International Max Planck Research School on
EARTH SYSTEM MODELLING

Managing the Transition to Hydrogen and Fuel Cell Vehicles

– Insights from Agent-based and Evolutionary Models –

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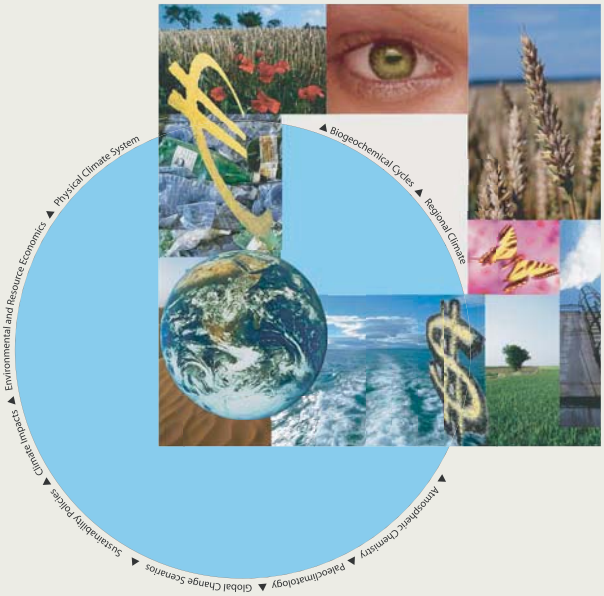

Summary

Environmental and energy security concerns call for alternative fuels and vehicle technologies in road transport. In this thesis, four papers address strategies to introduce, in particular, hydrogen along with fuel cell vehicles (FCVs) as a promising future technology combination.

Starting point of the first paper called *Simulating the Adoption of Fuel Cell Vehicles* is the current problem of a lack of hydrogen refueling infrastructure together with extremely high fuel cell production costs. In an agent-based model that portrays the behavior of car producers, consumers, and filling station owners, public infrastructure development scenarios combined with tax policies in favor of FCVs are implemented. Results based on the German compact car market suggest that a high tax on conventional cars can successfully promote diffusion even without pronounced public infrastructure investments. However, consumers and small car producers are negatively affected by the tax; and the negative impact on the latter is aggravated in case of a major public infrastructure program.

The second paper, *Learning by doing, Learning Spillovers and the Diffusion of Fuel Cell Vehicles*, extends the previous model by adding cost decreasing learning effects in fuel cell production. Model projections for the diffusion of FCVs turn out to be very sensitive to changes in the assumed magnitude of learning effects. Apart from that, the model exhibits a substantial first mover advantage, i.e., the producer who switches to the production of FCVs first tends to increase his profits. Moreover, results show that learning spillovers increase the speed of diffusion, because there are some additional producers who can profitably switch. But learning spillovers negatively affect the profitability of some of the producers, implying policy trade-offs.

The third paper presents a different model, which is *A Tool to Optimize the Initial Distribution of Hydrogen Filling Stations*. It is based on the assumption that consumers only consider buying a FCV if they actually perceive sufficient fuel availability. The German trunk road network is implemented in a spatial approach and artificial drivers make long distance trips through the network checking for fuel availability. A frequently advocated ring shaped distribution of initial hydrogen filling stations at trunk roads is tested for its potential success to generate a large scale adoption of FCVs. It turns out to be appropriate only under unrealistic assumptions regarding people's refueling concerns. However, the model indicates promising improvements of the initial distribution.

The last paper, *Flexible transition strategies towards future well-to-wheel chains: an evolutionary approach* (jointly with Floortje Alkemade, Koen Frenken and Marko Hekkert), also includes other potential future fuel and vehicle combinations than hydrogen and FCVs. Changes in the so-called well-to-wheel (WTW) chain are modeled as stepwise transitions in analogy to fitness improving mutations of genes in evolutionary biology. Transition steps are only possible if they reduce greenhouse gas emissions or energy requirements. Transitions are shown to be path dependent, so that current decisions regarding changes in the WTW system predetermine its future characteristics. Thus, flexible initial transition steps seem to be preferable, i.e., those steps that leave open a wide range of different transition paths later on. Analysis of empirical data suggests that improving vehicle technologies as a first step is most flexible in that respect.