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Carmen Cantuarias, Benno Weinberger, Leonardo Roses, Alexis Vignes, Jean-Marc Brignon

AN EARLY TRANSITION OF HYDROGEN-BASED TRANSPORT IN EUROPE BY INCLUDING THE CARBON PRICE

Carmen Cantuarias[1], Benno Weinberger[2], Leonardo Roses[3], Alexis Vignes[2] and Jean-Marc Brignon[1]
[1] INERIS, Economics and Decision for the Environment, [2] INERIS, Sustainable Process and Energy
Parc Technologique ALATA BP 2, 60550 Verneuil-en-Halatte, France.
[3] HyGear B.V. Industry Park De Kleefse Waard, Arnhem,The Netherlands.
email: carmen.cantuarias@ineris.fr

Abstract

Today the transport sector is responsible for one-fifth of the total European greenhouse gas emissions. The rate of integration of hydrogen technologies in the energy mix, and especially the use of hydrogen fuel cell (FC) vehicles can significantly reduce these emissions. We present a cost-benefit analysis to estimate the year of economic conversion – year when the replacement between FC and gasoline internal combustion engine vehicles begins profitable. From the economic conversion, we value the carbon price needed for the reduction of greenhouse emissions by FC. We estimate that carbon taxes could finance approximately 10% of the deployment costs of hydrogen-based transport.

This article focuses on the projected demand for decentralized hydrogen production infrastructure. Three potential hydrogen demand scenarios are examined. Further the associated hydrogen production and the impact of these scenarios on the reduction of greenhouse emissions are studied estimating the abatement cost. We consider a hydrogen production mix of natural gas reforming processes, with capture and storage of carbon, electrolysis, biogas processes and decentralized production. It is assumed that the hydrogen production will be integrated in the hydrogen fueling stations respecting the proposed European directive on the deployment of alternative fuel infrastructure which is taking into account safety aspects.

Keywords: *Hydrogen economy, hydrogen fuel cell vehicles, hydrogen refueling stations, cost-benefit analysis, abatement cost of hydrogen, Europe.*

1 Introduction

Several studies have explored the potential technological innovations, the associated economic conditions and prospective scenarios for the deployment of new power-trains in Europe [1]–[4]. Hydrogen requires a comprehensive support scheme which bridges the gap between three dimensions – market requirements, sustainability and climate requirements, and hydrogen technology development [5].

We present a cost-benefit analysis framework to assess the progressive replacement of gasoline internal combustion engine (ICE) vehicles by hydrogen FC vehicles in the European market over the period 2015-2055. We estimated the marginal abatement cost of the hydrogen transport in terms of carbon price for three scenarios. We included the valuation of carbon emissions in the net present value for the moderate scenario to estimate the share that carbon taxes could finance in the transition to hydrogen as an alternative fuel for transportation.

2 Materials and Methods

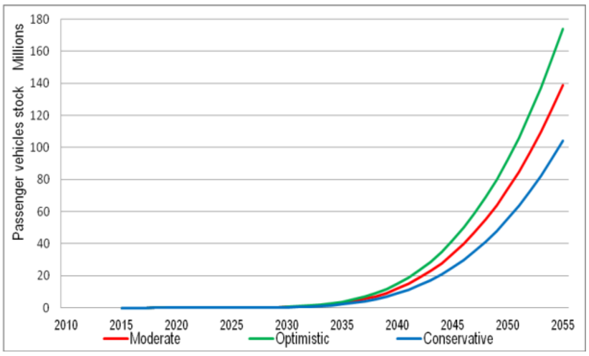
Hydrogen demand from FC vehicles in Europe

We assume new registrations of passenger cars in Europe – 11 825 400 cars in 2013 [6] – will be replaced by the FC vehicles gradually following the Energy Technology Perspectives (ETP) 2014[7] tendencies.

The ETP model estimates the energy flows highlighting the different fuels – coal and oil products, natural gas, biofuels, electricity and hydrogen – for three target scenarios of climate change rate through 2050. We work with base data for transport of passenger light vehicles of hydrogen that assumes actions to limit global warming to 2°C.

The forecasted demand of FC vehicles from 2015 to 2055 and the three scenarios namely optimistic, moderate and conservative follow the same exponential path as in the European project HyWays, POLES model and PROTEC H2 project [8], [9]. Based on demand from FC vehicles, we estimated hydrogen demand assuming a vehicle efficiency of 0.95 Kg H_2/100 km in 2015 to 0.7 Kg H_2/100 km in 2050 [10], [11]; a driving range on one fill-up of approximately 600 km; a lifetime vehicle of 10 years; and three group of countries with different average daily driven distance – Poland and Spain (80 km), Italy, Germany and France (60 km), and United Kingdom (40 km). Hydrogen demands are presented in Figure 1.

