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Opening the 'Black Box' of the Hydrogen Economy

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Introduction

The issue of a hydrogen economy or economies is undoubtedly controversial. Yet, seemingly paradoxically, the development of a hydrogen economy is hailed almost exclusively as positive (Rifkin, 2002; Billings, 2000). In this respect a predominant writer on the hydrogen economy, Jeremy Rifkin (2002), suggests as the subtitle to a recent book that such an economy will be underpinned by 'the creation of the world wide energy web and the redistribution of power on earth'. This enthusiasm has become embodied in a range of policy discourses at a variety of levels of governance. Interestingly, in this respect, Rifkin acts as an advisor to Romano Prodi, the President of the European Commission, who in this position has committed the Commission to the 'hydrogen revolution' (Prodi, 2003). Similarly, George W Bush in his 2003 State of the Union address committed $1.2 billion in research funding 'so that America can lead the world in developing clean, hydrogen-powered automobiles' (Bush, 2003)[i]. The premise of such a development is in the expectation that it will 'make our air significantly cleaner, and our country much less dependent on foreign sources of energy' (Bush, 2003). The development of hydrogen technologies and the move to a hydrogen economy, it is suggested, is both good for the economy and the environment. Whilst at the regional level, in London for example, the public transportation system, given its large number of taxis, buses and delivery vans, 'offers a massive opportunity for developing the use of hydrogen' (Mayor of London, 2004, p.86).

Much of this enthusiasm operates at a rhetorical level making a multiplicity of claims of the possibilities of the hydrogen economy. The ability to make such claims rests on certain assumptions about what the hydrogen economy(-ies) can 'deliver'. Yet, moving beyond these rhetorical visions necessitates different ways of understanding the hydrogen economy(-ies). It requires asking what a hydrogen economy(-ies) might look like. How can we understand it? We address this, here, through one particularly powerful and prevalent way of seeing hydrogen technologies known as technology characterisation (TC). A strong version of TC is outlined as encapsulating a view which focuses on the supply of technology as related to the 'state of the art', or what the technology can 'deliver in principle'. The claim, subsequently, is that there has been, and there remain

The paper moves onto scrutinise 10 documents that seek to represen

Technology Characterisation as a Way of Seeing the Hydrogen Economy

A key issue is the role TCs play in creating expectations and understandings of the hydrogen economy(-ies). Though there are numerous examples of what could be considered rationale for TC, within this context of the US Department of Energy (DOE), was to ‘institutionalize the development, collection and maintenance of technical information needed for preparation of RD&D strategies, analysis of budget priorities, communications outside the Department, and development of the Department’s annual reports (OAO Corp, 1979, section I-1). The importance of TC was in developing a ‘set of standardized procedures’ which would inform a ‘quantitative description of technology, process or conservation option’; ‘an estimate of future energy project costs and the uncertainty associated with these estimates’; and ‘an estimate of the funding required to develop the technologies required’. TC, furthermore, involved the creation of official Department data files and a process for ‘developing and updating’ these data files (OAO Corp, 1979, section I-1). In this respect this report focuses largely on ‘economic characteristics’, ‘technical characteristics’ and environmental issues (OAO Corp, 1979). TC, in this report, is seen as referring largely to ‘generic technology’ where characterisation would pertain to a ‘data base which would be useful for broad-based activities’ (OAO Corp, 1979, section III-1). The notion of generic also has a dimension which is relative to ‘their stages of development’ or whether a technology is a ‘near term technology’ or at a ‘relatively early stage’ of development (OAO Corp, 1979, section III-2). The suggestion was that the support and acceptance of TC amongst DOE staff required ‘high quality, unbiased data’ (OAO Corp, 1979, section II-1). Importantly, in this particular instance, a ‘successful’ TC was one which maintained a ‘record of the most up-to-date information’ thereby negating a ‘constant “reinventing of the wheel”’. It would also ensure ‘that there is a single official set of estimates for characteristics of a technology’. It would mean that ‘all official estimates of technology characteristics are based on constant underlying assumptions’ (OAO Corp, 1979, section I-2). The strong understanding of TC, which this report propounds, highlights a number of issues in its attempts to create ‘certainties’ around technological developments. In particular it requires us to look at not only what is important in this approach, but also what is problematic with it and to whom its practices are oriented.

