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The potential contribution of hydrogen to societal goals

by

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Research Paper 04/07

Research Papers from the Energy, Environment, and Climate Group (EECG) at the Department of Environmental, Social and Spatial Change (ENSPAC), Roskilde University, Denmark.

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ISBN: 978-87-7349-714-2

Abstract

The hydrogen future demonstrated in the Zero Regio and similar projects depends on a continuing government commitment to engage in the development of the technology and promote its use in transport in Europe. The prospects for such a persistent government engagement depend on the extent to which the technology can contribute to the achievements of societal goals. In this paper, the potential contribution to such societal goals from hydrogen and fuel cell technology is reviewed. The goals considered include energy efficiency, eco-efficiency, supply security, and cost-efficiency. The conclusion is that a significant contribution to these goals is beyond 2020 and requires that hydrogen is based on energy sources such as renewables and fourth generation nuclear energy the energy supply of which share these characteristics. High oil prices means that this may also be the most economic solution.

Acknowledgements:

This study is carried through as a part of the Zero Regio project financed through the European Union's 6th framework programme for research and technological development. The Zero Regio project tests and demonstrates hydrogen infrastructure solutions in Frankfurt (Germany) and Mantova (Italy) and at the same time explores how the hydrogen and fuel cell solutions will work in a socioeconomic context.

Valuable comments from the project partners are gratefully acknowledged.

Academic disciplines involved:

Energy economics, environmental economics

Keywords:

Energy economics

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Introduction

When the International Energy Agency (IEA) (2006) introduced the World Energy Outlook 2006 with the words *"The energy future which we are creating is unsustainable"*, it was not least referring to the fact that transport activity all over the world almost exclusively is fuelled by transport fuels based on mineral oil.

Globally, we will probably have 55% additional motor vehicles (or maybe more) on the roads in 2030, but the supply of oil will hardly grow at same pace.

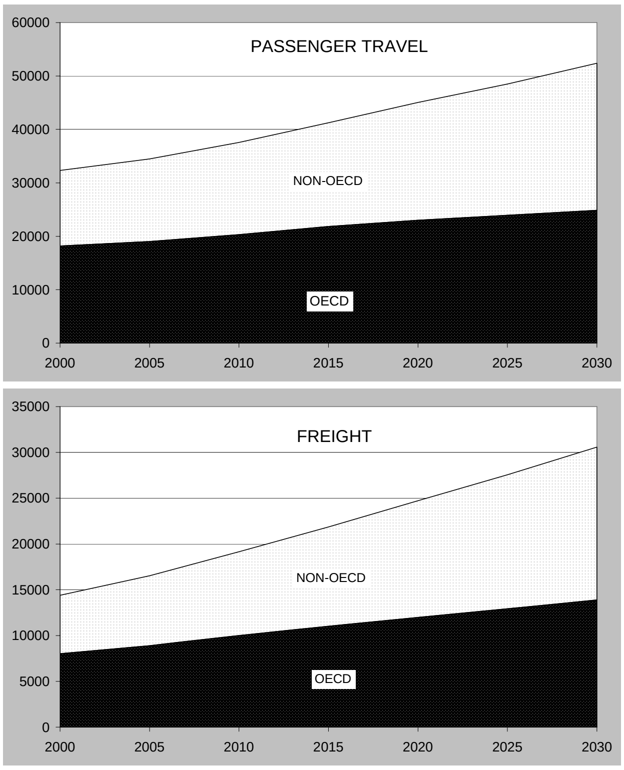

Figure 1. Global Transport Activity Projection 2000-2030 (passengerkm and tonkm)

Source: Reference Scenario in World Business Council for Sustainable Development (WBCSD) and International Energy Agency (IEA) (2004).

Additionally, the level of CO_2 emissions from this fuel combustion is already unsustainably high.

Excise of market power has increased and the tight market leads to increasing risk of supply disruptions due to natural disasters as well as social and political conflict in oil producing countries and even politically motivated use of market power.

This has made the supply of oil less reliable, more insecure, and much more expensive. On the other hand the high oil prices make alternative fuels economically competitive.

One of these is hydrogen and hydrogen and fuel cell technology assumes a central role in the strategy of the European Union to develop alternatives that can contribute to a sustainable energy future.

Despite the high oil prices, alternative fuels do not automatically compete their way into the transport fuel market. The technology in the transport sector is “locked in” to technologies using oil based fuels in combustion engines and it has been so for around a century. Alternatives are not able to break into the sectors for a number of reasons. One of the reasons is that hen-and-egg problem.