Figure 1: Hydrogen fuel cell vehicles EU-28



Supply of hydrogen refueling stations (HRS)

We assume the on-site production facilities at the fueling stations are designed for 50 Nm^3/h of hydrogen, which corresponds to refilling 25 vehicles per day [12] and a daily storage capacity of 100 KgH_2.

The capital cost per HRS with on-site production is estimated to decrease from k€ 1500 in 2015 to k€ 700 in 2050 and the annual operating and maintenance cost from 10% to 8% of the capital cost [10]. The number of HRS results from the demand of hydrogen for each three different daily driven distance scenarios.

Cost-benefit analysis (CBA) of hydrogen in Europe

The cost-benefit analysis is a comparative exercice between FC and ICE and it includes purchase and maintenance cost, fuel cost, infrastructure cost, lifetime of vehicles, and the hydrogen production mix (SMR off-site from natural gas, SMR with carbon capture and storage (CCS), electrolysis, biogas, SMR on-site type station). The main assumptions are the H2 production mix and the fuel cost associated, see Figure 2 and Figure **3**.

Figure 2 : Hydrogen production mix

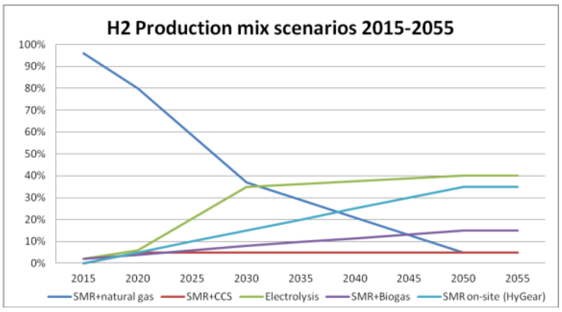
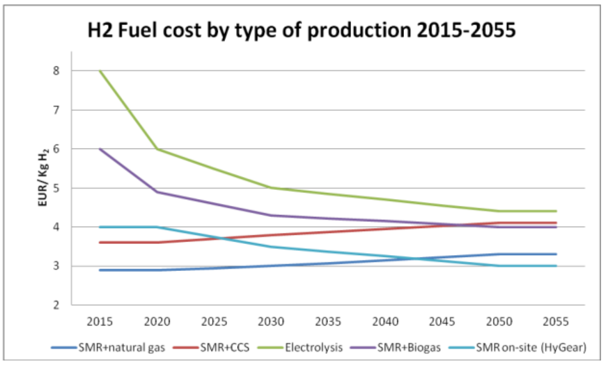


Figure 3 : Hydrogen fuel cost



The economic comparison between FC and ICE vehicles is based on the total cost of ownership – TCO[1], see Equation 1. It describes the costs associated over the lifetime of a vehicle and includes purchase price (sum of all costs to deliver the assembled vehicle to the customer) and running cost (infrastructure and fuel cost and maintenance cost of a vehicle).

TCO = Purchase price + Running cost

Equation 1: Total cost of ownership (TCO) equation

In a CBA framework, benefits and costs are computed in monetary units and all positives and negatives impacts produced on the project should be appropriately priced.

First, we consider the economic comparison by the difference between buying a FC including the infrastructure needed and the conventional case of buying an ICE vehicle. It is the variation of TCO, see Équation 2. The year of economic conversion is the time when the total cost of FC is equal to total cost of ICE for the period analyzed.

ΔTCO = Δ Purchase and maintenance cost [FC – ICE] +
Δ Fuel cost [FC – ICE]+
Infrastructure cost (HRS) per unit of car in market.
= Total cost of FC – Total cost of ICE.

Équation 2: Variation of the total cost of ownership

The total deployment cost of hydrogen-based transport is the variation of TCO multiplied by the number of cars.

Second, we assess climate change impacts avoided with hydrogen-based transport by estimating the abatement cost of carbon. Our aim is to estimate the carbon price needed to assess whether hydrogen FC vehicle should be social profitable. We determine the threshold price at which the replacement between FC and ICE is launched if and only if the price of CO_2 is above this threshold [10].

Abatement cost (AC) of carbon by delivered hydrogen

To evaluate carbon emissions, we used the life cycle analysis studies [13]–[15] for the emissions of the hydrogen production mix and emissions of the ICE vehicles. We assessed the variation of CO_2 avoided per vehicle.
Then, we calculate the abatement cost of CO_2 for the substitution of all cars each year as follows in Equation 3. We assume that this abatement cost represents the price of carbon in the year t.

AC_t = Total deployment $cost_t$ / Δ CO_2 $avoided_t$.

Equation 3: Abatement cost of carbon

We also compute the net present value of carbon price from annual value given by Equation 3. Then, we evaluate the whole deployment as an investment, spread from 2015 to 2055, in a fleet of vehicles that function and abate emissions and we measure the net present value in 2015 over the social discount rate of 5% [16]. This calculation of carbon price is carried out for each of the three scenarios.