The desire for certainty both informs what seeks to be achieved in the name of TC but also highlights that there are extreme difficulties with chasing such an ideal. One report, for example, form a project attempting to reduce uncertainties through developing a TC methodological approach suggested:

> For R&D planning purposes and for projecting commercialization dates of new energy technologies, it would be desirable to be able to describe the state of development of

> various technologies in a comparative, unambiguous and systematic way. Contractor difficulties in finding such criteria for defining the stage of development of new technologies led to the termination of the research effort about midway through the project (Taylor, 1978, p.v).

This suggests, whilst there were aspirations to characterise technologies in 'unambiguous and systematic' ways, that developing practices and processes to 'achieve' this were often problematic. This leads us to ask: what sorts of practices and processes constitute TCs? But also, how might we understand these practices and processes and the implications of this for how we see the hydrogen economy(-ies)?

A further related issue is in addressing what 'work' TC documents are doing. The importance of using TCs to confer 'certainty' to understandings of technology, through abstraction and perceived implicit technological neutralism, for example, also had the broader political aim of '[e]stablishing credibility on the Hill' (i.e. with the US Congress) (OAO Corp, 1979, section I-2). The stabilising of technical characteristics, and also bringing a certainty to economic characteristics, offers an interesting way of representing the supply of technology which may resonate with many in the policy and political classes in contemporary neo-liberal economies. This approach is illustrated through a number of the 10 papers drawn upon here being prepared for government departments (e.g. Myers *et al*, 2002) and, in some instances, used to

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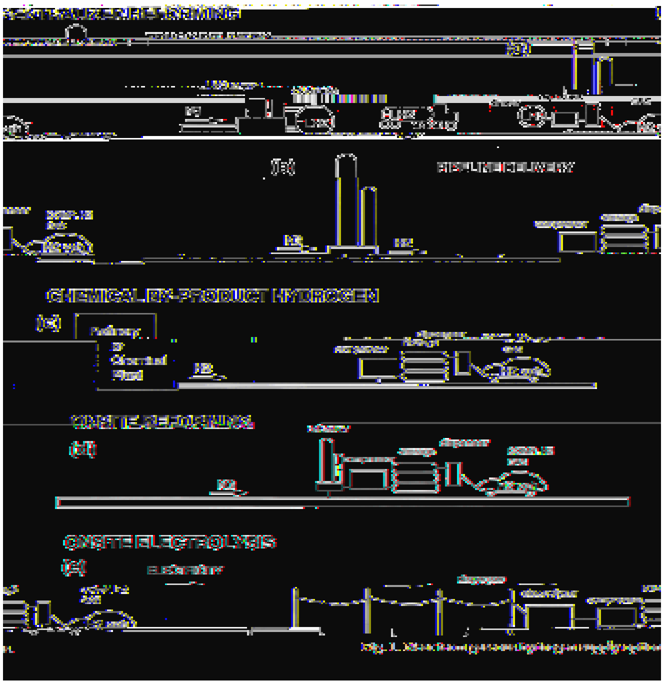
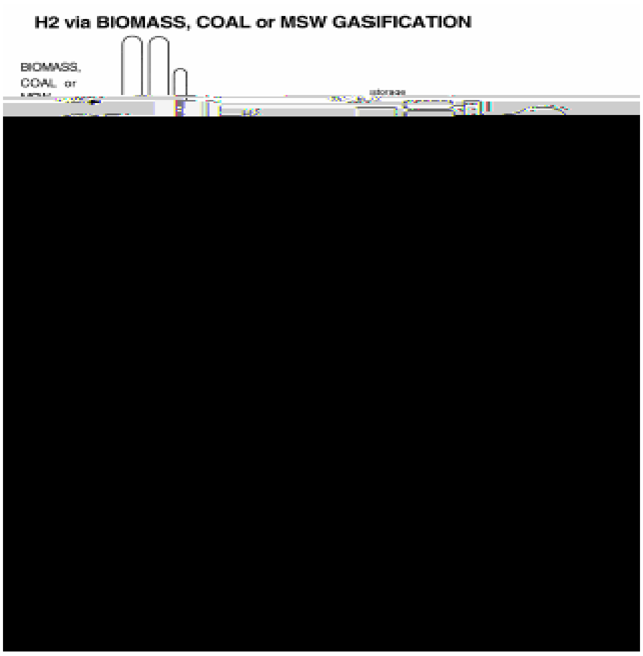
- as inclusive and exclusive of certain interests and practices. This, we claim here, can be understood through diagrammatic representations – or representational devices - of future hydrogen economies which are underpinned through a series of themes and issues, including: who is involved in such processes of representation; but also the ways in which TC practices and processes frame issues related to the technologies, the environment, consumption, economics and expertise.