The demand for alternative fuels come when there is a supply and the supply comes when there is a demand. Alternative fuel suppliers don’t establish an infrastructure and distribute the alternative fuels before there are sufficient alternative vehicles to use it. Consumers don’t buy alternative vehicles before they are sure they can buy the alternative fuels. Carmakers don’t develop and produce alternative vehicles before they are sure the consumers will buy them. And nobody devotes the necessary research and development resources to the development of the alternatives before they are sure that there is a market for them in the future.

Thus, the alternatives require government intervention. Not just in some years, but persistently over several decades and coordinated across borders and sectors. Such a consistent government endeavour is not plausible unless there are clear contributions to the societal goals that are classic in the sense that they survive shifting governments and political agendas.

One out of hundreds of government interventions in Europe is the Zero Regio project establishing two hydrogen filling stations in order to demonstrate and test the hydrogen and fuel cell technologies. The question addressed in this paper is how such technologies as those implemented in the Zero Regio project will be able to contribute to the achievements of the societal goals related to the development of the transport sector.

The paper is organised so that the introduction contains another two sections about the Zero Regio project and the relevant societal goals. Then the technologies are examined with respect to each of the societal goals. Finally, the potential contribution in a dynamic perspective is discussed.

The Zero Regio pathways

In the period 2006-2009 a set of hydrogen supply and use options are tested and demonstrated in the Zero Regio project in Frankfurt A.M. and Mantova (Italy). The project has a socioeconomic component the aim of which is to analyse the technical solutions in a wider social context.

This paper was originally intended to deal exclusively with the macroeconomic aspects whereas the microeconomic aspects should be treated in a separate analysis. However, during the process it was found to be more expedient to mix the two economic perspectives in particular in the case of regional economic effects.

The technical solutions in Frankfurt involve hydrogen as co-product from chlorine production, transported via a pipeline to a multifuel station and used as a fuel for a fleet of fuel cell vehicles. A side project in Frankfurt involves liquid hydrogen delivered by truck and used in hydrogen internal combustion vehicles, but this solution is not part of the ZR-project.

The fuel chain is depicted below.

