

The Ambivalent Question of Reflexive Transition into the Hydrogen Economy (HE)

Ágnes Fésüs

Abstract

Based on the fundamental principle that social studies into sustainable development are crucial, I concentrate on the special case of the hydrogen economy (HE). My particular focus is on the used and overused rhetoric on a future hydrogen economy. While widely shared long-term expectations may stabilise innovation dynamics, emerging breakthrough technologies such as hydrogen energy technologies and their economic utilisation necessarily occur in an extremely turbulent context and face deep information uncertainty. To avoid early lock-in, full-fledged reflexivity is needed for governing their transition dynamics. Different reasons may lead to different agents already being committed to some sort of HE at an early stage. Early commitment to excluding the search for alternative(s) to HE might cause otherwise avoidable lock-ins. Maintaining interest e.g. in repeated scenario building and expectation dynamics is thus the most important aspect to be integrated in considerations on possible futures.

Introductory remarks

Globalisation, the emergence of such immense opportunities as the nano-tech-based converging technologies and such threatening perspectives as irreversible climate change, and the growing gap between rich and poor countries all constitute challenges involving long-term, complex tasks of world-wide transitions. These transitions aim at realizing something that, for purposes of brevity, we can call socio-economic-technological regime changes. I said brevity, for these changes necessarily extend to and involve all parts of the complex social system. They have some impact on them or, seen from another perspective, occur in the complexity of the social system in its entirety. They involve political, cultural and ideological changes too; changes in at least some segments of everyday life. It is evident that all these complex regime changes interact with each other. These processes occur in an environment of complexity and incertitude. I use

the term 'incertitude', according to A. Stirling (2006), to include all the possible sorts of uncertainty, even ignorance. Appropriate development of cognition and management forms is also needed to meet such transitions. Both long-term strategic management and policy should be renewed to appropriately handle these issues. The magnitude of the tasks mentioned above already routinely extends the time perspective from twenty or so years to half a century or more. To meet this challenge, visions of radically new energy resources are also developed.

If uncertainty exists anywhere about the basic resources for the economy in the long-term future, then it is in energy. Nevertheless, it is still common not least in the energy field to present views of the future as prognostic forecasts. Forecasts are projections of trends into the future aiming at probability of score. We may now learn from forecasts that around twice as much energy as we use at present will be needed globally by 2050. Forecasting either the whole, or some elements of the long-term energy future of the world is based on and justified by the observation that energy is embedded in the economic environment. What is meant by this is the dependence of all other sectors of the economy on energy, furthermore the necessity of huge financial investments with slow returns, the need for planning a very long time into the future urging the implementation of simplifying policies and the security of trend-like developments. These are factors that make parts of the energy narratives trend-like and forecastable in different respects. But regimes as a whole also change in a non-linear way in the long run. It might be that we will need twice as much energy as we need now by 2050, but it seems that this extrapolative thinking might be fully misleading at least in other aspects, because it systematically neglects the need to take into account the non-linearity of the processes and the deep information uncertainty. Both are drivers and results of an enormously growing 'tight interaction'. Foresight scenarios move into the forefront since raising complexity in modelling is hardly an appropriate instrument for making processes more forecastable.

The energy analyst Daniel Yergin, president of CERA (Cambridge Energy Research Associates) summarises the basic problem with energy foresight in a short article: *Large Energy Stakeholders Face Challenges as Fossil Fuels Go Extinct Like the Dinosaurs*.

The Ambivalent Question of Reflexive Transition into the Hydrogen Economy (HE) 169

The energy business has one of the longest timelines of any industry. Decisions are being made today for oil or natural gas fields that will only begin to flow fifteen years from now. A power plant approved tomorrow may be operating for half a century. And, increasingly, many of the big decisions will be measured not in the hundreds of millions, but billions, of dollars. Investors, in the meantime, have to decide where to put their bets on technologies that will take years to come to fruition. Inevitably, much will change over those time frames. Unexpected geopolitical clashes will roil markets. Economic performance will surprise. Technology will bring in new energy sources and change the competitive playing field. Governments will undoubtedly change their minds on the balance between markets, on the one hand, and regulation and state ownership, on the other – and more than once. Today, the outlook for regulation of carbon emissions creates another layer of uncertainty. There could be strong pressure to change the fuel choices in the face of tighter carbon regulations. Or the international community may fail to agree on effective carbon controls, and regulations could be limited or not effectively enforced. There will certainly be much debate as to whether to rely on markets or on regulation to meet climate change goals. How to make decisions in the face of such uncertainty? ‘Scenarios’ can play a very useful role. A disciplined process of scenario development provides a framework for the uncertainties. These are not forecasts or extrapolations. Rather, they are logical ‘stories’ about alternative futures that force one to think about the ‘what-ifs’, the surprises and the range of uncertainties. Think of them as thought experiments, but grounded in wide-ranging research and analysis. Our energy scenarios combine structured narratives of how the larger world could evolve in the future with detailed energy market modelling. Yes, they are thought experiments, but the objective is to help people to think systematically about trends and the potential for changes, ruptures and discontinuities. Scenarios, of course, can be used for any industry or for public policy. Given the high stakes and uncertainty surrounding the future of energy, there is a need for structured ways of thinking about how the future may unfold. The next 25 years will be full of surprises. Scenarios can help us better prepare for these surprises – and perhaps even anticipate the surprises before they arrive (Yergin 2008).