Source: Ogden (1999).

The significance of diagrammatic representations, such as those above, at one level is in their power to influence debate and dialogue:

> What is so important in the images and in the inscriptions scientists and engineers are busy obtaining, drawing, inspecting, calculating, and discussing? It is, first of all, the unique advantage they give in the rhetorical or polemical situation. “You doubt what I say? I’ll show you”. And without moving more than a few inches, I unfold in front of your eyes figures, diagrams, plates, texts, silhouettes, and then and there present things that are far away and with which some sort of two-way connection has now been established. I do not think the importance of this simple mechanism can be overestimated (Latour, 1990, p.36).

Diagrams and representational devices have an important role to play in furthering and forwarding the interests of those who produce and construct them and who may draw upon these representations. This making visible of TCs also offers the possibility for their mobility across organisational, institutional and national boundaries not only as rhetorical devices but also as sources utilised in other TCs. This involves not only the mobilisation of diagrams but of networks of individuals, institutions, artefacts, etc, which constitute diagrams. With this in mind, how do we arrive at diagrams like those above? Of importance are the frequency with which this and similar diagrams (e.g. Schoenung, 2002), tables, graphs (e.g. PadróCs also ofswhicd

Programmes. In other examples the context within which papers were constructed was an academic one, both in the US (Ogden, 1999) and the UK (Brandon and Hart, 1999). This said, the networks within which such papers were implicated straddled the domain of the US example, on hydrogen refuelling station alternatives it was seemingly unapparent as to why ‘base cases’ assumed that there should be capacity to refuel 100 vehicles per day. This may have been, to some extent, as she suggested she had outlined this elsewhere. It may, however, be that these assumptions were in some way axiomatic. There was a considerable degree of re-citing secondary documentation, across the representations, with little discussion of the methodological underpinnings of these documents. In many instances they were seemingly offered up unproblematically from one context to another, thereby implicitly inferring that the data was transferable between contexts but also, more problematically, re-inforcing errors, over- and under-estimations and certain assumptions.

Framing Environment

Some documents also talked of ‘more conventional technologies’ (Dutton, 2002). The explicit, and implicit, aims of those writing the documents were varied. For some it was, at least notionally, to assess the possibilities of hydrogen technologies in terms of a ‘long-term role in greenhouse gas reduction’ (Dutton, 2002). In doing this, representations of environmental issues were in developing ‘a range of “bottom-up” estimates of carbon dioxide emissions from the UK energy sector up to 2050, and to identify the technical possibilities and costs for the abatement of these emissions’ (Marsh *et al*, 2002, p.iii). Addressing carbon emissions was frequently in terms of the ‘costs of production’, largely in terms of secondary data (Watkiss and Hill, 2002). Similarly, Schoenung (2002, p.10) drew on secondary sources to detail an ‘emissions analysis’ where the ‘primary figures of merit for this part of the study were fuel economy and emissions’. Often environmental issues were framed narrowly in terms of ‘costs’. One paper, for example, attempted to identify a range of ‘technical possibilities and costs’ for the abatement of CO2 emissions (Marsh *et al*, 2002, p.iii). A rider, in this case, was added suggesting that the results ‘are not forecasts [but] an analysis of what technology can in principle deliver, and of what the costs and effects on emissions might be’. With an eye to future developments and costs, the acknowledgement was that this ‘will turn on many factors including the policies implemented, the social acceptability of the technologies, the readiness of householders and business to invest in energy efficiency and the rate of innovation’ (Marsh *et al*, 2002, p.2).

Framing Consumption

Similarly, the framing of consumption, illustrated in a tabular representation below, was often in terms of estimations and assumptions of, for example, transportation use.

[redacted]

Source: Watkiss and Hill (2002, p.24).