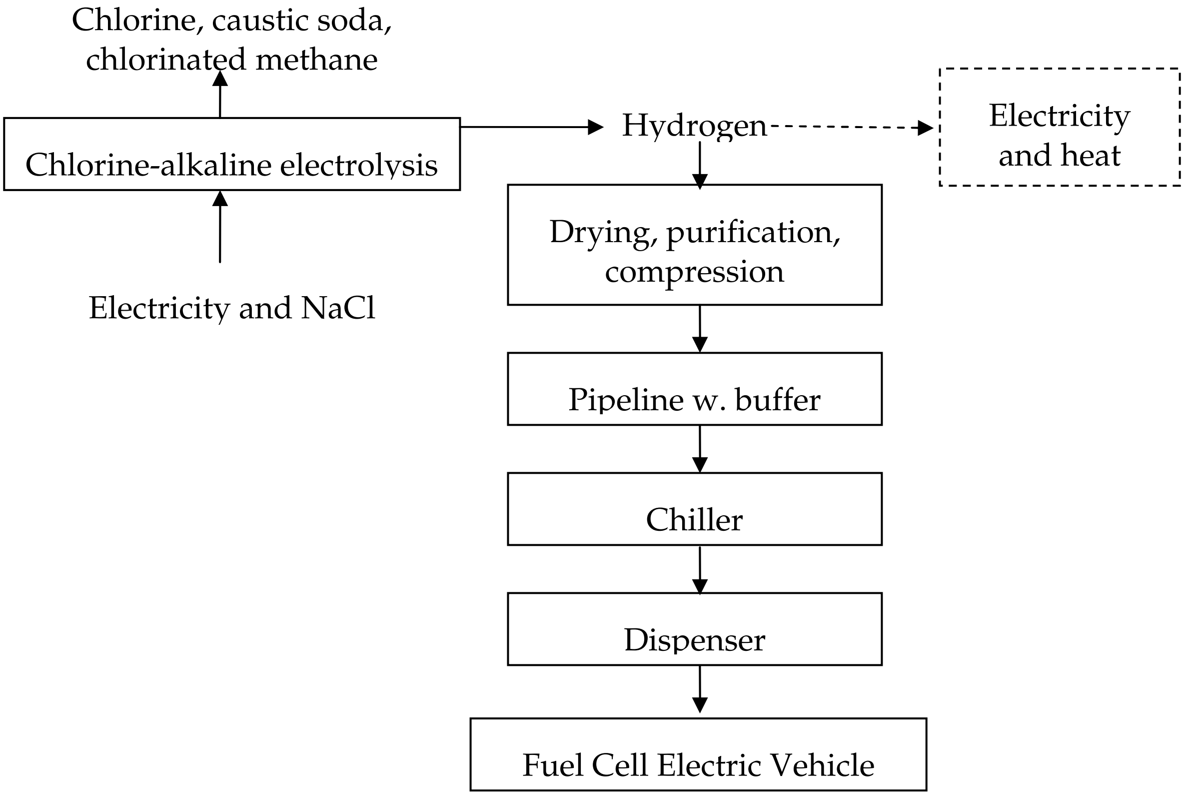

Figure 2. The hydrogen fuel chain at the Frankfurt project site.

The hydrogen originates as a co-product from production of chlorine at a plant in the Hoechst industrial area. Prior to the project, the hydrogen was fed into a power plant, producing electricity and heat.

A compressor raises the pressure of the hydrogen to 850 bars and a pipeline provides the transport of hydrogen to the filling station. Due to the compression, the temperature of the hydrogen is raised and needs to be cooled down a level safe for dispensing. The hydrogen is stored in the tank of a fuel cell vehicle in compressed form.

The energy required for the hydrogen in the tank can be decomposed into throughput energy and auxiliary energy requirements. The throughput energy requirement is the primary energy required for producing the electricity used for equivalent. The auxiliary energy requirement is the electricity consumed along the fuel chain for compression, chilling, and operating of other infrastructure equipment.

The hydrogen is primarily used in a car fleet of Daimler-Chrysler F-cell vehicle (A-class) vehicles leased by the Frankfurt Airport for operation outside the airport.

At the project site in Mantova, another set of options are tested and demonstrated. The fuel chain is shown below.

