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The Economic Feasibility of a Sustainable Hydrogen Economy

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1 Introduction

Feasibility of the hydrogen economy determined on battlefield for the car of the future

The feasibility of the hydrogen economy is often viewed in terms of the early deployment of hydrogen vehicles, because the transportation sector plays a key role in solving problems of both energy security and climate change [1,2]. The promise of the hydrogen car has however faded by the arrival of an alternative that appears to offer far more hope for the immediate future. The hydrogen car hype of the late 1990's has been replaced by the electric car hype of the late 2000's. This change of perception can be traced to three disparate causes: first, the economic shock from a meteoric rise of the oil price in early 2008; secondly, the emerging promise of fast improvements in cost and performance of batteries; third, the increasing commercial alertness of European electricity companies looking for market expansion. Certainly, the battle for the car of the future is shaped by ambitious intentions and public hypes. But ultimately, the prospects for particular car concepts are a function of comparative technological performance on the one hand and uncertain economic factors on the other hand. The most important economic factors in this battle apart from vehicle costs are the development of world oil prices and fiscal regimes for vehicles and fuels including carbon taxes. The intention of this study is to develop a stylized picture of the battlefield for the car of the future, that captures the essence of competitive forces quantitatively and allows a broad picture of potential outcomes based on key assumptions regarding the combined effects of technological progress (reflected in vehicle costs), fuel price developments (of crude oil, electricity and hydrogen) and fiscal regimes (tax rates on vehicles and fuels including carbon prices). As main indicator of competitive fitness on the battlefield for the car of the future we will use the levelized costs per kilometre of competing vehicle concepts as experienced by car owners.

2 The Conventional Gasoline versus the Advanced Hydrogen Option

Hydrogen vehicle costs are indeed crucial

If you buy a gasoline ICE car of € 20000 today and drive 12000 km annually, your levelized vehicle costs would be about 27 c/km.[1] With oil prices at 80 $/barrel, your levelized fuel costs

[1] Assuming interest rate of 5%, economic lifetime of 10 years and current European fiscal regime

would be about 11 c/km.[2] Total costs amount to 38 c/km of which 70% vehicle related and 30% fuel related. Now suppose there is a hydrogen car manufacturer who is able to put a hydrogen fuel cell car on the market that is only 50% more expensive than a gasoline ICE car, but improves energy efficiency with 50% (first heroic assumption). Its levelized vehicle costs per kilometre would be about 40 c/km. We assume that the hydrogen is produced by steam methane reforming (SMR), an established technology used at large-scale in the petrochemical industry. With European natural gas prices at 32 c/km and if distribution costs are roughly at the same level as production costs (second heroic assumption) its levelized fuel costs per kilometre would be about 4 c/km.[3] Total costs would amount to 44 c/km of which more than 90% vehicle related and less than 10% fuel related. These basic comparative figures show clearly that even with heroic assumptions about vehicle economic conditions. Even if hydrogen would be produced and distributed free of charge, advanced hydrogen cars would still remain more expensive to drive than conventional gasoline cars.

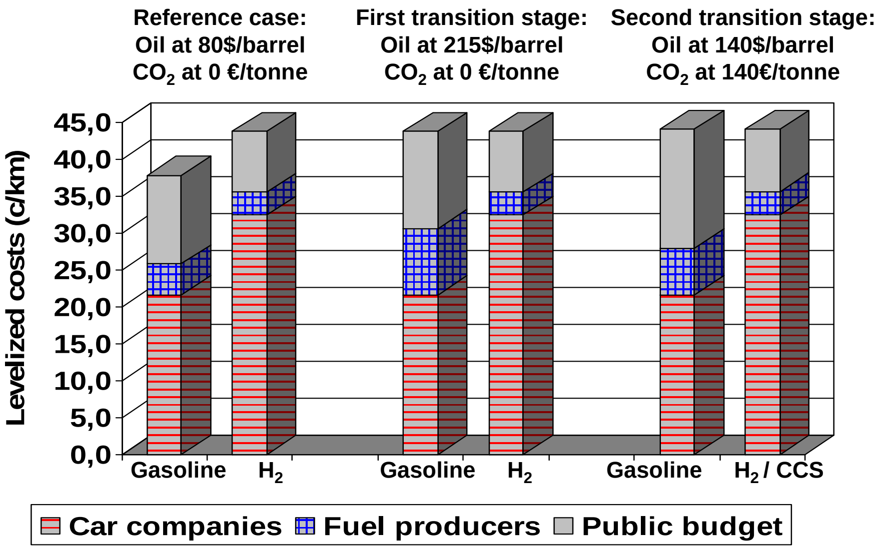

Figure 1: Transition stages towards sustainable hydrogen economy.

