



HY_Change

Transition to Hydrogen Based Transportation – Challenges and Opportunities

Scope of project

The project comprises two main streams: The ecological and economic assessment of alternative fuels and powertrains on the one hand, and the impact of these alternatives upon introduction into vehicle fleets on the other hand.

Goals and activities

Comprehensive life cycle assessment of biofuels and of hydrogen as energy carriers

– in particular methane from wood and hydrogen produced by solar chemistry.

Assessment of the whole ensemble of hydrogen production options

– decentralized production of hydrogen at fuelling stations, and centralized production from fossil or renewable primary energies, including storage and distribution via pipeline or truck delivery.

Assessment of the impact on atmosphere and climate.

As a starting point, the hydrogen emissions of present motor vehicles are determined by dynamometer tests, and are compared with field measurements of hydrogen in a freeway tunnel. Measurements of hydrogen emissions from fuel cell vehicles will then allow to upscale the emissions to entire vehicle fleets. Combined with results on the atmospheric chemistry of hydrogen, this will allow to assess the impact on atmosphere and climate.

Eco-efficient options in vehicle design.

The introduction of alternative concepts such as fuel cell vehicles provides an opportunity to re-design the vehicle as an entity, rather than making incremental improvements starting from existing models. In order to evaluate the potential of large numbers of combinations of vehicle and powertrain innovations, a comprehensive set of criteria has been chosen. The output will allow the user to select eco-efficient options, with the relative weighting of different criteria.

Development of a system dynamical model.

The decisions of individuals on the purchase of new vehicles are often dominated by non-economic arguments. In order to capture the behaviour of important actors, a system dynamical model has to be developed. The history of the introduction of diesel powertrains in Europe, and of natural gas cars in certain countries, has been chosen as the first application. The output of system dynamics, i.e. time-dependent customer preferences, is being coupled with a fleet model for European countries, developed in collaboration with MIT. This tool will allow to assess the impact of various climate protection policies on fuel consumption and greenhouse gas emissions of the European car fleet.

Bottom-up energy economic modelling.

On a longer time horizon, scenarios for the cost-optimum development of the European transportation system are developed by detailed bottom-up energy economic modelling. The study confirms the crucial influence of prices of alternative powertrains on the success of their market introduction. In the scenarios, the time of market introduction, the initial price and the floor cost after technical learning (mass production) are being varied. These studies provide important insights into the cost level that fuel cell systems will have to achieve if they are going to compete with the incumbent technology of the internal combustion engine.



Main Investigator
Alexander Wokaun, PSI

Project Partners
PSI
Empa
ETHZ

Life cycle analysis (ETHZ, PSI)

Ecological impacts and economic competitiveness of hydrogen produced by concentrated solar technologies have been compared with conventional production methods and alternative renewable pathways based on water electrolysis using electricity from solar thermal, PV, wind, and hydro power plants. A well-to-wheel (WTW) analysis has been conducted for production, transport, and usage of hydrogen in future passenger car transportation systems.

In general, the battery electric vehicle (BEV) shows the lowest GHG emissions because of its higher energy conversion efficiency compared to the fuel cell vehicle (FCV). The best performers are BEVs using hydro, nuclear, and wind power locally produced in Switzerland. Concentrating solar power (CSP) technologies employed in Southern Spain reduce GHG emissions for the production and supply of hydrogen by a factor of 7–14 vis-à-vis steam methane reforming (SMR) and advanced coal gasification (CGA), respectively, resulting in 50–70% CO₂ savings in a FCV. Total environmental impact of passenger car transportation can be reduced by replacing advanced gasoline vehicles with FCVs powered by hydrogen from CSP.

High capital investments for heliostat field infrastructure and long-distance transport result in 2.5–5.5 times higher hydrogen production and supply costs for solar scenarios compared to conventional SMR (4 US\$/kg H₂ in car tank). Total transportation costs may increase by 0.20–0.25 US\$/km for a FCV powered by solar hydrogen compared to an internal combustion engine (ICE) vehicle using gasoline.

Eco-efficiency is low for all solar hydrogen production technologies, since their relatively high costs are not outweighed by their environmental benefit, unless ecological aspects are stronger weighted than economics.

Hydrogen in the atmosphere (Empa)

Atmospheric H₂ has been measured quasi-continuously over a period of more than two years in Dübendorf, Switzerland, to study its sources and sinks in a suburban environment.

The measurements show pollution levels of H₂ up to ~1500 ppb (parts-per-billion, 10⁻⁹), which equals to ~3 times the levels of the «unpolluted» troposphere. H₂ also correlated strongly with carbon monoxide (CO), another combustion product. With pollution events removed, no significant long-term trend of atmospheric H₂ could be detected, a result that adds to the current debate on a potential trend in atmospheric H₂ over the past decade. The Dübendorf time series shows nicely a summer and early fall drawdown in H₂ due to seasonal enhancement of two major sinks, the tropospheric OH activity, and the yet poorly understood soil sink.

