# Sustainable Transport: The Hydrogen Case Study

The use of hydrogen as an energy carrier for the transport system has been discussed and tested in research niches for many years. High oil prices, the growing awareness that this will not be a temporary situation and the strong dependency of the European transport system on fossil fuels (more than 97 percent), which raises the issue of the security of energy supply for transport, provokes the search for alternative primary energy sources, new fuels and new technologies for the transport system. In addition, today's transport system causes other adverse impacts like greenhouse gas emissions, other forms of air pollution, transport noise, and accidents.

One of the alternative energy carriers for transport is hydrogen. It can be generated from a number of different primary energy sources, both fossil and non-fossil. These would improve the security of energy supply for transport by increasing the diversity of potential feedstocks and widening the range of geographical sources. Depending on the production pathway of hydrogen, the emission of greenhouse gases can be reduced or completely eliminated. Using hydrogen in fuel cells would solve the problem of air pollution, at least at the point of use, but potentially also at the point of production. Road transport noise in urban areas would be significantly reduced.

Of course, not all (environmental) problems of transport could be solved by hydrogen. For example, the land-take for transport infrastructure, the maintenance of a large and ageing infrastructure network and the congestion issue will not be influenced by changing the energy carrier driving the transport system.

## What was done?

This case study analysed the sustainability of a possible shift of the European transport system towards the use of hydrogen as an energy carrier from a stakeholder perspective and a model-based perspective. The first iteration of the ISA-cycle included stakeholder engagement to obtain different perspectives on sustainable transport, modelling scenarios with the ASTRA model and learning from the experiences for the second iteration. ASTRA (Assessment of Transport Strategies) is a system dynamics model generating time profiles of variables and indicators needed for policy assessment. ASTRA runs scenarios for the period 1990 until 2030 using the first twelve years for calibration of the model. The ASTRA model consists of eight modules, covering population, macroeconomics, regional economics, foreign trade, transport, environment, vehicle fleet and welfare. The model region is EU-25. The first ISA cycle showed that ASTRA is well suited for the analysis of sustainability impacts, but that extra tools would be needed to explore the relationships and processes that will be important for analysing transition dynamics.

For the second iteration ASTRA was extended to assess the prospects for – and environmental and economic impacts of – a transition to alternative fuel vehicles (including hydrogen fuel cell vehicles). Furthermore a new system dynamics ISA-tool was developed to assess the prospects for a hydrogen transition within transport, with a focus on economic policy analysis and

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exploring the co-evolution of fuel infrastructure build-up and vehicle development. Also a transport technology application of the generic transition model (see pages 40 - 42) was developed for an assessment of a hydrogen transition within transport in the context of broader technological change in the system. The new system dynamic model and the transition model were applied in a case study for Germany.

Another important step of the second cycle was the link to other case studies and model activities. This included the modelling of platinum use in hydrogen vehicles (see pages 19 - 22) and possible competition in the use of biomass (see pages 39 - 40).

## Model results

The ASTRA results for the EU-25 show that a transition to hydrogen transport fuels would have positive economic and environmental impacts: an increase in GDP, employment and investment and growth in a number of sectors (electronic, chemical, mechanical, automotive) associated with fuel cell vehicle (FCV) technology. Other sectors are negatively impacted, however, due to expenditure diverted away from other consumer goods (e.g., food, textiles, paper, plastics and catering) towards transport consumption. $CO_2$ emissions from driving activity decline by -4.6 percent by 2030; and there are lower levels of fossil fuel imports (see table below).

Using ASTRA to model vehicle sales, the prospects for - and economic and environmental impacts of - a transition to low-carbon vehicles were assessed. The results indicate that a carbon policy would lead to reduced support for conventionally powered vehicles (Internal Combustion Engine - (ICE) vehicles) both petrol and diesel, and enable a take-off of hydrogen vehicles by 2030. By 2050, hydrogen vehicle sales would account for 20 percent of the total European market. Under baseline and carbon tax scenarios, hybrid and LPG (liquified petroleum gas) cars see initial, limited support around 2000, but do not take off. Under both scenarios, other biofuelled cars (fuelled with bio-ethanol) and Compressed Natural Gas cars take off around 2010, but begin to decline after 2020. Overall, we conclude that due to the policies changes of the vehicle fleet composition as well as the types of fuel consumed are substantial. The carbon tax would have little impact on the economy (up to +0.3 percent of GDP in 2050), but would lead to substantial reductions of $CO_2$ emissions from transport.