But world oil prices may play key role in short run

Now suppose that world oil prices increase to 215 $/barrel. This would raise the levelized costs of the gasoline ICE car to 44 c/km and there would be no need for further cost reductions along the hydrogen chain from generation to end-use (see Figure 1). An oil price of $ 215/barrel may seem extremely high, but far from implausible. It already reached close to 150 $/barrel in 2008 and the IEA presents increasingly alarming signals regarding

[2] Assuming vehicle efficiency of 7.5 liter/100 km, refinery efficiency of 85%, refinery cost margin of 5 c/liter, fuel distribution margin of 14 c/liter and current European fiscal regime including 65 c/liter excise tax

[3] Assuming a SMR plant efficiency of 75%, SMR production cost margin of 2 €/GJ, distribution cost margin of 12 €/GJ and current European fiscal regime including an excise tax of 2.7 €/GJ on gas for transportation purposes.

potentially dramatic developments on the global oil market in the short term [3]. However, such a high oil price would undoubtedly lead to increased investments in alternatives for conventional oil and lower liquid fuel prices in the long term.

While CO_2-taxes may play key role in long run

Similarly, one can calculate the required CO_2-tax to equalize levelized kilometre costs of conventional gasoline and advanced hydrogen cars. We assume here that these CO_2-taxes are based on well-to-wheel emissions.[4] To equalize levelized kilometer costs for both cars, CO_2-taxes have to reach a level of 500 €/tonne CO_2 for levelized costs to become equal. The plausibility of CO_2-taxes increasing to this level seems remote. But such high levels of CO_2-taxes are likely to make CO_2-capture and storage (CCS) in hydrogen production economically attractive and would change the underlying parameters of the calculation completely. Assuming hydrogen to be produced with SMR including CCS, a CO_2-tax of 140 €/tonne combined with an oil price of 140 $/barrel would make hydrogen cars competitive.[5] These figures are far from unrealistic for the period after 2020.

However, assumption of stable fiscal regime unlikely

Figure 1 also displays the effects on revenues for stakeholders in the automotive market from a transition from conventional gasoline to advanced hydrogen. In particular, it shows that such a transition would result in a significant reduction of government revenues, even when carbon prices become high in the long term. This may eventually lead to changes in fiscal regimes that prevent the continuous erosion of fiscal revenues. Nevertheless, this simplified static picture of competition on the automotive market demonstrates the two key messages of this analysis adequately. First, the economic feasibility of the hydrogen car can be viewed as a three-stage balancing act over time between increasing oil prices (most likely in the short term), reduced vehicle cost (most likely in the medium term) and increasing CO_2-taxes (most likely in the long term). Secondly, transitions to other vehicle concepts will have profound impacts on the distribution of revenues in the automotive sector, in particular on tax revenues and this is likely to lead to changing fiscal regimes along the transition path.

3 Competitive Position of Vehicle Options in the Long Run

Long-term dynamics on automotive market

The simplified picture presented as an introduction to our stylistic analysis of the battlefield for the car of the future is misleading in several ways. First of all, hydrogen fuel cell cars will not compete with conventional gasoline cars, but with new car drive trains that may use new fuels such as biofuels or electricity. Secondly, gas price developments are not independent of oil price developments and as long as hydrogen production is based on SMR processes, higher oil prices will also imply higher hydrogen costs. Finally, increasing carbon taxes will ultimately lead to new hydrogen and electricity production processes that may reduce carbon emissions drastically and thereby affect the future competitiveness of vehicle options in a

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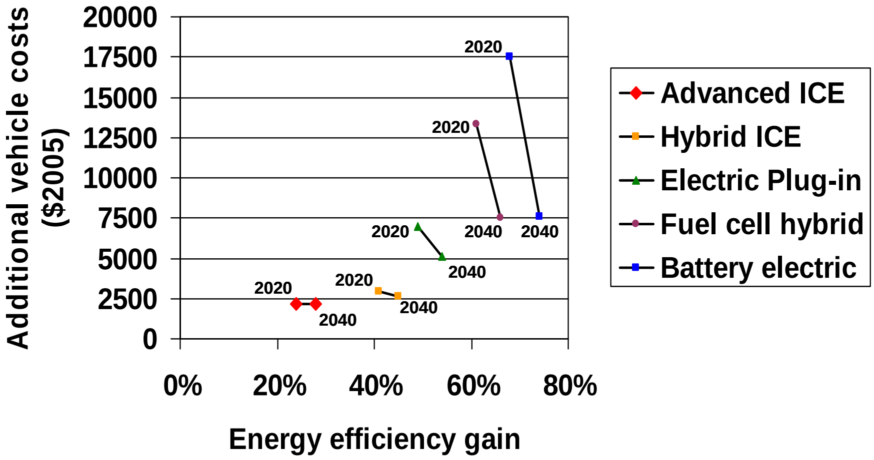
[4] Well-to-wheel emissions are assumed to be respectively 206 and 103 gCO_2/km for the gasoline ICE and hydrogen car.

