**Forks in the Road: Contrasting Transition Pathways in the Delivery of Sustainable Hydrogen**

Nick Hacking[1] and Prof. Malcolm Eames[1]

[1]Low Carbon Research Institute, Welsh School of Architecture, Cardiff University, Bute Building, King Edward VII Avenue, Cathays Park, Cardiff, Wales

SUMMARY

This paper reviews the literature on hydrogen innovation systems and contrasts insights from two current European case studies: the United Kingdom and Germany. Specifically a conceptual framework derived from innovation systems literature will be used to explore the differing patterns of development and emerging innovation trajectories in the two countries. Whilst the UK has a science base with clear strengths in hydrogen production and storage R&D, a number of regionally based hydrogen demonstration projects and private sector actors with interests in hydrogen technology, national government has yet to stimulate a coordinated and sustainable innovation policy regime for hydrogen. Instead, national policy makers in the UK have largely focussed on prospects for electric vehicles. By contrast, in 2009 a memorandum of understanding (MOU) was signed between the German government and number of major automobile manufacturers, gas companies and energy utilities to coordinate a cross-sectoral approach to rolling out mass-produced hydrogen fuel cell vehicles by 2015. This has been under the banner of a countrywide 'H2 Mobility' programme which aims to establish Germany as an economy that can meet Europe's low carbon targets for 2050 whilst simultaneously boosting parts of its domestic economy. Investment a public hydrogen refuelling network is part of the German economic stimulus package (Konjunkturpaket II). Overall, the paper concludes with an assessment of the broader societal and policy implications of these emerging national differences, and what this tells us about possible innovation pathways to a hydrogen economy in an increasingly capital- and carbon-constrained world.

INTRODUCTION

Whilst recognising that economic factors are important, innovation studies views transitions as *co-evolutionary*, *enacted*, *relational*, and *interactional* processes, dependent upon the creation of new innovation systems, technological novelties, networks, visions, expectations, niche markets, user-practices and preferences, regulations, institutions, social learning, competitive strategies and so on [1-7]. Moreover, in an increasingly globalised world new technological developments are rarely embodied in or confined to a single national or sectoral context [8]. This is particularly the case with disruptive, systemic technological innovations such as hydrogen energy [9].

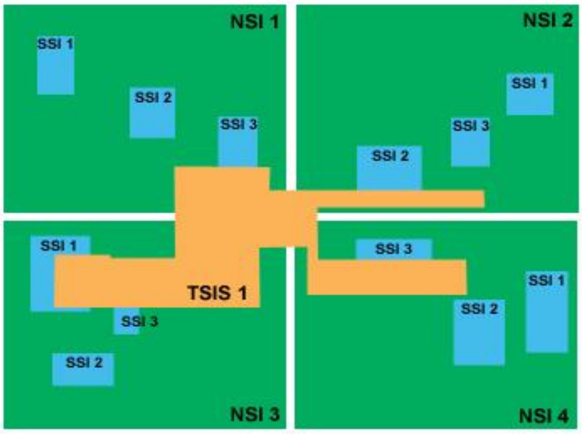
At the same time, the global rate and direction of innovation in hydrogen energy will be heavily influenced by the specifics of individual national and sectoral innovation systems, as well as the strategic decisions of the transnational energy companies and auto manufacturers which span, and link, these national and sectoral systems [8, 10-12].

Within the broad socio-technical and innovation studies literatures, there is a growing body of work that seeks to examine a prospective transition to a hydrogen energy system through regional/national and supranational case studies [9-15]. Moreover, a number of authors have specifically sought to understand and explain the dynamics of such regional/national case studies from the perspective of innovation systems [8, 16, 17]. This includes work on the 'functions of innovation systems' and the 'multi-level perspective' (MLP) [1-3, 18-20]. While systems approaches have their critics [21-28] they nevertheless continue to offer a potentially promising analytical framework for better understanding the co-evolution and dynamics of innovation systems given their use in policy making [29-32].

In the following paper we first briefly review the range of innovation systems concepts/approaches of relevance to understanding the development and deployment of sustainable hydrogen, before describing comparative case study methodology and initial results.