The **hydrogen diffusion model** shows for Germany that, since a transition to hydrogen as an energy fuel in the transport sector is a disruptive innovation, relevant support is needed in different areas for a limited time period; in an optimistic case, for around eight to ten years. In particular, support is needed in three areas:

- Subsidies for vehicles (highest support necessary)
- Subsidies for at least 500 filling stations (in urban areas and at highways)
- No VAT and no taxes for hydrogen in the introduction phase (first one million FCVs)

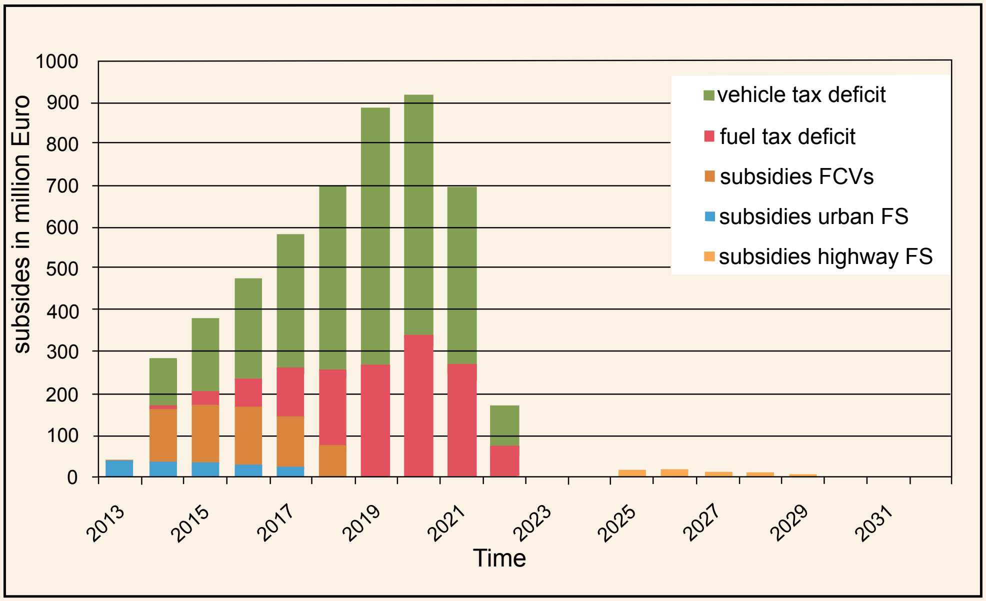
| | | | | |
|---|---|---|---|---|
| **Economy** | GDP | Employment | Investment | |
| Impact of $H_2$ cars | ↑ | ↑ | ↑↑ | |
| **Resources** | Gasoline | Diesel | Import of natural gas | Platinum |
| Impact of $H_2$ cars | ↓↓ | ↓ | ↑ | ↑↑ |
| **Transport emissions** | $CO_2$ driving | $CO_2$ upstream | $CO_2$ total | $NO_x$ emissions |
| Impact of $H_2$ cars | ↓ | ↑ | ↓ | ↓ |

*Source: ASTRA scenario results*

Summary of major quantified impacts of introducing $H_2$ vehicles in the EU-25 with an exogenously given market penetration of $H_2$ vehicles

The figure on the right shows model results regarding the levels of support needed for fuel cell vehicles and filling stations for one of the scenarios that was modelled. After a period of support, the hydrogen vehicles have a lower total cost than conventional vehicles. This assumes that the cost reduction targets of hydrogen vehicles are reached, which depends on learning curves. It is important to reach a certain level of market penetration of hydrogen vehicles and infrastructure build-up very fast; otherwise hydrogen would fail. The overall financial support is much lower in the case of fast market penetration than with slow market penetration. However, even with massive financial support, only one-third of all vehicles would be FCVs by 2040.

