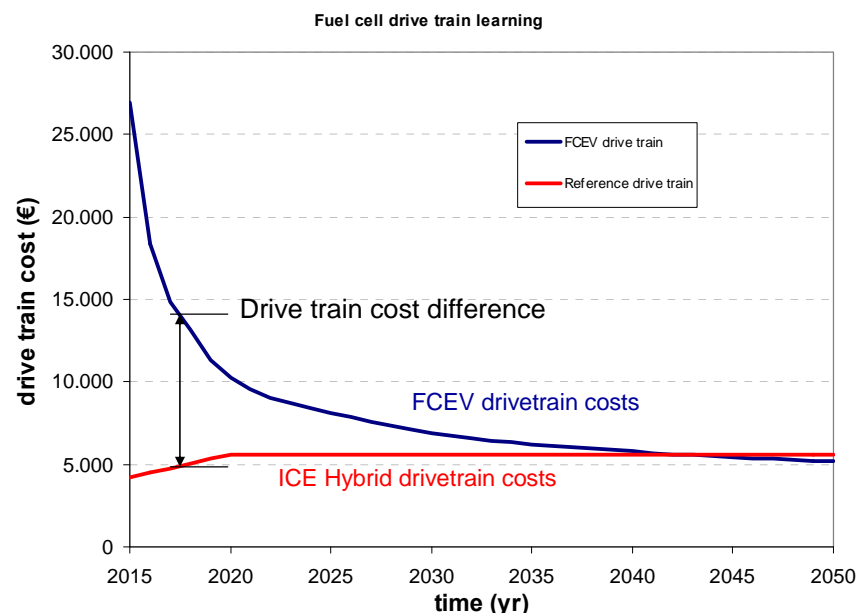


Figure 2: The expected cost price development of an 80kW fuel cell vehicle compared to that of the reference car, an 80kW ICE hybrid.

The difference between the cost-price of the FCEV and the ICE hybrid in year X is the basis for calculating the cost gap in year X. The total cost-gap of a future transition equals the summation of all the annual cost-gaps over the whole transition-period 2015-2050.

3 Calculations

The annual cost-gap is calculated for the three scenario's based on low, medium and high policy ambition. The result is shown in figure 3. To get a feeling for when the FCEV cost-price is within a close range of the cost-price of the ICE hybrid, the orange crosses in figure 4 indicate when in time the FCEV costs still only 10% more than the ICE hybrid.

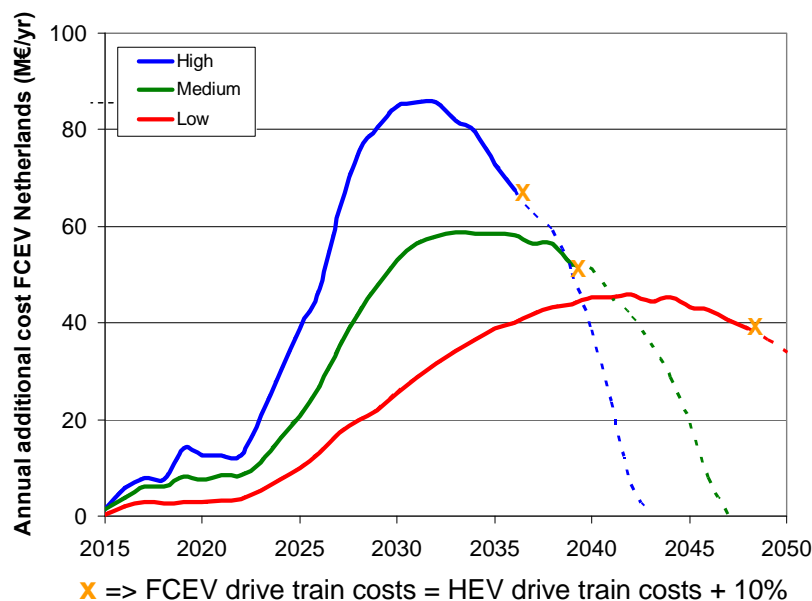


Figure 3: The annual cost-gap for the three different scenario's based on low, medium and high policy ambition.

4 Discussion

4.1 The order of magnitude of the cost-gap

The analysis performed in this study gives an indication of the range of investment required to bridge the cost-gap between FCEV's and reference cars, ICE-hybrids. Yet in order to get a feeling for the relative size of the total investment, the yearly cost-gap has been divided over the sales of non fuel cell vehicles. For the three scenarios built on low, medium and high policy level, the resulting costs per non-FCEV sold are plotted in figure 4. The figure reveals that the amount of required investment in the Dutch car-market, would translate to about 75 to 160 euro per non-FCEV car.