Finally, we evaluate the share of monetarized emissions (carbon emissions avoided multiplied by the carbon price estimated) in the present value of the whole deployment cost in 2015. It represents the contribution of carbon tax – if this tax is set at previously computed carbon prices – to the transition of an hydrogen-based car transportation system.

3 Results and Discussion

The results for the base scenario are given in Annex 1. In the optimistic scenario the economic comparison by TCO converges in 2049, in the moderate scenario in 2052 and in the conservative in 2054. These are the years when the FC and ICE vehicles have the same lifetime cost. It is nevertheless a first step in the total deployment evaluation. Next, we integrate the abatement cost of hydrogen vehicles by the estimation of carbon price for each year (in each scenario) in 2055 and we actualized the carbon price to 2015.

Based on the moderate scenario, we estimate the abatement cost by delivered hydrogen in approximately €18/t-eq. CO_2 in 2015, and a net present value of deployment cost €382 MM. We value greenhouse emissions avoided by FC at 2 MM tonnes CO_2 in 2015. From these results, we estimate that carbon taxes could finance 10.5% approximately of the hydrogen transition for the period analyzed.

While the different technologies of onsite production have to prove their economic feasibility, further normative work is also necessary in order to facilitate their introduction to markets and enable interoperability to the existing infrastructure and appliance providing an enhanced protection of users. This is in the scope of Directive 2014/94/EU on the deployment of alternative fuels infrastructure making technical specifications for hydrogen refueling points for vehicles. Therefore the directive takes reference to several norms actually treated by the CEN 268 WG 5 hydrogen refueling station in order to guarantee also safe aspects.

4 Conclusions

The present cost-benefit analysis integrates the societal benefits in terms of reduction in greenhouse gas emissions. We compare carbon prices estimated in this study with the ETP model assumptions and our estimates are close to this model. The ETP model (2°C) estimates the carbon price between €30 – €50/t-eq. CO_2 in 2015 and €140 – €170/t-eq. CO_2 in 2050.

We conclude that the replacement from ICE to FC conveys a net social benefit from 2052 onwards in the moderate scenario and including carbon tax could accelerate this transition. Today, under our moderate assumptions, to internalize carbon price could finance approximately 10% of the hydrogen-based car transport from 2015 to 2055.

Like shown today Finland, the Netherlands, and Israel among others have nevertheless reformed existing ad valorem taxes on new cars to affect relative prices of cars by emissions level and to promote proliferation of low-emissions vehicles[18].

To extend the present cost-benefit analysis of hydrogen-based transport, it would also be important to consider other aspects such as air pollutant emissions[17], noise benefits and social acceptability of hydrogen risks.

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Annex 1: Cost-Benefit Analysis of FC/ ICE vehicles in EU-28

Base Scenario	Unit	2015	2020	2025	2030	2035	2040	2045	2050	2055
Demand: number of H2 FC vehicles		110	125 055	136 247	477 425	2 995 407	11 893 057	33 574 123	74 034 993	138 994 978
∆ Purchase and maintenance cost FC-ICE / year per unit of car	k€	40,60	13,14	13,10	9,82	5,50	2,72	0,89	-0,34	-1,22
∆ Fuel cost FC-ICE/year per unit of car	k€	-1,10	-1,34	-0,90	-0,94	-1,02	-1,10	-1,20	-1,30	-1,35
Supply: number of hydrogen refueling station (HRS)		1	534	217	1 629	9 939	37 703	104 495	225 514	418 912
Infrastructure costs (capital and O&M) per HRS	k€	1 650	1 237	1 282	1 183	1 100	1 043	1 001	971	947
Infrastructure costs (HRS) per unit of car in market	k€	9,41	5,28	2,04	4,04	3,65	3,31	3,12	2,96	2,86
∆ TCO per vehicle *	k€	48,90	17,09	14,24	12,92	8,13	4,92	2,81	1,32	0,29
Deployment cost**	M€	5	2 137	1 940	6 167	24 359	58 549	94 332	97 643	39 718
Climate change impacts										
∆CO_2 emissions avoided per vehicle	t-eq. CO_2	-2,25	-2,07	-1,66	-1,93	-2,00	-2,06	-2,13	-2,18	-2,18
CO_2 Prices										
Conservative (14600 Km/year)	€/ t-eq. CO_2	41,73								293,77
Moderate (21900 Km/year)	€/ t-eq. CO_2	18,58								130,78
Optimistic (29200 Km/year)	€/ t-eq. CO_2	5,64								39,72

* ∆ TCO = ∆ Purchase and maintenance cost [FC-ICE]+∆ Fuel cost [FC-ICE]+ Infrastructure costs (HRS) per unit of car in market = Total cost FC - Total cost ICE.
**Deployment cost =number of cars*∆ TCO.