state of technology against primarily technical criteria' (Taylor, 1978, p. S-1). The predominant rationale for TC within the 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).

While these are very specific purposes, there are close affinities with the objectives of the 10 hydrogen TC reports that for example, provide a 'survey of the economics of hydrogen technologies'; 'cost and performance comparison of stationary hydrogen fuelling appliances'; and 'technoeconomic analysis of different options for the production of hydrogen'. TC has also been viewed as a necessary precursor of technology assessment (TA) where the 'greatest need for TC is in the early stages of R&D, while TA is normally applied to technologies which are at least approaching commercialisation' (Taylor, 1978, p. 8). There are clearly potential overlaps between both approaches as a complex set of energy technologies move at differential rates from R&D to commercialisation.

The second features are the practices of Tb;;AOs50hy0technolj:I0a5-IY:I0ofjfi55;:;0Tb;;A(;;AY:50ofjfi‘flAInolj:I9A;-;sncicspf sorts of practices and processes constitute TCs? And also, how might we understand these practices and processes and the implications of this for how we see the hydrogen economy (-ies)?

Second, 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 Table 1, 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/yr and consume 5.88 ton of hydrogen per year whilst a taxi would travel 105,000 km/yr consuming 0.935 ton 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).

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?

Finally, there were consistent attempts to standardise data and move it unproblematically from one context to another, thereby implicitly inferring that the data was transferable between contexts but also, more problematically, re-inforcing, over- and under-estimations and certain assumptions. For instance 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 fi;:50djte5flI th2 dollarllar-yea2teused

(below) of a range of literature costs for central production of hydrogen (Fig. 1).

Analysis of the people, practices and processes involved in the production of TCs of hydrogen technologies highlights that TCs offer a partial, but powerful, way of understanding a future hydrogen economy (-ies). This, we suggest, manifests itself through diagrammatic representations—or representational devices—of future hydrogen economies (Figs. 2 and 3).

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

Putsche, 1999) and schematics (e.g. Brandon and Hart, 1999) occur in TCs but, also, the ways in which the practices and processes which constitute these diagrams, graphs and tables privilege certain aspects of the hydrogen economy(-ies), including often narrowly defined economic costs and technical possibilities, to the exclusion of other aspects including social contexts of innovation, appropriation and consumption in use.

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 [illegible] that define and concretely situate such devices clearly ignores a salient—perhaps [illegible] salient—influence on the construction and utility of RDs' (

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.

This then, as Callon highlights, suggests possibilities for two particular emphases: one which focuses on stabilisation or closure and mutual agreement between players within the frame and the second being the links between the frame and the outside world in terms of 'overflows'. The distinction here is one between focusing on micro-level interactions and the other being the 'factors that sustain these interactions' (Callon, 1998b, p. 250). The focus on the micro-level context of the 'laboratory' is one of the creation, acquisition and circulation of forms of knowledge. It also raises the issue of how various forms of 'local' knowledge come to be translated in to 'universal' abstract knowledge. It is important not only to understand the forms of such knowledge, but also processes of knowledge creation/acquisition, communication/circulation, and also the implications of such in interplay.

The framing of TCs may be seen to narrow the issues for debate around hydrogen technologies. Yet, this should not be taken for granted in that 'far from limiting the possibility for political conflict and negotiation, framing forms something like a surface on which forms of political reflection, negotiation and conflict can condense' (Barry and Slater, 2002, p. 185). TCs offer an important but challengeable way, broadly speaking, amongst many for understanding hydrogen technologies and the hydrogen economy(-ies). This addresses issues about why 'some occupational groups are more effective than others in claiming expert status for their knowledge and skills. This raises questions about who gets to be seen as skilled or expert' (Faulkner et al., 1998, p. 7). It also highlights issues about how we might understand the partial knowledge, skills and expertise which constitute TCs in relation to other ways of seeing the hydrogen economy.

TCs work at a level of abstraction dealing with the supply of technologies in relation to costs and technical capabilities. If we return to the political proclamations (from the contexts of the US, the EU and London) at the beginning of this paper we acknowledge, at least implicitly, the relationship of developing a hydrogen economy to particular places. Yet, TC as a dominant way of seeing the hydrogen economy says little about the notion of place. The issue then is: how do we think about linking the supply of technologies (through costs and possibilities) to embedding hydrogen technologies within particular social contexts? In detailed case study fieldwork, we have discussed elsewhere (Hodson and Marvin, 2005) the difficulties of translating Technological Characterisations, or understandings of what the technology can 'deliver in principle', have been highlighted by numerous actors who, whilst coming from a technological background, have grappled with attempts to develop a hydrogen economy 'on the ground'. As an example,

> I think there's a big dichotomy between the global, societal benefits that you can get from transitioning to hydrogen versus what does it give to the public in the street. The first hydrogen [fuel] station that you build somewhere or the first project that you implement locally…it's difficult to demonstrate the very immediate local benefit because you have to speak to these more global concerns all the time.