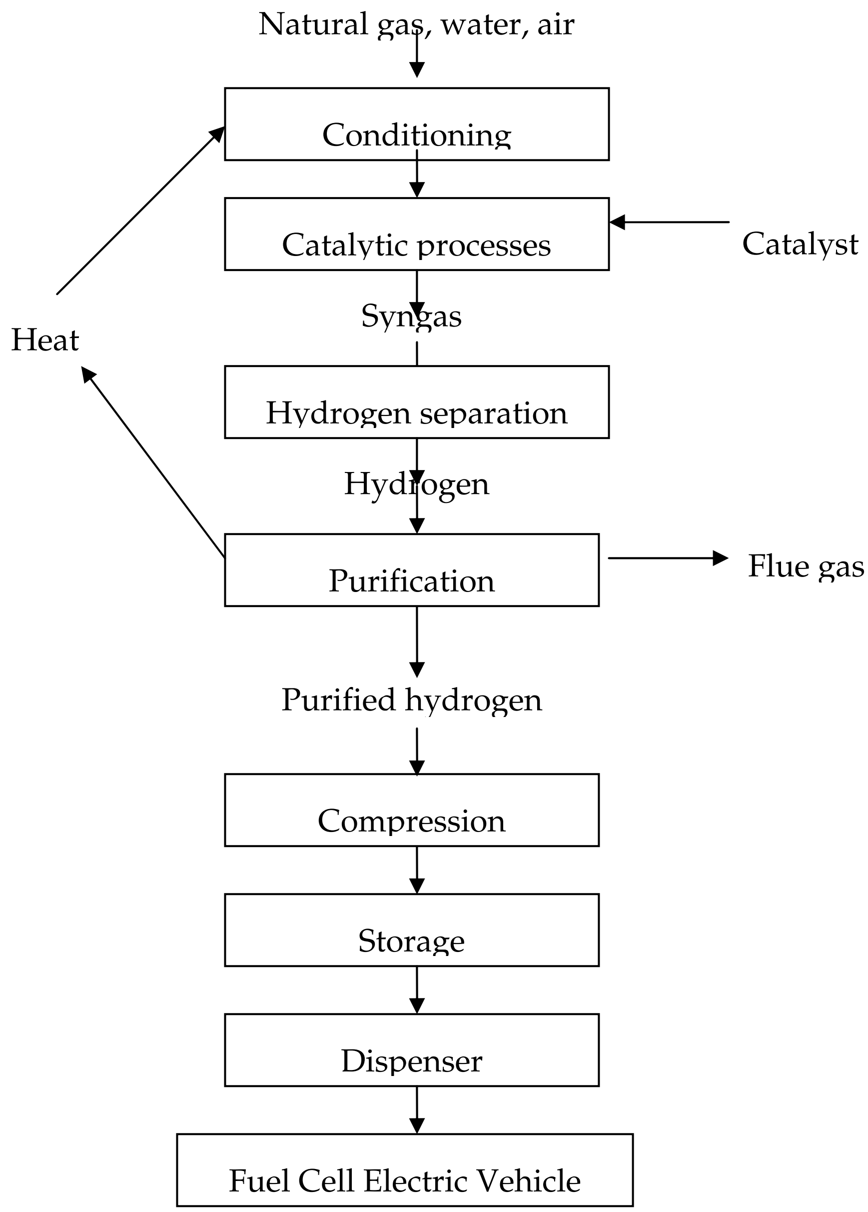

Figure 3. The hydrogen fuel chain at the Mantova project site.

The hydrogen is produced from natural gas using the partial oxidation technology developed by ENI. This conversion process has the attractive property that it is endothermic, which means that the process itself does not involve combustion of natural gas. The individual processes do, however, need auxiliary energy in the form of electricity.

The processes also involve emissions in the flue gas, the amount of which will be studied during the test.

What this technology basically does to the problem of oil lock-in is that it allows for the use of natural gas as feedstock for the production of a transport fuel. Compressed natural gas is already used as fuel directly in internal combustion engines, but hydrogen can be used in a fuel cell which in combination with an electromotor is much more efficient than an internal combustion engine. Moreover, varieties of the technology can be used with gasification of other fuels including coal and biomass.

The hydrogen is used in a car fleet of Fiat Panda Hydrogen vehicles leased by the city of Mantova.

Societal priorities

The societal priorities of Europe are expressed in the energy policies of each country as well as the common policies of the European Union. They include the Lisbon strategy, the sustainable development strategy, the energy policy, and the programmes for sustainable mobility and the CAR21 programme.

These energy policies are concerned with very many aspects relating to the development of a sustainable transportation sector, but they also share four fundamental societal priorities. They include using the energy made available in the best way, achieving the energy services at as low costs as possible, damaging the environment as little as possible, and obtaining the best possible security of supply of the energy commodities.

Obviously, they are related to growth objectives and such they represent macroeconomic challenges. The following primarily macroeconomic terms reflect these societal priorities on the aggregate level:

1. Energy efficiency
2. Eco-efficiency
3. Security of energy supply
4. Cost effectiveness

In the following these societal priorities will be reviewed.

Energy efficiency

The superior energy efficiency of the H_2&FC power-train is the main benefit of the technology. It enables exhaust and noise free electric motor propulsion with a minimum of energy input. Compared to the ICE technology, fuel cells get much more usable energy out of the fuel. Some studies estimate that fuel cells on hydrogen can get extra 140% transport work out of a given amount of energy.

The problem is that the transformation of primary energy to hydrogen and its distribution to the tank can consume a lot of this prospective gain. For H_2&FC

technologies to be a solution to the challenges described above, the efficiency of the entire fuel chain must be high.

The ratio of energy content in the fuel "at pump" to the energy content in primary energy feedstock is called the *system efficiency*. Since the experiences with hydrogen production for automotive purposes are all with experimental projects it is difficult to know what the system efficiency will be when the technology is implemented. National Academy of Science (2004) assumes system efficiencies of converting fossil energy to hydrogen ranging from 54% (coal with CCS) to 78% (future natural gas reforming). Based on the European literature Hansen (2007c) and Hansen (2007e) use the system efficiencies 62% and 70% for natural gas based hydrogen and 62% and 75% for electrolysis based hydrogen.

Another problem is that fuel cell vehicles will not be competing with today's vehicles, but rather with some of the more advanced generations of ICE, hybrid electric, and battery electric vehicles as described above. The table below shows the assumptions of Tank-to-Wheel (TtW) efficiencies for fuel/powertrain technologies that will be competing with H_2&FC according to the leading analysts in the Europe and USA.

Table 1. Additional Energy Efficiency of Hydrogen and Fuel Cell Vehicles Over Most Efficient Competing Technologies in 2010

JRC EUCAR and CONCAVE (2006):	
Direct hydrogen	0%
Direct hydrogen hybrid	-11%
Gasoline PISI hybrid	72%
Gasoline/ethanol DISI hybrid	73%
Diesel/biodiesel DICI+DPF hybrid	55%
CNG PISI	48%
LH2 PISI	40%
Argonne National Laboratory (2007):	
CIDI Vehicle (CD, BD, FTD, DME,RFG)	71%
Gasoline etc. hybrids (EtOH, MeOH, NG, RFG)	53%
Diesel etc. hybrids (BD, FTD, or CD)	33%
Hydrogen Fuel-Cell Vehicles	0%
Electric Vehicles	-34%

The table shows the expected nearest competitors. Compared to hybrid electric vehicles or advanced diesel technology the efficiency advantage is still significant, but much more modest than when comparing to conventional technologies.