DISCUSSION - INNOVATION SYSTEMS

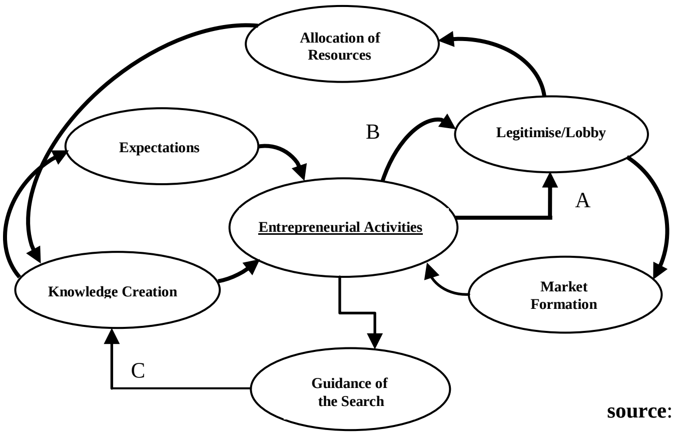
The innovation systems literature seeks to understand innovation as a social process involving actors, networks, institutions and resources. The original literature was concerned with the role of innovation in national competitiveness through the lens of National Systems of Innovation (NSI) [33, 34]. Subsequent work focussed on the role of Regional Innovation Systems (RIS) [35] and Sectoral Systems of Innovation [36] in economic development. The concept of a Technology Specific Innovation System (TSIS) has since been proposed as a means of understanding the global development of specific technologies and the relationship between National Systems of Innovations (NSIs) and Sectoral Systems of Innovation (SSIs) to which they relate [18]. The TSIS concept can be regarded as a special version of an innovation system [37] where, as Figure 1 suggests, there is a network of agents interacting in the economic/industrial area under a particular institutional infrastructure and which is involved in the generation, diffusion, and utilization of technology [38] and where "[There] is a combination of interrelated sectors and firms, a set of institutions and regulations characterizing the rules of behavior and the knowledge infrastructure connected to it." [37].




**source**: Hekkert et al (2007)

Figure 1: Boundary relations for a TSIS covering four countries

An alternative approach seeks to understand the introduction of sustainable innovations through an analysis of the 'functions' of these innovation systems. This looks at evidence for the following functions: i) entrepreneurial activities, ii) knowledge creation/development, iii) knowledge diffusion through networks, iv) guidance of the search, v) market formation, vi) resources mobilization, and vii) creation of legitimacy/counteract resistance to change . Empirical work suggests that when these functions are dynamically linked together into positive feedbacks, they can act as 'motors of change' towards sustainable goals [18, 39]. Three potentially positive motors of change are shown in Figure 2 as 'A', 'B' and 'C' as they link certain functions together:




**source**: Hekkert et al (2007)

Figure 2: Three motors of change in a TSIS – A, B and C feedback loops

These three positive feedback loops can be described in more detail:

i) loop A - entrepreneurs lobbying for better economic conditions that will encourage further research and development (R&D) seek new market formation typically in the absence of a level playing field,
ii) loop B - entrepreneurs lobbying for better economic conditions to encourage further R&D seek more resources which can lead to higher expectations
iii) loop C - the 'guidance of the search', the process whereby societal problems are identified and government targets are set to reduce environmental damage, leads to new resources, new knowledge and increasing expectations about technological options.

Usefully, the number of actors, networks, and relevant institutions in a TSIS is generally much smaller than in a National System of Innovation (NSI) [18]. This reduces system complexity and makes a dynamic analysis possible revealing how leading actors, their opponents, and various external events combine to shape emerging governance of the TSIS. Functions of innovation also highlight the "co-evolutionary processes of regulation adaptation and learning experiences from previous institutional arrangements" [18], the effectiveness of government innovation policies and entrepreneurial activity, resource accessibility and the level of legitimisation in society for a technology. "In short … [functions] provide insights in the interaction of forces that determine the slow and difficult change of a merely locked-in system towards a new equilibrium" [18].

## METHODOLOGY

Examining the relative performance of the UK [NSI 1] and Germany [NSI 2] in the supranational hydrogen TSIS involves explaining national performance variations of institutions and institutional settings. These affect the ability of firms and individual actors to innovate [40]. Initially, institutional maps were created for hydrogen activities in both countries. The mapped institutions are the "building-blocks of social order: they represent socially sanctioned, that is, collectively enforced expectations with respect to the behaviour of specific categories of actors or to the performance of certain activities" [41]. Regional geographical areas of actual and hoped-for hydrogen activity in each country have been denoted as 'clusters' in line with traditional growth pole theory from economics and economic geography [41-44] although the ability of hydrogen technologies to underpin the economic growth and/or regeneration is a theoretical possibility, it remains unproven [16, 45, 46] which is a potential concern given the need for new infrastructure.