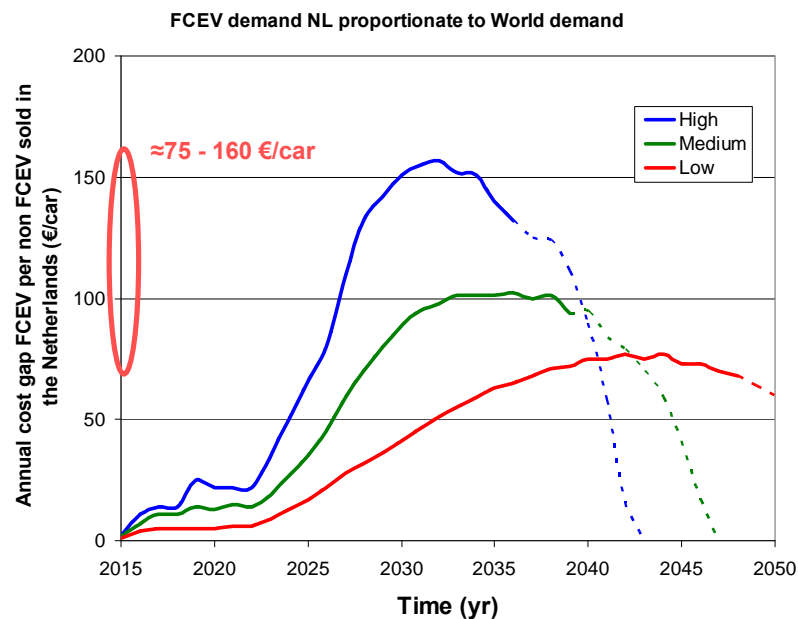


Figure 4: The annual cost gap divided by the total amount of non-FCEV's per year.

4.2 The influence of cost-reduction rates induced by different progress ratios

So far, little attention has been paid to the influence of the chosen progress ratios **Pr**. History has shown that for new technologies, progress ratios of 0.8 are rather typical and achievable. Yet the progress ratio **Pr** cannot be predicted, as it is an empirical methodology; the value for **Pr** can “officially” only be established in hindsight. Yet, an alternative approach is to establish a value for **Pr** that should be achieved, in order to keep a market situation which is competitive for FCEV's. In other words, if a **Pr** value is monitored real-time and it shows a deviation of the target **Pf** that was established as the necessary value, this can be interpreted as an indicator for the viability of FCEV's on the market. Figure 5 presents plots for different combinations of values of the progress ratio **Pr**. As was mentioned earlier, it is logical to assume that the **Pr** values will not be constant over time but will show flattening over time. In our calculations, we introduced two transition points in time on which the progress ratio changes: after 1 million and after 20 million cars globally produced.

4.2.1 Case I

In case I, the optimal 'default' case is analysed, this is the case that follows the **Pr** values for the different parts such as is given in table 1. This also translates to only 1 **Pr** transition after 1 mln cars and no further transition after 20 mln cars. The annual additional costs of FCEV's for the default case is one of the three curves displayed in figure 5. The figure shows that for the default case, the annual additional costs do not exceed the 100 M€ and are reduced to 0 €/year around the year 2043.

4.2.2 Case II

To analyse the influence of the progress ratio **Pr** on the annual additional costs, the value for **Pr** has been varied. The first variation on the default case is based on an increased value of **Pr** for only the fuel cell system during the first million cars. The input looks as given in table 2.

Table 2: Input for the case II scenario: $Pr > 0.8$ during the first million FCEV's produce. Deviations from the default case are printed in bold.

Progress Ratios	Fuel Cell	H ₂ tank	E-motor	Battery
Phase I	0.85	0.90	0.90	0.90
Phase II > 1mln cars	0.90	0.95	0.95	0.95

In figure 5, the Case II scenario is represented by the graph named "Reduced FC cost decrease". The sensitivity of the annual additional costs for the progress ratio **Pr** is made clear once the default case (Case I) and the "reduced FC cost decrease" (Case II) are compared. Case II leads to maximum annual additional costs of around 350 M€, whereas the maximum annual additional costs in the default case do not exceed 100 M€. Furthermore, whereas the annual additional costs have decreased to 0€ around the year 2043 in the default case, the annual additional costs in Case II are in decline after the year 2043 but still around 300 M€ in 2050. This difference is significant and already indicates the need for continuous R&D efforts to keep the progress ratio **Pr** at a minimum of 0.8 and preferably lower.