The potential contribution to overall energy efficiency depends on the fuel efficiency advantage as well as the system efficiency of fuel production. They are often labelled Tank-to-Wheel (TtW) and Well-to-Tank (WtT) respectively. Together they give the Well-to-Wheel (WtW) efficiency. Replacing low WtW efficiency with high WtW efficiency technology in transport increases the overall energy efficiency of the economy.

Table 2. Possible contributions to energy efficeincy per fuel cell vehicle.

		Hydrogen and fuel cell efficiency						Conv. fuels and ICE	
TtW advantage	*X*	*50%*	*50%*	*75%*	*75%*	*100%*	*100%*	*0%*	
WtT efficiency	*Y*	*62%*	*70%*	*62%*	*70%*	*62%*	*70%*	*92%*	
TtW									
Fuel efficiency	1+x	150%	150%	175%	175%	200%	200%	100%	km/GJ
Fuel required	v=1/(1+x)	0.67	0.67	0.57	0.57	0.50	0.50	1.00	GJ/km
WtT									
System efficiency	Z	62%	70%	62%	70%	62%	70%	92%	GJout/GJin
Primary energy required	u=1/z	1.61	1.43	1.61	1.43	1.61	1.43	1.09	GJin/GJout
WtW									
Primary energy required	v*u	1.08	0.95	0.92	0.82	0.81	0.71	1.09	GJin/km
Efficiency	1/(v*u)	0.93	1.05	1.085	1.225	1.24	1.4	0.92	km/GJin
WtW advantage		1%	14%	1%	18%	33%	52%	0%	

Source: Autor's calculations.

The table shows that the efficiency advantage of the fuel cell vehicle can be "eaten up" by the efficiency loss in the WtT-section of the fuel chain.

The European Union has adopted a target of reducing energy consumption by 20% in 2020 compared to what it otherwise would have been. This is an ambitious target amounting to an annual progress rate in energy efficiency of 3.3%. This should be compared to an annual progress rate for EU25 of 1.3% in the preceding 10 years.

It is the ambition that the transport sector now – as opposed to the previous period – should deliver a serious contribution to this progress in energy efficiency (Commission of the European Communities (2006)) including legislation to reach the target of 120 gCO2/km for new cars in 2012.

The potential contribution of hydrogen and fuel cell vehicles is quite modest as very few fuel cell vehicles will be on the street at that time and there are plenty of opportunities in existing ICE related technologies to improve the energy efficiency of the vehicles. However, the 20% target does not make much sense if it is not continued beyond 2020 and at that time, hydrogen and fuel cells will begin to be able to contribute to the societal goal of curbing the growth of energy demand.

Moreover, this ambitious policy will – if it succeeds – lead to a market situation at the time of introduction of fuel cell vehicles in large scale where the least efficient vehicles will be out of the market. It is thus very likely that fuel cell vehicles will be competing with advanced diesel and hybrid electric vehicles where the efficiency advantage of the fuel cell vehicle will be 50% or even lower.

A model simulation of the future car market based on the Sustainable Mobility Project Model (World Business Council for Sustainable Development (WBCSD) and International Energy Agency (IEA) (2004)) (see the following section) based on this assumption showed that even a fast rise in the market share of fuel cell passenger cars would have a very modest impact on overall energy consumption. This is because it takes market shares from advanced diesel and hybrid electric vehicles as much as it takes market shares from the least inefficient conventional vehicles.

In this situation any government still has reason to support the use of fuel efficient cars, but only little reason to prefer fuel cell cars for other efficient cars. This is in the medium term, i.e., 10-30 years from now. In the long and very long term, however, there are scientific reasons to believe that fuel cell and electro motor technology will be more efficient than the internal combustion engine. In that case, there is no reason to continue using the internal combustion engine longer than necessary.

Eco-efficiency

The EU target of reducing CO_2 emissions by 20% of the 1990 level in 2020 also implies a similar targeted rate of progress in *eco-efficiency*, the ratio of an indicator of economic activity to an indicator of the environmental pressure, it causes. On the level of aggregate GDP for EU27, the macroeconomic requirement derived from the GHG target is to sustain an average growth rate in eco-efficiency of 3.3% from 2005 to 2020. This is ambitious too as the GHG-efficiency growth rate achieved from 1995 to 2005 was on average 2.4%.