Diminishing the turbulence requires some sort of long-term alignment too. Voluntary alignment of the actors in the arena around a good alternative may be a very strong factor in making the processes more forecastable. By bringing in, ‘taking into account’ localities voluntary alignments help make the targeted endeavour more robust and flexible. In most of the cases engagement also precedes and accompanies voluntary alignment. Alignment works

170 *Ágnes Fésűs*

as an early selection trial and is risky in itself, i.e. it implies the risk of early lock-in. I will investigate one case to concentrate on the role of rhetoric in communication in the engaging process and the rhetorical communication instruments around the emerging hydrogen economy.

My case study gives a bird's eye view of the issues by concentrating on the possible utilisation of hydrogen for transportation, as part of the HE vision. A HE is a hypothetical economy in which the energy needed for motive power (for automobiles and other vehicle types) or for producing electricity (for stationary or for micro-informatics applications) is derived from the reaction of hydrogen (H₂) with oxygen. HE is a complex involving the economy, politics, legal regulation, everyday life, culture, and ideology around a special technology. HE is one of the long-term strategic visions forming part of the overall global strategic energy vision. From the perspective of science and technology studies the aim is a socio-economic-technological regime / industrial sector change by developing a new worldwide actor network engaged in this sort of global strategic innovation. A comprehensive assessment of the HE is in itself a strategic task that needs both reflectivity and reflexivity.

Scientific and technological basis of a HE

Let me first briefly refer to the natural scientific and technological basis of hydrogen as a fuel. The first attempt to utilise hydrogen for fuelling what we would today call a concept car, was made some 200 years ago in 1808.¹ Hydrogen is abundant on Earth, but in the 'natural state' it mostly occurs in compounds such as hydrocarbons or water. Hydrogen is routinely produced and used in industry, e.g. for ammonia production. Annual hydrogen production worldwide amounts to roughly 100 million tons. Interest in utilising hydrogen as a fuel increased substantially when the need for diminishing the negative environmental effects of hydrocarbon fuels became more urgent. The combustion of hydrogen produces only water, which means that the end-use of hydrogen does not pollute the environment. This characteristic of hydrogen is paired with two other characteristics that also became very important with the lasting instability of the energy market and its uncertain global outlook. First, hydrogen is versatile and can serve

as an intermediate form of storage for a very wide range of primary energy sources, making hydrogen the second most important storage option after electricity. Taking hydrogen into account as a possibility can thus make storage decisions more flexible.

Hydrogen is not a primary energy source, but an energy 'carrier'; it must be produced from primary sources. The energy balance will thus be comprised of the energy needed for production, the losses from transfer and storage, the losses from utilising it for fuelling and the energy won by its end use. While this balance is inevitably a loss of energy, using hydrogen as a fuel will be worthwhile if more emphasis is placed on clean end use and / or the storage advantages and / or the fact that hydrogen can be produced from a very wide range of primary sources. Hydrogen competes with electricity in all these respects.

The possibilities for producing hydrogen from primary energy sources include steam reformation from natural gas, or using renewables, it can be produced from water by electrolysis, or biologically utilising algae, to mention but a few of the very wide range of possibilities. Hydrogen as a component in ammonia production is used not as a fuel but as a raw material in large-scale industry. Up to 97 to 98 % of hydrogen is currently produced by steam reformation, which produces a significant amount of CO₂ as a by-product. For a HE this poses an additional CO₂ sequestration problem further deteriorating the above mentioned energy balance. Energy for hydrogen production can be taken from utilising heat from nuclear energy production, or electricity from photovoltaics, wind energy, etc.

Hydrogen for transportation was a 'dormant technology' for 150 years. It has been used in space technology and military applications since the 1950s. The utilisation of hydrogen as a fuel for cars now concentrates on its use in fuel cells. Fuel cells promise and to some extent already deliver high efficiency in this respect. Hydrogen can be stored in three different ways: cryogenic storage, compression and binding in metal hydride compounds. All of these methods involve immense difficulties.