A tunnel study in Gubrist Tunnel (Switzerland) has been conducted to determine road vehicle emission factors for H₂ (and CO and CO₂) under highway driving conditions. Mean emission factors for H₂ were found to be 49.7 (± 16.5) mg km⁻¹ and were enhanced for congested traffic. The results of the study were extrapolated to yearly traffic-related H₂ emissions for Switzerland (5.0 – 6.6 Gg) and on a global basis (4.2 – 8.1 Tg) using different, nearly independent approaches. It also showed a downward trend in H₂ emissions over the next years, which is attributed to improved exhaust-after-treatment technology.

Exhaust emissions from various vehicle types were measured at the Empa dynamometer test stand. As expected the diesel-powered car showed very low H₂ emissions after the initial start-up period, whereas emissions of motorcycles have particular peak values also during normal driving cycles. The origin of these spikes awaits further examinations. Diffusive emissions were determined for the hydrogen-fueled vehicle in addition to exhaust emissions.

Continuous H₂ measurements from the high alpine observatory at Jungfraujoch, Switzerland are processed and interpreted to understand trends and seasonality of H₂ in the atmosphere and to assess upwind emissions from technological processes.

Heuristic vehicle design (PSI)

The commercial powertrain simulation software CRUISE from AVL was selected to perform this research. The model was validated in four ways:

Contact

Project manager
Alexander Wokaun, PSI
Phone: +41 (0)56 310 2751
E-mail: alexander.wokaun@psi.ch

Competence Center for Energy and Mobility CCEM
Philipp Dietrich, Managing Director
Phone: +41 (0)56 310 4573
E-mail: philipp.dietrich@psi.ch



from literature, using driving data provided by AVL, by collecting real-world driving data and simulating the vehicle on the same route, and by comparing simulated vehicle performance to Empa dynamometer driving data. The results showed agreement between measured and simulated values as close as 1%, and not worse than ~20%.

Data was also obtained for several important powertrain components. A model of plug-in and fuel cell hybrid vehicles was prepared to examine the synergies and competitions that exist between these two advanced vehicle technologies.

The framework for an online data collection tool called «CARTography» has been laid out. It will allow users to accurately estimate their fuel use for a trip entered in the Google™ maps applications programming interface. The expectation is that the registered users will provide useful fuel consumption data while using the tool to get information about their trip costs.

Dynamics of transportation technology development (PSI)

The simulation experiments give evidence that substitution processes between different drive train technologies may be much faster than historical diffusion rates of conventional drive trains, under the assumption that strong preference changes will be triggered by the upcoming energy and climate challenges.

Also, aggressive substitution scenarios towards alternative drive train technologies seem to be more promising in the long run than aggressive promotion of improved conventional drive train technologies with respect to CO₂ reductions goals.

The policy and scenario analyses for different European countries give evidence that their future fleet diffusion behaviour may be very heterogeneously depending on country specific scenario and policy conditions. Similarly, the future European automotive fleet development with respect to the uptake of different alternative drive train technologies may differ significantly from the USA development path.

Energy-economic modelling of hydrogen-related issues (PSI)

Main findings to date indicate that hydrogen as well as biofuels could contribute to reducing CO₂ emissions on a European scale. One decisive factor affecting the role of hydrogen is the ultimately achievable cost of fuel cell technologies. The earlier fuel cell manufacturing costs can be reduced, the more prominent the role that hydrogen can play in the European transport sector.

Secondly, it was found that more stringent CO₂ reduction targets favour an increasing use of hydrogen. Again, a decisive factor for the application of hydrogen fuel cell vehicles is that fuel cell costs are reduced to competitive levels. However, under more stringent CO₂ targets, our modelling shows fuel cell vehicles can become cost-competitive even under less optimistic estimates of the ultimately achievable fuel cell production cost. For biofuels our modelling analysis shows that the limited European biomass potential means that biomass is rather utilized for decarbonization of other sectors. Despite this general finding, we see that biofuels can still act as a bridging fuel in the transition to a low-carbon transport sector until competitive fuel cell costs are reached.

The analysis of the cost of hydrogen production shows that hydrogen from fossil fuels can be expected to dominate hydrogen production for the years to come. Coal gasification as well as natural gas reforming were identified as the most cost-effective means of producing hydrogen, even if accounting for the cost of carbon capture and storage. Naturally, increasing fossil fuel costs or rapid progress of other hydrogen production technologies could alter this picture in the long-run.

For the delivery of hydrogen to fueling stations, it was found that even though pipeline delivery is the cheapest option, delivery of liquid hydrogen by truck is a cost-competitive possibility. Without substantial hydrogen demand in place, the latter could be the option of choice for early phases of a hydrogen economy due to its higher flexibility with regard to the location of hydrogen demand centres.

