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Are scenarios of hydrogen vehicle adoption optimistic? A comparison with historical analogies

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ABSTRACT

There is a large literature exploring possible hydrogen futures, using various modelling and scenario approaches. This paper compares the rates of transition depicted in that literature with a set of historical analogies. These analogies are cases in which alternative-fuelled vehicles have penetrated vehicle markets. The paper suggests that the literature has tended to be optimistic about the possible rate at which hydrogen vehicles might replace oil-based transportation. The paper compares 11 historical adoptions of alternative fuel vehicles with 24 scenarios from 20 studies that depict possible hydrogen futures. All but one of the hydrogen scenarios show vehicle adoption faster than has occurred for hybrid electric vehicles in Japan, the most successful market for hybrids. Several scenarios depict hydrogen transitions occurring at a rate faster than has occurred in any of the historic examples. The paper concludes that scenarios of alternative vehicle adoption should include more pessimistic scenarios alongside optimistic ones.

1. Introduction

There is a substantial existing empirical literature examining the rates at which technologies have historically diffused into markets (Hirooka, 2006; Rogers, 2003). A number of authors have studied energy technologies in particular, including both supply and demand technologies (Grübler et al., 1999; Lund, 2006; Nakicenovic, 1986; Wilson, 2010). This literature makes clear that the diffusion of new energy technologies is frequently characterized by inertia (Fouquet, 2010; Grubler, 2012; Kramer and Haigh, 2009). Incumbent socio-technical regimes are durable, for a number of technical, social and economic reasons (Geels, 2002). The apparent stability of observed diffusion rates for power generation technologies has even led Kramer and Haigh (2009) to propose that the relatively slow rates of adoption of energy technology can be described as "laws" (Kramer and Haigh, 2009). In particular, barriers associated with the deployment of complementary goods – such as new vehicles and the infrastructure to supply them with fuel – are important in determining the dynamics and speed of alternative vehicle adoption (Meyer and Winebrake, 2009).

How well do scenarios of future energy technology adoption represent this inertia? Studies of long-term technology futures are an important source of evidence for policymakers considering interventions in R&D and technology deployment. While many such studies have examined the potential for transitions to new low-carbon vehicles, very few have focused on

Abbreviations: AFV, alternative fuel vehicle; FCV, fuel cell vehicle; CNG, compressed natural gas; LPG, liquefied petroleum gas; SUV, sports utility vehicle; HEV, hybrid electric vehicle.

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the rate at which such a transition might be expected to occur. Over-optimistic rates of transition depicted in the literature, if believed by policymakers to represent possible or likely futures, create two risks for policy. First, over-optimistic expectations of transition rates may lead to disappointment and perceived failure of an attempt to foster a new fuel. This could lead to policy support being abandoned even when a technology has a good long-term potential. Second, if new technologies are required to meet emissions goals but transitions are slow, action to initiate adoption of such vehicles must be taken sooner rather than later. In contrast, over-optimistic adoption rates may lead to policymakers adopting a wait-and-see approach, since such scenarios imply that the vehicle market is more responsive to interventions than is in fact the case, and that policymakers can wait and act later when more information is available about the relative performance and costs of particular technologies.

Furthermore, scenarios of possible transitions (to hydrogen or other low carbon systems) are widely used as inputs into analyses of the costs and implications of such transitions. In the case of hydrogen, many studies have used exogenous adoption scenarios as an input to calculations of the possible costs of hydrogen infrastructure, yet few have tested the sensitivity of their findings to this assumption (Agnolucci and McDowall, 2013). One of the few studies to do so (Murthy Konda et al., 2011) showed that the costs are indeed rather sensitive to assumptions about the rate at which a transition might take place, with costs up to 40% higher in scenarios with slower demand growth. Others have used projections of hydrogen demand as inputs into macro-economic analysis (Jokisch and Mennel, 2009).

Understanding whether the rates of alternative fuel vehicle adoption in scenarios are possible or likely is clearly desirable, and one approach to attempt such validation is to examine historical precedents. Indeed, a number of recent authors have taken this approach, both exploring future scenario consistency with historic patterns of the same technology (such as historic and possible future deployment of nuclear), and also deriving insights from comparing future scenarios with historic diffusion of analogous technologies. Wilson et al. (2012) describe the rationale for comparing historical technology diffusion rates with those observed in long-term global energy modelling studies (using the MESSAGE and REMIND models), arguing that learning from the past is important for testing the feasibility of future scenarios. Similarly, Höök et al. (2012) compare two sets of global energy scenarios to historic global growth rates of fossil fuel and nuclear technologies. While Wilson et al. (2012) find that the scenarios they examine have been conservative with respect to technology deployment rates and extents, Höök et al. (2012) show that the scenarios they examine have been optimistic compared with the slow pace of historic energy resource growth. Other recent examples include van Sluisveld et al. (2015) and Iyer et al. (2015).

However, it is also clear that transitions in the past are conditioned by social, economic and technological contexts that will change in future. How can evidence from the past then be used to inform our judgements about whether these scenarios do indeed represent possible, or even likely, futures? Betz (2010) provides some guidance here, by clarifying different domains of 'possibility' with respect to scenarios. To say that something is possible, in his view, means that its occurrence is consistent with what we know (or alternatively, is not inconsistent with what we know[1]); in which case, a judgement on whether something is possible is dependent on a certain source of knowledge. In this context, historic analogies can be understood as providing knowledge about the nature of change in vehicle systems—these analogies represent 'what we know' about how fast such change can occur. This is not to say that this body of knowledge defines the limits of what is possible. Rather, it shows what range of futures is 'consistent with what we know', and what can thus be stated as 'realistic' or 'serious' possibility.

Though differently framed, this approach has some resonance with the work of Wiek et al. (2013), who have suggested that the "plausibility" of scenario elements can be to some extent validated by looking at whether similar things have happened in the past. Implicitly, their definition of plausibility is similar to the 'consistent with what we know' approach of Betz (2010) and it is that sense in which the term 'plausible' is used here.

This paper compares rates of diffusion of hydrogen fuel cell vehicles (FCVs) in scenarios with a set of historical alternative fuelled vehicle analogies. In doing so, it assesses future scenarios in terms of their consistency with our historical knowledge about technology diffusion. The paper also examines the socio-political and techno-economic characteristics that have been associated with rapid alternative vehicle adoption in the past, and uses this to reflect on the appropriateness of this historical knowledge for thinking about the future possibilities for hydrogen. Previous studies have drawn on historical examples of alternative fuelled vehicle transitions to inform the potential for hydrogen FCVs (Backhaus and Bunzeck, 2010; Hu and Green, 2011; Yeh, 2007). However, this paper is the first to draw on such examples to address the question of how fast alternative fuelled vehicles can be plausibly assumed to penetrate vehicle markets. The paper thus addresses the following two questions: *how fast have new types of vehicle achieved a given market share in the passenger car fleet? Are the rates of adoption in hydrogen futures in the literature consistent with these historic analogies?*

2. Methods: comparing rates of alternative vehicle adoption

The approach taken by this study was four-fold:

1 Identification of relevant analogies and collection of data;
2 Examination of key attributes of each analogy;

[1] The distinction being between verificationist and falsificationist positions.