[5] For this calculation we have raised the SMR production cost margin by 50% with a capture efficiency of 90%.

carbon constrained world. We will consider this dynamic storyline in the next step of our analysis.

Basic technological data from recent IEA study

The International Energy Agency (IEA) has recently published a detailed scenario study for global developments in the transportation sector including assumptions about performance improvements of vehicle options [4]. We have used the technological data of this IEA study as the basic data for future technological improvements for five competing vehicle concepts: the advanced gasoline ICE, the hybrid ICE, the electric plug-in, the fuel cell hybrid and the battery electric car.[6] Figure 2 illustrates the essential data presented in this study.



Source: Transport, Energy and CO_2, IEA/OECD, 2009

Figure 2: Long term vehicle performance improvement.

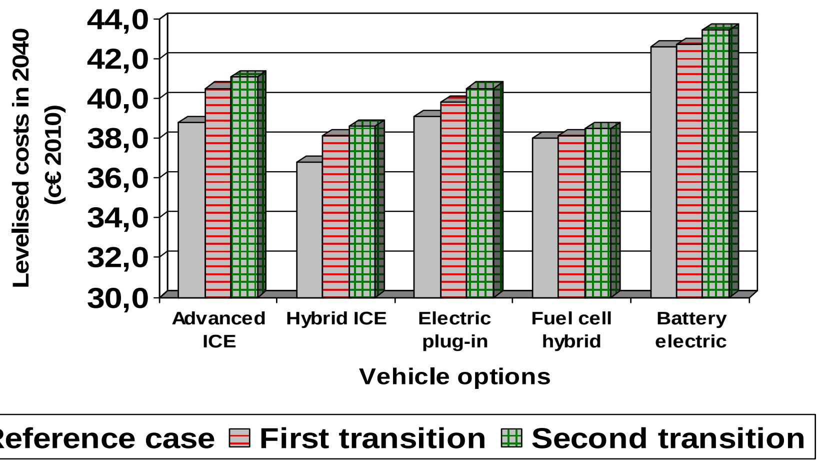
Comparative performance of vehicle options in reference case

In the reference case we now follow the world oil price assumptions of the IEA transport scenarios. They assume oil prices at 100 $/barrel in 2020 and 120 $/barrel in 2030 remaining constant afterward. For European natural gas prices we assume a 2020 level of 0.36 €/m3 in 2020 and a coupling with oil prices reflecting a cross-price elasticity of 0.4.[7] European electricity gate prices are assumed to move to 0.07 €/kWh in 2020 and remain stable afterwards. For carbon prices we assume a modest level of 30 €/tonne CO_2 in 2020 rising to 50 € from 2030 onwards. Under these reference conditions the gasoline hybrid ICE is the

[6] The IEA considers 10 drive train configurations in addition to the advanced ICE vehicle. We have left out the compression ignition options here because they are essentially similar to spark ignition alternatives. We have left out the pure fuel cell alternative, because its performance will never compete with the fuel cell hybrid. From the battery electric vehicles we have only included the 200 km range vehicle. Moreover, we assume that short-term improvements are technically feasible by 2020 and long-term improvements by 2040.

[7] This relatively low estimate reflects expected changes in natural gas pricing away from conventional coupling to oil prices in long-term contracts towards independent markets with relatively ample supplies from unconventional sources.

winner in both the short and the long term (see figure 3). It is interesting to note, that the electric plug-in is the runner-up in the short term, while the fuel cell hybrid is the runner-up in the long-term. Somewhat surprisingly in view of the present electric car hype, the battery electric car is the only clear loser, both in the short term and in the long term. Apparently, many experts in transportation, both in industry and government, use different assumptions about vehicle costs and fuel prices than the IEA or they have other reasons than levelized costs calculations to sustain their views on the future of the battery electric car.



Key assumptions: IEA performance data, first transition based on oil price of 170$/barrel, second transition based on oil price of 140$/barrel, CO_2 price of 140 €/tonne

Figure 3: Long-term competitive performance of alternative vehicle options.

First stage of transition towards sustainable hydrogen: higher oil prices

The continued success of hybrid ICE vehicles in the short run will not only weaken the competitive position of alternative vehicle options, it will also lead to continuing pressure on global oil markets and increasing oil prices. This development will ultimately strengthen the long run competitive position of fuel cell hybrids. When oil prices would move to 170 $/barrel in 2020, the hybrid ICE would remain the winner in the short run, but the fuel cell hybrid would be able to compete in the long run.