4.2.3 Case III

The third case considered, is the case which is identical to Case I up to 20 million cars. After 20 million cars however, there is a transition to higher values for the progress ratio **Pr** for not just the fuel cell system, but also the hydrogen tank, the electromotor and the battery pack. The input for case III is as given in table 3.

Table 3: Input for the case III scenario. After 20 million cars, the following values are introduced: $Pr(\text{fuel cell system}) = 0.95$, $Pr(\text{H}_2 \text{ tank}) = 0.98$, $Pr(\text{e-motor}) = 0.98$, $Pr(\text{battery}) = 0.98$. Deviations from the default case are printed in bold.

Progress Ratios	Fuel Cell	H ₂ tank	E-motor	Battery
Phase I	0.80	0.90	0.90	0.90
Phase II > 1mln cars	0.90	0.95	0.95	0.95
Phase III > 20mln cars	0.95	0.98	0.98	0.98

In figure 5, Case III is represented by the curve "Further decrease rate of cost reduction > 20 mln". The annual additional costs in Case III do not exceed 175 M€, which is half the maximum annual additional costs of Case II. Yet, Case III like Case II shows a much longer period of annual additional costs than the default case, Case I. From the comparison of Cases I, II and III it can be concluded that the influence of the progress ratio **Pr** is much more significant in the initial stages (< 1 million cars) than in later stages. Furthermore, figure 5

indicates that in order to keep the time-interval in which annual additional costs are a reality short, it is recommended to especially keep the progress ratio **Pr** for the fuel cell system at around 0.8 or lower. This can only be achieved by continuous and sustaining R&D efforts.

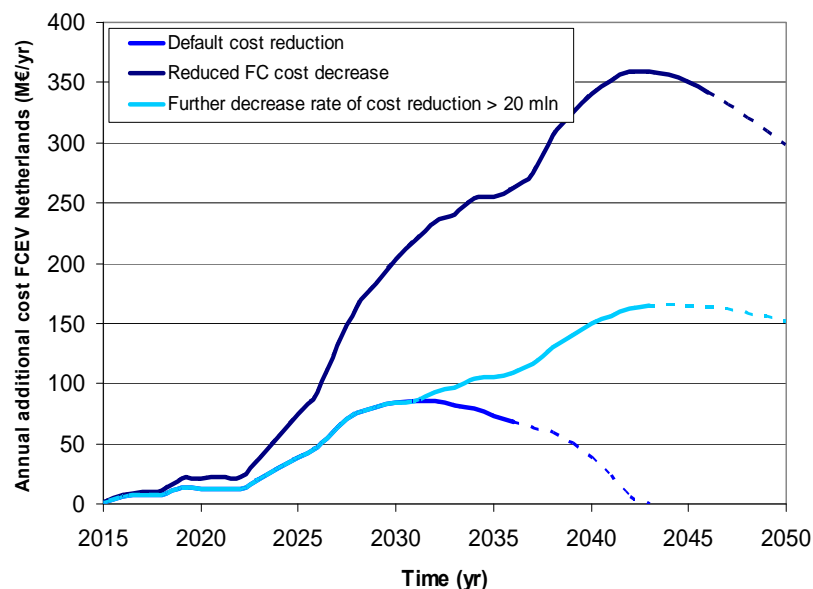


Figure 5: The annual additional costs for Case I, II and III.

5 Conclusions

This study intended to create insight in the mechanisms which shape the market for hydrogen vehicles in the Netherlands.

Calculations on the basis of estimations for input data showed that the implementation of FCEV's seems feasible. Plausible scenarios indicate annual additional costs of maximally 40 – 80 M€ which would translate to an order of magnitude of 160€ per non-FCEV sold on the Dutch car market.

In order to achieve these 'low' annual costs however, strong R&D efforts remain required in order to further decrease fuel cell system costs.

It is not the intention of this study to give accurate predictions of cost developments. There are many parameters involved, and the development of these parameters in time are uncertain: thus, uncertainty accumulates easily in the calculations. Slight perturbations in the progress rates have large consequences for long term cost developments. However, reverse reasoning allows us to explain which conditions minimally need to be fulfilled in order to make fuel cell vehicles competitive. If these conditions were to be absurd, this would lead to the conclusion that fuel cell vehicles will not be able to compete decently with mainstream alternatives.

Furthermore, there are antagonist forces when it comes to the introduction of FCEV's in the Netherlands. The Dutch car market is about 1/100 x the size of the global car-market. The

influence that the Dutch market can have on the globally induced fuel cell system cost reduction is tiny and insignificant. From that perspective, the Netherlands have an interest to be a follower, rather than an early adopter. Yet because of the integration of the European market and road-network, the Netherlands do have an interest to keep up with for example neighbouring country Germany.

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