At an even more 'mundane' level:

> Let me take an example, like putting one [a fuel cell] into a school. You say well this is hydrogen, as a petro-chemical professional, I know how to design safe hydrogen installations or chemical plants. How do you take something which is engineered to be safe in that environment and re-engineer it to be safe in a school?

Likewise, if government, beyond TC, is uncertain as to how the hydrogen economy may develop 'on the ground' the issue becomes how do they go about addressing this in particular societal contexts?

> We have been saying to DTI [UK Department of Trade and Industry], if you are serious about developing a hydrogen economy but are not sure what it is going to be then we on Teesside can provide a national scale experimental platform. So come and play around and do it here until you know what you want it to be.

These questions and quotes pose challenges in terms of researching different policy interventions (i.e. R&D and the supply of technology and local level developments appropriating these technologies) which impinge on the same overall hydrogen economy agenda. As a means of connecting issues related to the supply and consumption or appropriation of hydrogen technologies it is useful to think about alternative ways of seeing the hydrogen economy. Thomas Hughes (1987), in his work on LTS, points out that the development of technologies is not merely to do with cost or technical issues but needs to be understood within the institutional and organisational arrangements of current systems. 'If a component is removed from a system or if its characteristics change, the other artefacts in the system will alter characteristics accordingly' (Hughes, 1987, p. 51).

A key point is…'the reason these system elements come together does not depend solely on attractive economics' (Watson, 2002, p. 11). This permits us to think of the stability or path dependencies of existing technical systems, through deeply embedded interrelationships. Technological change is not merely about costs and technical possibilities but is bound up with a series of relationships of utility providers, regulators, vested interests, consumers, etc in particular national and sub-national contexts. Attempting to radically alter these relationships is difficult in that:

> Such reconfiguration processes do not occur easily, because the elements in a sociotechnical configuration are linked and aligned to each other. Radically new technologies have a hard time to break through, because regulations, infrastructure, user practices, maintenance networks are aligned to the existing technology (Geels, 2002a, p. 1258).

This focus on the stability of existing incumbent technologies and the webs of relationships which underpin their functioning largely answers the question: 'why [are] such [novel] technologies not introduced into the market when their benefits to society are so evident'? (Hoogma et al., 2002, p. 12). It, however, ignores how novel hydrogen technologies begin to develop processes of building such interrelationships, forms of knowledge and learning.

The idea of socio-technical niches is of '''protected'' spaces at the local level in which actors learn in various ways about new technologies and their uses' (Geels, 2002b, p. 365), where innovation and processes of learning by trying keep alive novel technological developments which otherwise may be 'unsustainable'. This requires 'special conditions created through subsidies (including government) and an alignment between various actors' (Geels, 2002b, p. 367). This necessitates a process of network building and an alignment of actors including various users, producers and political actors. 'In the niche model, lock-in and path dependency assumptions are relaxed…. Niches may also persist because actors such as firms and governments act strategically by keeping certain options alive which might be important for future competition or other broader societal goals' (Hoogma et al., 2002, p. 26). Important in this process is learning about the potential uses and limitations of a novel technology on the basis of a series of issues including: technical and design aspects; the role of policy in stimulating applications of technology; addressing symbolic aspects around technology; constructing; shaping markets for technology in relation to consumers; etc (Geels, 2002b, p. 368).

This paper has addressed a partial but powerful view of the hydrogen economy known as TC. 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 emblematic documents highlighted. Through these documents a series of people, practices and processes were outlined in the production of TCs. The use of diagrams, in particular, as symbolic representations of partial but powerful TCs of the hydrogen economy(-ies) was addressed.

The paper looked 'inward' in terms of critically examining processes of producing and constructing interrelationships and thus sensitising policy to the relationships between technological possibilities and societal contexts.

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Padró, C.E.G., Putsche, V., 1999. Survey of the Economics of Hydrogen Technologies. National Renewable Energy Laboratory,