Since the start of the GHG accounts in 1990, transport activities have caused a rising share of Europe's total GHG emissions to the level of 21% in 2004 (EU15). The 20% target is hardly achievable without reversing this trend and it raises the question whether hydrogen and fuel cells in automotive use can contribute to this.

The immediate answer is no for the simple reason that until 2020 there will in any case be a very small number of fuel cell vehicles on the roads. Too few to make any difference in the European GHG accounts. However, climate policy doesn't end in 2020 and the perspective as far as the EU is concerned is to continue to reduce GHG emissions to a level that is 60-80% lower than the 1990 level in 2050.

To study the possible contribution to GHG emission reduction from the introduction of passenger cars with hydrogen and fuel cell technology on the European market, a series of scenarios were produced with the Sustainable Mobility Project Model

(World Business Council for Sustainable Development (WBCSD) and International Energy Agency (IEA) (2004)). They are documented in Hansen (2007b).

The scenarios introduced passenger cars with fuel cell technology on the European market from 2015 with a market share growing to 43% in 2050. Two different scenarios with respect to feedstock for hydrogen production were created. One scenario assumed that the hydrogen was produced on the basis of natural gas whereas the other scenario assumed that it was produced by electrolysis from renewable based power.

The contribution to the GHG emission reduction was very different in the two scenarios. In the natural gas based scenario, the aggregate GHG emissions from passenger cars in Europe 2050 was reduced by 14% corresponding to 5% of the emissions from the total transport sector. With the production of hydrogen from CO_2 neutral feedstock the emissions from passenger car transport was reduced by almost 60% corresponding to 18% of the emissions from the total transport sector.

With reference to these scenarios, governments would have reason to support hydrogen as transport fuel as long as it is based on non-fossil energy, but only little if it is based on natural gas or coal without carbon capturing and sequestration.

The two scenarios were also used to study the impact on local air pollutants emitted from passenger car transport such as particle matter (PM), nitrate oxides (NOx), volatile organic compounds (VOC), and carbon monoxide (CO). These pollutants are among other things responsible for smog formation and respiratory system diseases.

The study showed that on the aggregate level the emissions of these pollutants were already drastically reduced in the reference scenario at the time when the fuel cell cars are introduced to the market. This is a result of the EU and member state efficiency requirements, fuel and exhaust standards, and other initiatives under the CAFÉ programme for elinot minating air pollution that damages human health.

The aggregate emissions are, however, not the adequate indicator for local pollutants. These pollutants are trapped in locked air sheds and city air at several locations around in Europe. In these locations governments have a particular reason for continuously supporting the use of electric vehicles whether battery or fuel cell electric and even in some places hybrid electric.

Supply security

The security of supply is as mentioned above maybe the most important driver for looking for alternative fuels. Almost complete dependence of transport on oil based fuels and almost complete control by a few governments of the global oil supply is an unstable situation. To study whether hydrogen could be a transport fuel the supply of which is more secure, the supply security of the various feedstocks that hydrogen can be made from was reviewed. The results are documented in Hansen (2007d).

Hydrogen has a quality that makes it more attractive from a supply security point of view than many other fuels: All other fuels - and in particular electricity - can be converted to hydrogen. The fuels considered for the security of their supply to the European market included natural gas, coal, renewable electricity sources, biomass, and nuclear energy.

The aspects of supply security that was considered included their oil price dependence, market power excised on their markets, and the global scarcity. Additionally, the dependence of the European economies on oil and gas was examined.

The study concluded that renewable electricity sources provided in all three respects the most secure energy supply whereas natural gas was in all three respects the worst alternative to oil. The fuels in between were thorium, biomass, uranium, and coal (with carbon capture and sequestration).

From a supply security point of view, there are good reasons for European governments to continuously support hydrogen based on renewable energy and other carbon free sources, but not to support hydrogen based on natural gas.

Cost effectiveness

Affordable or even inexpensive mobility increases accessibility and is thus a lever as well as a purpose for economic growth. Therefore, cost effectiveness in transport activity is a central concern for governments. The important question is whether and when hydrogen and fuel cell technology provides the same services as conventional technology but at lower costs. This question is addressed by Hansen (2007c).

As described in the energy efficiency section above, it is necessary to take both the costs of the fuel as well as the efficiency of the fuel in the vehicle into account. The decisive parameters in analysing the cost competitiveness (to begin with exclusive of taxes and subsidies) of hydrogen relative to conventional fuels are the system efficiency, the fuel efficiency, the non-energy costs of fuels, and the international oil price.