Contact

Project manager
Alexander Wokaun, PSI
Phone: +41 (0)56 310 2751
E-mail: alexander.wokaun@psi.ch

Competence Center for Energy and Mobility CCEM
Philipp Dietrich, Managing Director
Phone: +41 (0)56 310 4573
E-mail: philipp.dietrich@psi.ch



- Felder R., Meier A. (2006) «Well-to-Wheel Analysis of Solar Hydrogen Production and Utilization for Passenger Car Transportation», Proc. 13th SolarPACES International Symposium, Seville, Spain, June 20–23, 2006.
- Felder R., Meier A. (2006) «Well-To-Wheel Analysis of Solar Produced Hydrogen for Future Transportation Systems», Proc. 16th World Hydrogen Energy Conference (WHEC 16), Lyon, France, June 13–16, 2006.
- Gül T. and Stenzel T. (2006): Intermittency of Wind: A Wider perspective, International Journal of Global Energy Issues, Vol. 25, Nos. 3/4, 2006.
- Felder R. (2007) «Well-to-Wheel Analysis of Renewable Transport Fuels: Synthetic Natural Gas from Wood Gasification and Hydrogen from Concentrated Solar Energy», Ph.D. Thesis, ETH No. 17437, ETH Zurich, Switzerland, 2007.
- Felder R., Dones, R. (2007) «Evaluation of ecological impacts of synthetic natural gas from wood used in current heating or car systems», Biomass and Bioenergy, 31(6), pp. 403–435.
- Felder R. (2007) «Well-to-wheel analysis of solar produced hydrogen for future passenger car transport systems», 3rd International Conference on Life Cycle Management (LCM 2007), Zurich, Switzerland, August 27–29, 2007.
- Meier A., Felder R. (2007) «Life Cycle Assessment of Hydrogen Production Using Concentrating Solar Power Technologies», SPS Annual Meeting, Zurich, Switzerland, February 20–21, 2007.
- Steinbacher, M., A. Fischer, M. K. Vollmer, B. Buchmann, S. Reimann, C. Hueglin, 2007. Perennial observations of molecular hydrogen (H₂) at a suburban site in Switzerland, Atmospheric Environment, (41), 2111–2124.
- Vollmer, M. K., N Juergens, M. Steinbacher, S. Reimann, M. Weilenmann, B. Buchmann, 2007. Road vehicle emissions of molecular hydrogen (H₂) from a tunnel study, Atmospheric Environment, (41), 8355–8369.
- Wilhelm, E., Fowler, M.W., Fraser, R.A., Stevens, M.,(2007). Hardware-in-the-loop platform development for hybrid vehicles. November 1–2, 2007. PHEV 2007 Conference, Winnipeg, Manitoba.
- Bosshardt M., Ulli-Beer S., Gassmann F. and Wokaun A. (2007). Developing a diffusion model of competing alternative drivetrain technologies (cadt-model), Proceedings of the 25th International Conference of the System Dynamics Society, July 29 – August 2, 2007, Boston, USA.
- Gül, T., Kypreos, S., Barreto, L., 2007: Hydrogen and Biofuels – A Modelling Analysis of Competing Energy Carriers for Western Europe. Proceedings of the World Energy Congress «Energy Future in an Interdependent World». 11–15 November 2007, Rome, Italy.
- Krzyzanowski, D., Kypreos, S., Barreto, L., (2007): Supporting Hydrogen Transportation: Case Studies with the Global MARKAL Model. Journal of Computational Management Science (Special Issue on Managing Energy and the Environment).
- Turton, H., Barreto, L., (2007): Automobile Technology, Hydrogen and Climate Change: A Long-term Modeling Analysis. International Journal of Alternative Propulsion 1, 397–426.
- Felder R., Meier A. (2007) «Well-to-Wheel Analysis of Solar Hydrogen Production and Utilization for Passenger Car Transportation», J. Solar Energy Engineering, in press.
- Felder R., Meier A., Wokaun A. (2007) «Solar Hydrogen as Future Transportation Fuel – Well-to-wheel Analysis and Economic Assessment», Proc. 14th International Biennial SolarPACES Concentrating Solar Power Symposium, Las Vegas, Nevada, USA, March 4–7, 2008.
- Krzyzanowski, D., Kypreos, S., Barreto, L., (2007): Assessment of Market Penetration Potential of Hydrogen Fuel Cell Vehicles. International Journal of Energy Technology and Policy (Special Issue on Technology Characterisation and the Modelling of Energy and Climate Policy), accepted.
- Turton, H., Moura, F., (2007): Vehicle-to-grid systems for sustainable development: an integrated energy analysis. Technological Forecasting and Social Change (accepted).