Ogden (1999), for example, addressed fuel consumption in the Los Angeles area. Data was obtained from the South Coast Air Quality Management District for current and projected numbers (to 2010, then ‘extrapolated linearly to estimate vehicle populations to 2020’ by Ogden) of automobiles, trucks and so on. This, according to Ogden, based on the assumption about numbers of new cars and light trucks as zero emissions vehicles (ZEVs) from 2003, allowed the ZEV population for the Los Angeles Basin to be calculated by year. This projection of ZEVs then took the assumption that 50 per cent of ZEVs would be hydrogen fuel cell vehicles after 2005. This, in addition to the ‘assumed characteristics of hydrogen fuel cell vehicles’ (fuel economy, miles/year, fuel storage, hydrogen use per year, etc) permitted the estimation of total hydrogen demand in the South Coast Basin.

Framing Economics

The possibilities of hydrogen technologies, in many ways, were reduced to narrow economic considerations. So, for example, there was talk of ‘the relative merits of hydrogen storage systems and comparison of costs’ (Dutton, 2002, p.17). Or: ‘The capital cost of infrastructure and the delivered cost of hydrogen are estimated for each hydrogen supply option’ (Ogden, 1999, p.709). This leaves an obvious question as to how the notion of cost is conceptualized and framed. That is, to what does cost refer?

Many of the papers calculated technological and/or economic performance data on the basis of estimates. These estimates often rested on assumptions. Watkiss and Hill (2002), for example, in their paper highlighted a variety of ‘key assumptions for modelling’ (see above, sourced from ETSU/IC). These assumptions included that a vehicle would operate 350 days a year, that an ‘urban bus’ would travel 70,000 km per year and consume 5.88 tonnes of hydrogen per year whilst a taxi would travel 105,000 km per year consuming 0.935 tonnes of hydrogen a year. The interesting point to note here is that there was little sensitivity to, and appreciation of, the context in which such vehicles may operate, other than the broad term 'urban'.

The data used in calculating estimates were from a number of sources, sometimes primary sources such as local environmental monitoring bodies and 'industry sources' (Ogden, 1999), but largely from secondary sources (Padró and Putsche, 1999). Some of the assumptions upon which calculations rested could and should be questioned. Ogden (1999, p.711), for example, suggested that the primary data she received for vehicle populations, for her study, only stretched to 2010. Ogden was concerned to extend this time horizon to 2020 and so 'extrapolated linearly to estimate vehicle populations to 2020'. Similarly, in another example: 'Gaps in data time series were filled by interpolation and extrapolation' (Marsh *et al*, 2002, p.8). In the case of hydrogen fuelling appliances, Duane B. Myers and colleagues, using the DFMA Methodology, suggested that the cost of any component part of the fuelling appliances could be calculated through direct material cost, manufacturing cost and assembly cost. The cost of materials was usually based on 'either historical volume prices for the material or vendor price quotations'. However: 'In the case of materials not widely used at present, the manufacturing process must be analyzed to determine the probable high-volume price for the material' (Myers *et al*, 2002, p.6). This asks the question: why the high-volume price?

Methodologies used were explicitly characterised, for example in terms of DFMA Methodology (Myers *et al*, 2002), but also implicitly contained within the text of documents to a greater or lesser degree – sometimes as they had been articulated in other reports by the author(s) (Ogden, 1999; Schoenung, 2002) whilst in other instances with limited explanation (Brandon and Hart, 1999). This, of course, may be as the methodological underpinnings had been published elsewhere, the authors may not have considered them 'relevant' to their expected or intended audience, or readers may have been assumed to have developed the 'necessary' forms of knowledge to appropriate such documents.