Hansen (2007c) constructs a model for the analysis of cost effectiveness (or cost competitiveness) of these parameters. As noted above, there is some consensus in the literature about the plausible range of the technical parameters, whereas there is no consensus about the prospects of the future oil price. Thus, the study does not attempt to answer the question of whether hydrogen will be competitive in 2015-2025, but only at which oil price we must expect hydrogen to become competitive. Whether the oil price will be higher or lower than that level in 2015-2025 is a matter of further debate.

The study shows that with a 50% efficiency advantage of fuel cell vehicles over vehicles fuelled by diesel or petrol, system efficiency of 62-70% and non-energy costs of hydrogen at €10-13 per GJ, the oil price would have to be $188-542 per barrel (Brent quality, in 2005 US dollars) to make hydrogen the most cost effective fuel for driving a given distance (assuming that the costs of the vehicle are equal). With a breakthrough in hydrogen handling reducing non-energy costs to €7 per GJ, hydrogen would be come competitive at an oil price of $127 per barrel.

Hydrogen fuelled driving would, however be competitive to petrol and diesel fuelled driving when the fuel cell vehicle is compared to less fuel efficient cars. If hydrogen competes with cars that are only half as fuel efficient as the fuel cell vehicle (i.e., the fuel cell vehicle has an efficiency advantage of 100%), the fuel cell vehicle will be the most cost efficient at oil prices of $60-107 per barrel ($37 in the case of €7 per GJ non-energy costs).

However, the study also shows that at this level of oil price, natural gas will not necessary be the most economic primary energy basis for the production of hydrogen. Even with conservative assumptions about the future efficiency of electrolysis, non-fossil based electricity could be a more economic feedstock in hydrogen production.

Still, advanced diesel technology and hybrid electric technology would be equally competitive. At such an oil price level there will be a cost advantage of buying fuel efficient technology but no cost advantage of buying hydrogen and fuel cell technology rather than advanced diesel and hybrid technology. And as concluded above, in 2015-2025 it is probably more realistic to assume a 50% efficiency advantage to competing solutions than a 100% efficiency advantage. Fuel cell vehicles will just be one out of more efficient solutions. Still, governments - and to some extent consumers too - could prefer it if it is more in accordance with the other societal priorities discussed above.

The government policies in Europe are already strongly supportive to fuel efficient vehicles. The fuel taxes are the highest in the world and in addition to that vehicle taxes are reformed towards fuel efficiency graduation. This is a case where government finance coincides with the societal priority of energy efficiency.

European transport fuels are taxed according to the fuel tax directive at a rate of at least around €10 per GJ. Some member states, however, apply tax rates up to €20 per GJ. Such high fuel taxes vehicle taxes boost the competitiveness effect of the efficiency advantage. Hansen (2007a) analyse the oil price that will make hydrogen competitive using the same model as above, but including fuel taxes.

The results show that applying the same €10 per GJ tax to both conventional fuels and hydrogen in the 50% efficiency advantage case would make hydrogen competitive at an oil price of $85-150 per barrel. This price level is the price that would make non-fossil electricity based hydrogen competitive. Natural gas based hydrogen would be more expensive at this oil price level. This result should be compared with the $188-542 per barrel in the case without taxes referred to above.

It would, however, not be logic to apply the same tax rates to both fuels. A GJ of hydrogen involves much more primary energy consumption upstream in the fuel chain than a GJ of petrol does. Moreover, if the hydrogen is produced using non-fossil fuels there is no rationale in taxing it to further the societal priority for reducing air pollution and GHG emissions. The study showed that if fuels are taxed according to their Well-to-Tank energy use and their environmental impact - that is €10 per GJ for petrol and diesel and €8 per GJ for natural gas as feedstock – then hydrogen based on natural gas would be competitive at oil prices in the range of $115-452 depending on system efficiency etc. Hydrogen based on non-fossil electricity would, however, become competitive at oil prices of $45-110 per barrel. In the member states with fuel taxes at the €20 level, non-fossil electricity based hydrogen is very competitive in any case.

Conclusions

This paper has reviewed the potential contributions of hydrogen and fuel cell technology to furthering some of the important societal goals related to energy and transport in Europe.

Hydrogen and fuel cell technology will be able to contribute to the progress in the European economies as to energy efficiency, eco-efficiency, supply security, and cost-effective transport. But subject to important conditions.