The institutional maps were then used to identify the key sectors of current and planned hydrogen activity [the SSIs in Figure 1]. It is in these SSIs that many nationally- and regionally-based actors are located. Individuals in these SSIs were approached for confidential face-to-face interviews. An interview topic guide was iteratively drawn up on the basis of identifying the functions of innovation believed to be at work in each NSI. At the same time, quantitative market data on the actors' activities and their institutions along with academic, grey and policy literature has begun to be searched. At the time of writing, 22 out of 45 planned interviews have been undertaken. This qualitative data is being analysed in QSR Nvivo software package.

## ANALYSIS

The institutional maps for each suggested cluster in each country contain three layers of networked institutions: i) supranational, ii) national and iii) regional. Each set of institutions interacts with the others making direct connections across national and regional boundaries in an institutional topology that can be described of 'folded space' in which areas that are far apart are actually in close interaction with each other [47]. For example, Figure 3 shows one of six potential cluster areas of hydrogen activity for the UK, that of London. Here, as in Germany, the top layer contains relevant European institutions of governance, plus public-private partnerships, private transnational corporations (TNCs), original equipment manufacturers (OEMS), lobby groups and management consultancies, These institutions, and the actors within them, are constantly creating and re-creating network connections with other institutions in the national and regional tiers below.

### Case Study 1 – The United Kingdom

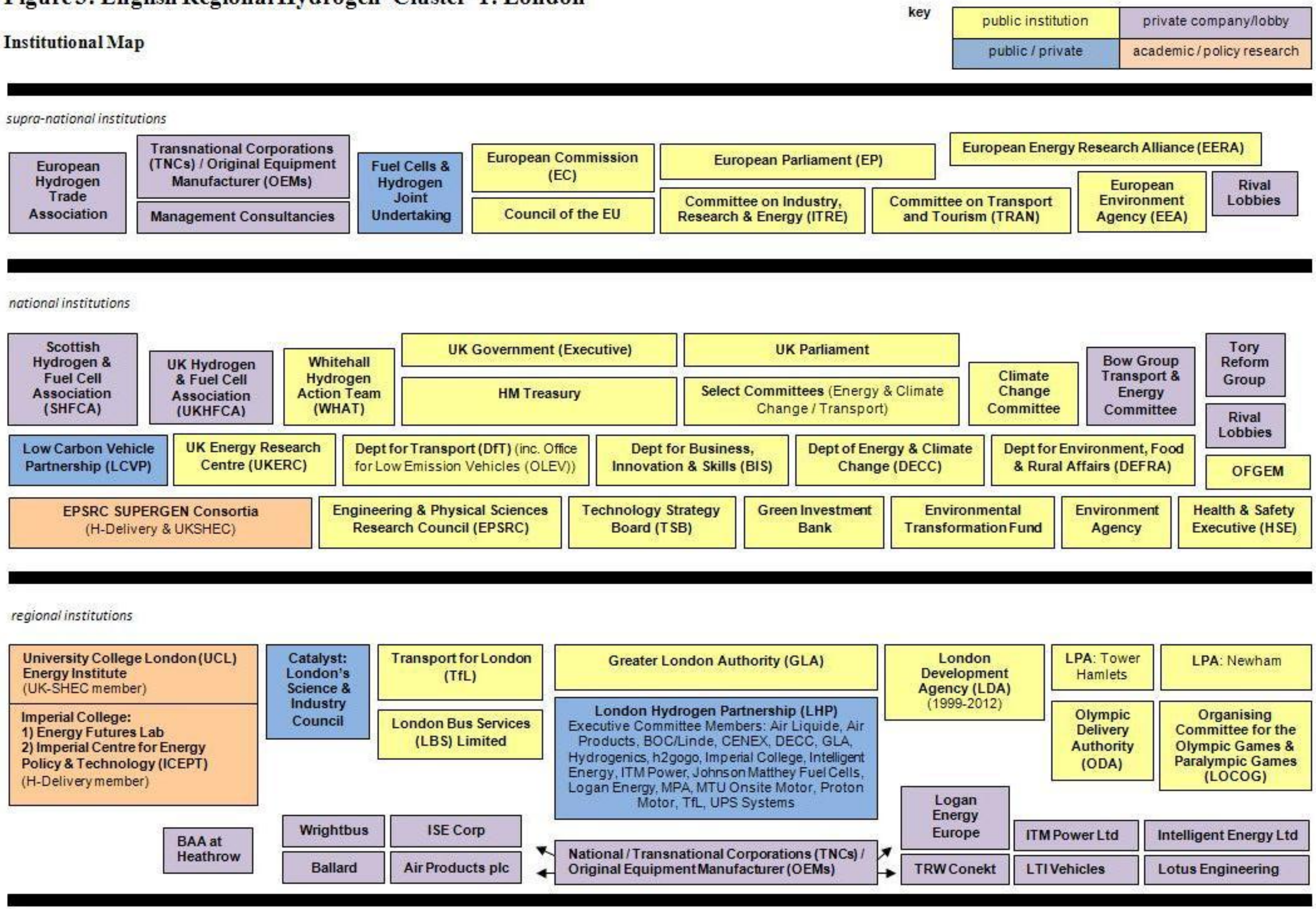
The UK has a science base with clear strengths in hydrogen production and storage R&D, a number of regionally based hydrogen demonstration projects and private sector actors with interests in hydrogen technology. However, the UK national government has yet to match this bottom-up activity with a coordinated and sustainable top-down innovation policy regime for hydrogen. Instead, national policy makers in the UK have largely focussed on the nearer-term prospects for electric vehicles. There are six geographical areas where economic activity linked to hydrogen is currently in action or is hoped for in the future in terms of a cluster/growth pole approach: London (see Figure 3), South Wales, the Midlands, the North East, the East Coast of Scotland and the Outer Hebrides/Orkney Isles. So far, key concerns for the UK's national system of innovation system identified are:

1) the lack of a top-down, politically-sanctioned medium- to long-term vision for hydrogen makes it more difficult to coordinate the various knowledge creation activities currently funded publicly and privately,
2) the short-term trading emphasis of Britain's capital markets affecting the relatively poor allocation of R&D resources in comparison to Germany,
3) persistent under-resourcing and under-valuation of education and training which impacts upon knowledge creation and the ability of entrepreneurs to find skilled staff,
4) the effectiveness of institutional links between universities doing hydrogen RD&D and regional development agencies (RDAs) / local planning authorities (LPAs) pursuing hydrogen infrastructure to initiate regeneration,
5) concerns that the lack of home-grown R&D in the automotive sector may be a significant factor in terms of lack of government political priority and strategic support leading to poor funding allocation.

Despite such concerns, one academic researcher says of their longer-term challenges "There is optimism [in the UK], but there is also a lot to be done." For those already in the marketplace, the message is more bullish "In the UK, we have moved beyond the demonstration stage," says a spokesperson from a transnational corporation. "We're ready to go to market." Most actors conclude that the UK is unlikely to be first selling hydrogen technologies in bulk or building major infrastructure but can still be a strong second or third mover.

## Figure 3: English Regional Hydrogen 'Cluster' 1: London

### Institutional Map



**Case Study 2 – Germany**
By contrast to the UK situation, the German central government and number of transnational automobile manufacturers, gas companies and energy utilities signed a memorandum of understanding (MOU) in 2009 in order to coordinate a cross-sectoral approach to rolling out mass-produced hydrogen fuel cell vehicles by 2015. This commitment to future hydrogen infrastructure is taking place under the banner of a countrywide 'H2 Mobility' programme which aims to establish Germany as an economy that can meet Europe's low carbon targets for 2050 and simultaneously boost its domestic economy through i) regional industrial regeneration, and ii) increased exports of technology and know-how. Investment in a public hydrogen refuelling network is also part of a central government economic stimulus package known as Konjunkturpaket II. Early interviews in Germany are citing i) the importance of a collectively agreed public-private vision for hydrogen's future development, ii) the ability of the sixteen fully devolved Länder to boost funding for national and supranational hydrogen projects especially in certain cities like Hamburg and Berlin, and iii) the historically close institutional links between certain academic researchers and industry. As one participant has said: "It's really about innovation and innovation isn't just about novelty, it's about bringing novelty to the market. [This is when] you need a stronger input by industry."

## CONCLUSION

Despite this work being at an early stage, it is already clear that the UK and Germany are on very different innovatory paths with respect to emerging hydrogen technologies. This is due in part to the nature and character of the National Innovation Systems (NISs) at work in each country which is being highlighted by our focus on the functions of these systems. Further analysis in the coming months will explore the broader societal and policy implications of these emerging national differences and what this tells us about possible transition pathways to a hydrogen economy in an increasingly capital- and carbon-constrained world.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