Framing Expertise

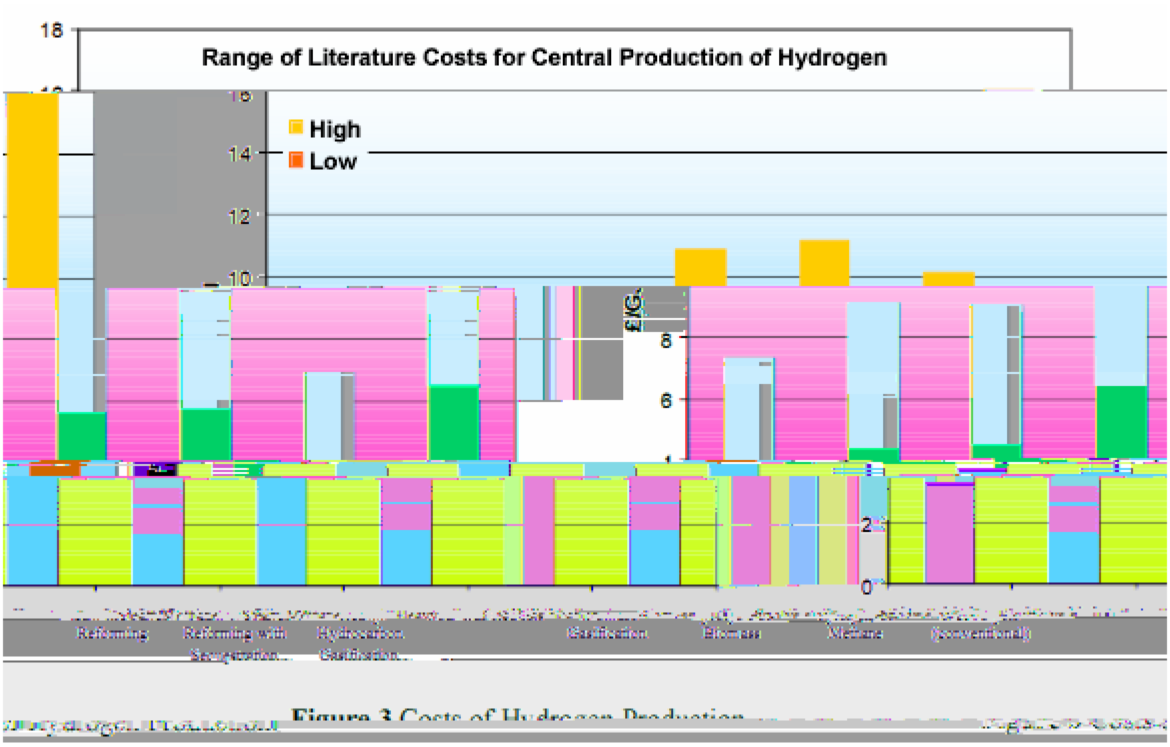
Within a number of the papers analysed there was a degree of the same papers, as sources, constantly recurring. In Padró and Putsche's (1999, p.50) paper, drawing on more than 100 publications and surveying the economics of hydrogen technologies, standardisation was undertaken to 'ensure level comparisons among the technologies, they were converted to a standard basis because each report used its own assumptions and methods', drawing on assumptions from a variety of secondary sources and also 'engineering judgement'. This begs the question: what is meant by 'engineering judgement'? Standardisation was only for the:

> capital and major operating costs for each technology…Unit operating costs (e.g., fuel price) were modified to match the standard value and capital costs were scaled to mid-1998 US dollars using the Chemical Engineering C&E index of 387. If a source did not provide the dollar-year estimate, then it was assumed the same as the publication year (Padró and Putsche, 1999, p.51).

As many of the sources drawn upon in the report used currencies other than US Dollars then a conversion to Dollars was made using a conversion table:

> No attempt was made to match the dollar-year used in the publication with the currency conversion for that year. After converting costs to US dollars, the values were escalated to 1998 dollars as described earlier (Padró and Putsche, 1999, p.53).

This attempt at standardisation appears to be less a methodological reflection on the underpinnings of the sources used and more a means of an administrative mechanism aiding comparison across sources. That is, there is little attempt to reflect on the basis of the assumptions and methods of other papers rather more an attempt to standardise their data. The authors are from the US-based National Renewable Energy Laboratory. The attempts to standardise the assumptions and costs pertaining to a variety of different reports from a number of different countries suggests, at least implicitly, that the authors tried to disembed the assumptions, costings and findings from various contexts and standardise them in terms of their own abstract criteria. Interestingly, the data from this report then subsequently informs numerous other documents (including Dutton, 2002; Watkiss and Hill, 2002). A series of different papers and assumptions, furthermore, informed Watkiss and Hill's graphical representation (below) of a range of literature costs for central production of hydrogen.



Source: Watkiss and Hill (2002, p.17).