First, implementation of hydrogen and fuel cell technology in automotive use will not be able to give a significant contribution to the societal goals in the near future, that is, until 2020. This is for the simple reason that too few fuel cells will be operating before 2020 to make any significant difference. The ambitious targets of the European energy and climate policy are, however, within reach with already available technological and institutional solutions.

Second, the primary energy basis of the hydrogen is decisive to the potential contribution to the societal goals in Europe when using it. Notably, non-fossil, European, and renewable sources possess qualities that are socially preferable to natural gas based sources. In the medium and long term, hydrogen and fuel cell technology will allow automotive transport to shift from oil based to electricity based fuels.

Third, the natural gas based hydrogen was in recent years regarded as the most cost-effective. However, if the now much higher oil and gas prices remain at their high levels or increase further, the socially more preferable sources will also be the most cost effective.

Fourth, the societal priorities for energy efficiency and eco-efficiency are already implemented in the high fuel taxes in Europe. Specific incentives for hydrogen and fuel cells are not necessary in Europe to make hydrogen fuel cost-efficient to consumers if fuel and vehicle taxes tax energy use and environmental pressure sufficiently. If the current high fuel taxes in Europe relative to the USA are maintained - and if no other incentives are introduced - when the fuel cell technology is ready for commercialisation, the technology will be competitive in Europe a long time before it will become competitive in the USA.

The long term nature of the potential contribution to societal goals also means that the efforts in the near future in the field of hydrogen and fuel cell technology can not be assessed on their contributions to achievement of the near future targets – such as the 3x20 targets – but rather on their contributions to hydrogen and fuel cell technology as a realistic and workable option for Europe in the medium and long term.

The review of how hydrogen and fuel cell technologies relate to the societal priorities in this paper suggests that basing the future supply of hydrogen on non-fossil, European, and renewable energy sources would constitute a solid basis for persistent government engagement in the development of a future hydrogen supply and implementation of fuel cell technology. However, basing hydrogen production on fossil, foreign, and non-renewable sources like natural gas can be necessary as a first generation steppingstone to the second generation advanced and sustainable hydrogen production.

These conclusions paper point forwards to other research including the competition about scarce sustainable energy sources, the dynamics in the relief of one technology generation by the next, and how to use a potential head-start in the use of fuel cell vehicles to exploit industrial first mover advantages.

Literature

Argonne National Laboratory (2007). The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (Greet) Model (The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (Greet) Model).

(2006). Action Plan for Energy Efficiency: Realising the PotentialCOM(2006)545 final

Hansen, A. C. (2007a) Fuel and Vehicle Taxation and Hydrogen Competitiveness in Europe. EECG Research Papers Forthcoming Roskilde University, Department of Environmental, Social, and Spatial Change (ENSPAC) Roskilde

Hansen, A. C. (2007b) Hydrogen and Fuel Cell Technology in Eu Ldv Transport: Potential Contribution to Environmental Goals. EECG Research Papers 2/07 Roskilde University, Department of Environmental, Social, and Spatial Change (ENSPAC) Roskilde http://rudar.ruc.dk/handle/1800/2434

Hansen, A. C. (2007c) The International Oil Price and Hydrogen Competitiveness. EECG Research Papers 1/07 Roskilde University, Department of Environmental, Social, and Spatial Change (ENSPAC) Roskilde http://rudar.ruc.dk/handle/1800/2433

Hansen, A. C. (2007d) The Supply Security of Hydrogen as Transport Fuel. EECG Research Papers Forthcoming Roskilde University, Department of Environmental, Social, and Spatial Change (ENSPAC) Roskilde

Hansen, A. C. (2007e) When Will Hydrogen Become Economic? EECG Research Papers Forthcoming Roskilde University, Department of Environmental, Social, and Spatial Change (ENSPAC) Roskilde

International Energy Agency (IEA) (2006). World Energy Outlook 2006, (ISBN: (World Energy Outlook 2006).

JRC EUCAR and CONCAVE (2006) Well-to-Wheels Analysis of Future Automotive Fuels and Powertrains in the European Context. Version 2b.

National Academy of Science (2004). The Hydrogen Economy: Opportunities, Costs, Barriers, and R&D Needs, National Academies Press, (ISBN: ISBN: 0-309-53068-7), http://www.nap.edu/books/0309091632/html/ (The Hydrogen Economy: Opportunities, Costs, Barriers, and R&D Needs).

World Business Council for Sustainable Development (WBCSD) and International Energy Agency (IEA) (2004). Sustainable Mobility Project Model (Sustainable Mobility Project Model).