Second stage of transition towards sustainable hydrogen: increasing carbon taxes

When both oil prices and carbon taxes are permanently higher than assumed in the reference case, it is not only technological change in the automotive industry that determines the competitive position of vehicle options. Technological changes in the generation of liquid fuels, electricity and hydrogen will be induced that may threaten the competitive position of the hydrogen fuel cell hybrid. In particular, biofuels will increase their share in the liquid fuel market and low-carbon electricity generation options will increase their share in the European generation mix. Also, higher levels of natural-gas derived hydrogen will undoubtedly start to affect European natural gas prices. Let us assume that an permanent oil price of 140 $/barrel would induce a 50% share of biofuels in the liquid fuel market by 2040 and that a carbon price of 140 €/tonne would induce a generation mix halving European average emissions from roughly 270 to 135 gCO_2/kWh by 2040. Let us also assume that under these conditions all hydrogen is produced from CCS equipped SRM plants and that natural gas prices follow oil prices completely. In this second transition stage, the fuel cell hybrid is still able to compete with the advanced ICE and continues to outperform the electric plug-in hybrid.

The crucial role of European fiscal regimes

The conclusions on competitive performance drawn in this analysis are based on one key assumption that may prove decisive on the battlefield between vehicle concepts: fiscal regimes in the automotive market. The calculations presented are all based on a stable fiscal regime with high excise taxes on liquid fuels, moderate excise taxes on electricity and low excise taxes on natural gas in transportation, which is representative of the average European situation today. It should be noted, that without fiscal regime changes government revenues would erode during a transition towards non-liquid, low-carbon fuels, in particular when regulatory carbon taxes prove to be effective in changing the vehicle fleet and fuel generation mix fast. Moreover, although ownership taxes offer a better window-of-opportunity to stimulate transitions towards efficient, low-carbon cars than fuel taxes in view of the limited, economic time horizon of average car owners and the increasing share of vehicle cost in total levelized costs, the European fiscal regime is moving away from vehicle ownership taxes in order to stimulate a homogenous European automotive market. If Europe wishes to compete in the oil-scarce and carbon-constrained world of the future by creating an attractive home market, innovations in long-term fiscal regime strategy are required: first replacing excise taxes with carbon taxes to absorb oil price shocks, second replacing fuel taxes with ownership taxes to stimulate entry of new vehicle concepts and finally replacing carbon taxes with road charges to prevent erosion of tax revenues in a space-constrained instead of carbon-constrained world.

4 What Makes a Sustainable Hydrogen Economy Feasible in the Long Run?

Global oil price escalation, vehicle cost reduction and high carbon price levels

Recent studies on the comparative performance of future car concepts arrive at similar conclusions regarding the future competitive position of hydrogen cars [5,6]. In this study we have analyzed specifically how oil price escalation and fiscal regimes could improve the competiveness of hydrogen cars. In our view, the economic feasibility of the hydrogen car and thereby the hydrogen economy can be viewed as a three-stage balancing act between increasing oil prices (most likely in the short term), reduced vehicle cost (most likely in the medium term) and increasing CO_2-taxes (most likely in the long term). This is the first major message of this analysis. A sustainable hydrogen economy depends on consecutive, major changes in these three key economic parameters. Global oil price escalation must first reduce the competitive edge of the fossil fuel hybrid ICE around 2020. Than hydrogen vehicle cost must be reduced drastically after 2020 to gain share in the market and finally, increasing carbon taxes must induce a continuous shift towards low-carbon generation technologies that could dominate the fuel market after 2030 and favour hydrogen cars.

Sustainable fiscal regime strategy must interact flexibly with market forces

Policy makers can actively strive to guide the evolving automotive market in a sustainable direction by consecutive changes in fiscal policies that support the move towards low-carbon vehicle choices. The present European fiscal regime is inclined towards high levels of excise taxes on liquid fuels and zero vehicle ownership taxes that are considered detrimental for a competitive European market. The feasibility of a sustainable hydrogen economy would be substantially enhanced, if European fiscal regimes would follow a flexible strategy, in which today's excise taxes on liquid fuels are gradually replaced by increasing carbon taxes that keep government revenues stable in the short run. Once vehicle costs enter competitive levels, ownership taxes and subsidies (bonus-malus arrangements) should speed up penetration rates. But ultimately, regulatory carbon taxes, if successful in reducing emissions drastically, would again erode the tax base. At that time, road charges may have gained sufficient support to follow-up fuel charges and keep governments revenues stable.

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