Interrogating Technology Characterisation: Beyond Products to Process

The claim raised with regard to TCs previously is the paradox that its aspirations for ‘certainty’, ‘abstraction’ and ‘universalism’ offer one way, in amongst numerous others, of understanding hydrogen technologies. Importantly, there are not only numerous ways of understanding hydrogen technologies but there are also possibilities to reflect on who may be involved in producing and constructing different ways of understanding, from which position(s) and drawing on what sorts of resources. This is particularly important when there is significant controversy around an issue, as there is with hydrogen technologies and the hydrogen economy(-ies), before (often temporary) closure or stabilisation (Pinch and Bijker, 1987) has been achieved and where there may be significant ‘interpretative flexibility’ (Bijker *et al*, 1987).

There are, thus, two intricately linked issues here. The first is in trying to understand the ways in which TCs frame a partial, privileged understanding of hydrogen technologies and the hydrogen economy(-ies). The second relates to trying to gain greater understanding of the processes of TCs, and their social construction and production, as the consequence of such a way of understanding. The scope of this paper permits us to begin addressing through documentary analysis the first point but also to make headway in raising issues for subsequently addressing the second issue.

A key concern from a social science perspective is the emphasis on inputs and outputs, but also the opening up of the ‘black box’ of technology (Latour, 1987) with regard to processes

This resonates with the characterisation of the technology of the hydrogen economy(-ies). Many TCs, as outlined above, draw on tables and diagrams as powerful illustrations, reducing the complexity of the various assemblages which constitute such diagrams. Through the processes of calculation, outlined above, an artefact or object may be diagramatically produced and constructed. A series of these may be pieced together as assemblages offering a forceful visual representati

(2002) UK-based work drew on Padró and Putsche which, itself, was based on more than 100 publications, examining the economics of hydrogen technologies. The sources that Padró and Putsche utilised were often originally produced within a series of different contexts, with various assumptions and temporal frames. ‘Standardisation’ of documents was undertaken, by Padró and Putsche, where to ‘ensure level comparisons among the technologies, they were converted to a standard basis because each report used its own assumptions and methods’ (Padró and Putsche, 1999, p.50).

The static image on the paper also does little to highlight the dynamic nature of developments in hydrogen infrastructures and the interplay between hydrogen technologies, and systemic and local contexts. Attempts to capture this dynamism may be limited to arrows showing feedback or the ‘direction of change’. What is of interest here are the ways in which these components of hydrogen infrastructures come to be produced and constructed as discreet, calculable, separative technologies (Slater, 2002) and how these are then assembled into options of infrastructures for certain periods of time. This requires an understanding of the heterogeneous resources which are drawn upon in the ‘laboratory’ context including theories, assumptions, equipment, and so on. That is to say: ‘Any account which divorces RDs [representational devices, such as diagrams, graphs and tables] from the contexts of *praxis* that define and concretely situate such devices clearly ignores a salient – perhaps *the* salient –
M a tr i eo u cs h 6

requires the drawing of boundaries ‘between the relations which the agents will take into account and which will serve in their calculations and those which will be thrown out of the calculation as such’ (Callon, 1998a, p.16). Entangled webs and relationships of goods and agents must be disentangled and framed. Frame is in the sense, it was developed by the US sociologist Erving Goffman (1974), of establishing ‘a boundary within which interactions – the significance and content of which are self-evident to the protagonists – take place more or less independently of their surrounding context’ (Callon, 1998b, p.249). Framing allows for the definition of individuals, groups, objects, goods and so on in that they can be disentangled or disassociated from entangled webs and relationships. Framing, thus, permits us to conceive and ‘calculate’ ‘separative technology’ (Slater, 2002), where in this case TCs take hydrogen technologies as distinct and individuated.

Andrew Barry and Don Slater, in a discussion of Michel Callon’s work *The Laws of the Markets*, suggest that, ‘the capacity to calculate depends on a set of technical devices and discursive idioms that make calculation possible. In the case of markets, ‘calculativeness’ depends upon the separation or individualization of objects into discrete transactable entities, with (temporarily) stabilized properties, that can be placed within a frame of calculation’ (Barry and Slater, 2002, p.181). This discussion of calculativeness and markets also resonates with calculativeness and TCs. It permits a degree of delineation through framing, the consequence of which may be stability of a framework and ‘certainty’ upon which ‘calculation’ can be premised and transferred between contexts (Slater, 2002). It also encompasses tacit expectations and agreements within the frame which relies on a physical framework – in TCs a laboratory, scientific papers and books, maybe lecture theatres, seminar rooms, or other shared spaces for dialogue, and so on – and an institutional framework – including perhaps tenure, safety regulations, funding streams and on – ‘which help to ensure their preservation and reproduction’ (Callon, 1998b, p.249). Through delineation, framing ‘puts the outside world in brackets, as it were, but does not actually abolish all links with it’ (Callon, 1998b, p.249). The drawing on scientific papers, for example, in conducting TCs acknowledges that these papers also have their own histories often outside of the frame.