**The Transport Technology Transition modelling** for Germany shows biofuels-based and hybrid-electric technologies dominating in the medium term, before hydrogen takes off in the longer term (see also pages 41 - 42). This is consistent with the literature on technological development within the transport sector.[1,2] Crucially, the scenario assumed no restrictions on the use of biofuels (unlike in the ASTRA model), which is why we see an overly optimistic (unrealistic) growth of this niche. It is also noteworthy that we do not include battery electric vehicles (BEVs). ASTRA results suggest little prospect (under current trends) for BEVs to take off.




Simulation results of the so-called Lead Scenario where the state assumes all financial burdens and the fuel cell vehicles are seen as perfect substitutes for conventional vehicles and the support strategy is optimized (FCVs: fuel cell vehicles, FS: Filling station).

## Inputs from stakeholder involvement

Stakeholder engagement is relevant to the issue of shifting transport to hydrogen use given the complexity, ambiguity and subjectivity of persistent problems of unsustainability, such as those of transport. In this case study, two European-scale and two national-level stakeholder workshops were organised (see also pages 43 - 46).

The aims were to elicit stakeholders' visions of sustainability in relation to both hydrogen transport technology and transport itself and their views on viable pathways and any barriers to sustainable hydrogen-based transport. Stakeholders' input led to the reframing of the case study from a focus on a hydrogen transition to that of a wider mobility transition, as well as the definition of sustainability criteria for sustainable transport/mobility and pathways to sustainable hydrogen-based transport. Feedback on model design and experiments was also provided.

Results reveal a wide consensus that sustainable transport requires diversified and renewable primary energy supplies and diversified delivery of mobility solutions. International competitiveness is a serious economic, social and political concern. Hydrogen fuels and electrochemical conversion technologies could contribute to sustainability, but outcomes depend on how and where hydrogen is produced, the cost and technical performances of technologies, how these are improved, and whether the technologies induce new resource or sustainability constraints.

The views of the experts highlighted a need for both technological and non-technological measures to tackle rising transport demand. Citizen stakeholders supported the view of experts that transport in its current form and ongoing trends in the sector are unsustainable and that a 'business-as-usual' approach should be rejected. They identified similar environmental, social and economic criteria for sustainable transport and located responsibility for fostering sustainable transport primarily with governments. In contrast to experts, citizens tended to place more emphasis on behavioural change policies than on transport technologies. Moreover, citizens considered amenity aspects of transport to be most important, while experts stressed the technological issues.

## Conclusion

A sustainable solution for the transport sector is becoming increasingly linked to a sustainable solution for the energy system. Both depend on a diversification of energy sources and modes of delivery of final energy services. Both also require sustainable sourcing of fuels. Although hydrogen used in fuel cells producing electricity to propel electric engines appears to provide a promising option for a sustainable transport system, it still has to overcome significant technological barriers and it must compete with other plausible solutions. The barriers also apply to competing technologies and it is unclear yet which technology will break through its barriers faster and how competition between technologies will play out. There is also international competition to consider. An important aspect from a European perspective concerns the economic and trading implications of being (or not being) in the forefront of hydrogen technology development. For these reasons, investing in hydrogen research, technology development and demonstration projects may also be justifiable as a hedging strategy in the event that breakthroughs are achieved in hydrogen energy chains and mobile fuel cell technologies that lead to hydrogen emerging as a dominant technology in the future.

[1] European Commission (2001). *European transport policy for 2010: time to decide. White Paper.* Brussels: European Commission.

[2] Wehnert, T., Oniszk-Poplawska, A., Ninni, A., Velte, D. and Joergensen, B.H. Eurendel Project. Final Report. November 2004. Available at: www.eurendel.net.


### Further reading

Schade, W., Wietschel, M. and Weaver, P.M.(2007): Reframing Sustainable Transport: Exploring Hydrogen Strategies Using Integrated Sustainability Assessment. MATISSE Working Paper 16. Available at: www.matisse-project.net

Whitmarsh, L., Bohunovsky, L., Jäger, J., and Nykvist, B. (2007). Stakeholder Feedback on MATISSE Sustainable Hydrogen Visions and Pathways: Findings from the June 2007 Hydrogen Stakeholder Workshop. MATISSE Working Paper 18. Available at: www.matisse-project.net

Whitmarsh, L. and Wietschel, M. (2006). Sustainable Transport Vision: What Role for Hydrogen and Fuel Cell Vehicle Technologies? MATISSE Working Paper 2. Available at: www.matisseproject.net