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other being the ‘factors that sustain these interactions’

that what ‘works’ in one niche may not necessarily develop in other niches despite its ‘general promise’ – the example here may be the use of fuel cells in space applications (Rip and Schot, 2002).

Both the LTS and the niche approaches suggest shortcomings in the TC view of standardisation and abstraction underpinning economic and technical characterisation. Thus, we should not only be seeking to problematise the processes and practices of TCs but also trying to build dialogue between the different interests implicit in ways of understanding the hydrogen economy(-ies) as not only an ‘R&D’ issue but also in systemic and localised contexts. We need to look to creating a ‘nurtured space’ (Hoogma *et al*, 2002) which permits a dialogue between TC exponents in the R&D context and representatives of various interest groups which attempts to draw closer processes of supply, existing systems and infrastructures and local contexts of controversy and innovation.

Such a view, articulated by proponents of constructive technology assessment (CTA) (Schot, 1998), moves beyond viewing technology as either a technological fix or a social/cultural fix and seeks to address the co-production of technological development. In doing this, ‘barriers’ to technological change are addressed through attempts at synergising, via ‘experiments’, the anticipations of hydrogen technologies and the hydrogen economy(-ies) of different actors through unfolding ‘reflexivity’ and social learning. Learning may happen in two ways. First in terms of cultivating articulations of the specifics and definition of particular ways of understanding. But second, and related, through second order learning understanding the assumptions and articulations which characterise specific ways of understanding and the consequences and possibilities which this opens up.

Summary

This paper has addressed a partial but powerful view of the hydrogen economy known as technology characterisation. This offers particular representations of the supply of hydrogen technologies through ‘measuring’ the ‘state of the technology’ or the ‘state of the art’. In its strong focus it has an emphasis on creating ‘certainty’ and informing attempts to ‘plan’ and ‘project’ through ‘unambiguously’ seeking to generate ‘constant’, ‘unbiased’ single ‘official’ sets of data for ‘generic’ technologies, to inform future technological development and ‘projection’ of costs. This view was seen as an important means of generating political and policy support for technological developments through outlining technical ‘possibilities’ and ‘options’ in relation to ‘costs’. The ‘achievement’ of this ideal of TC was problematic, as analysis of 10 documents highlighted. Through these documents a series of practices could be

Annex: Contents of Papers

1. Geoff Dutton, ‘Hydrogen Energy Technology’, April 2002, Tyndall Centre for Climate Change Research.

2. Joan Ogden, ‘Developing an Infrastructure for Hydrogen Vehicles: a Southern California Case Study’, 1999, International Journal of Hydrogen Energy, vol.24, pp.709-30.

3. George Marsh, Peter Taylor, Heather Haydock, Dennis Anderson, Matthew Leach, ‘Options for a Low Carbon Future’, February 2002, AEA Technology PLC.

4. Duane B. Myers, Gregory D. Ariff, Brian D. James, John S. Lettow, C.E. (Sandy) Thomas, and Reed C. Kuhn, ‘Cost and Performance Comparison of Stationary Hydrogen Fueling Appliances’, April 2002, Directed Technologies Inc. paper prepared for the Hydrogen Program Office, Office of Power Technologies, US Department of Energy, Washington DC.

5. J.B. Lakeman and D.J. Browning, ‘Global Status of Hydrogen Research’, 2001, Contractor, Defence Evaluation and Research Agency as part of the DTI Sustainable Energy Programmes.

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New Directions in the Sociology and History of Technology, MIT Press: Cambridge, Ma., pp.17-50.

Prodi, R., (2003), 'The energy vector of the future', Conference on the Hydrogen Economy Brussels, 16 June. Available:
http://europa.eu.int/rapid/start/cgi/guesten.ksh?p_action.gettxt=gt&

Notes

[i] http://www.whitehouse.gov/news/releases/2003/01/20030128-19.html Accessed 15/10/2003.

[ii] 'TC' refers to the notion of technology characterisation. 'TCs' is the plural of this and is used here to highlight