Bossel et al. show some of the main technological problems with hydrogen. First, natural gas can do what hydrogen does in most practical applications. There is no need for a conversion of natural gas into hydrogen, which is more difficult to package and distribute than the natural

energy carrier (Bossel, Eliasson & Taylor 2005, 13). Furthermore, hydrogen gas contains less energy per unit volume than methane (Bossel, Eliasson & Taylor 2005, 9). Secondly, concentrating on crucial technological solutions in the hydrogen economy does not preclude the need for urgent steps to counteract climate change.

When the issue is about using hydrogen for transport, many experts believe that over and above these problems the real crux is the problem of infrastructure, especially the need for distribution if hydrogen is produced at central production stations. That is why distributed production of hydrogen is a matter of outstanding importance. On-board hydrogen generation is also given consideration. And last but not least, using hydrogen in transport also involves considerable safety problems.

In summary, the utilisation of hydrogen as a fuel has several appealing characteristics. It does not lead to greenhouse gas emission when burned, it can act as a storage medium, and it can be produced from a very wide range of primary sources. Producing electricity in fuel cells is highly efficient. Furthermore, like electricity, it can be scaled at any level (meaning it can be used in both micro and macro equipment). There are many further advantages to the use of hydrogen, e.g. in fuel cells for energy production. For example, fuel cell driven cars are noiseless and they can be accelerated smoothly. All these characteristics make hydrogen a strategic competitor with electricity as a storage material or fuel. However, one must consider the huge challenges arising when the weaknesses of utilising hydrogen are also taken into account. Every step indicated above also contains major challenges. If production of hydrogen is realised in a 'black way', i.e. from carbon containing compounds then the already mentioned CO₂ sequestration problem places a great burden on the process. Storage also involves serious difficulties. Distribution is a further difficulty, especially since the provision of a distribution network, similar to the electricity grid or gas station network would represent an enormous infrastructure problem both in technological and in financial terms. Fuel cells themselves may not be competitive on the market for a long time to come in terms of duration and especially in terms of costs. Another technological challenge a possible HE must take into account is an expected platinum shortage resulting from the production of hundreds of millions of fuel cells. In general a 'hydrogen econ-

omy' would require a vast number of breakthroughs resulting from a whole series of radical technological innovations, a huge and indeterminate volume of financial investment together with a series of institutional, legal, and political innovations. But an undertaking to realise a 'hydrogen economy' may be problematic from the start on its very physical-chemical basis, raising the question whether it could be made worthwhile at all. The implementation of a 'hydrogen economy' is a very long-term high-advantage, high-risk undertaking, characterised by a great complexity of coupled issues and 'incertitudes'. All these uncertainties mean that the communication process may be given a role of special importance and that rhetoric will probably have a unique role to play.

Use and 'overuse' of rhetoric in a scientific expert group report on hydrogen vision and roadmap

Rhetoric is not only unavoidable in communication but it is an ingredient of its success. We know this both from politics and everyday communication. Political communication is an approach to political action through use of language and rhetoric. Rhetoric also serves the process of influencing hesitant actors in everyday life. In a discourse each party tries to gather as much as possible of the sort of 'evidence' that will be sufficient to convince and commit at least some sub-groups of those participating in the discourse. What is the position for the advice experts give in policy arenas? This advice is based on expert factual knowledge and is typically a mixture of scientific factual knowledge and 'expert assessment'. And what is the position here with regard to the possible rhetorical side of expert advice? The demonstration that scientific texts also have rhetorical functions has only received recognition relatively recently. This again is part of the relatively recent understanding that the progress of scientific research is achieved through an ongoing discourse. This discourse is its medium. The question arises of how the functioning of rhetoric relates to such scientific norms as exposing candidates of scientific truth to probing questions that are as extensive and as deep in scope as possible.

Hydrogen is claimed to be a clean energy solution to the climate change problem

The European Commission set up a high-level expert group (HLEG) in 2002 (Commission 2003) to assess the contribution that hydrogen and fuel cells could make to the realisation of sustainable energy systems in the future. From assessing its role in some later documents this report had an important effect on the commitment of the European Commission (EC) to the HE. The work of the HLEG was initiated in October 2002 by the then Vice President and Commissioner for Energy Transport of the European Commission, Loyola de Palacio and Philippe Busquin, then Commissioner for Research. As we saw in the short description of the institutionalisation in the first years of the 21st century, HE was 'in the air' in the USA, Japan, Australia and in some European countries. The time had come for the EC to also take a stand. Some preliminary explanatory notes on the constitution of the HLEG are appropriate here. It had 19 members chosen in a 'balanced way', as stated in the summary (Commission 2003, 24). The group consisted of 13 representatives of major industrial stakeholders, 1 from a national parliament (Iceland), 1 from a commission, 2 from research centres, 2 from a social organisation, all of them committed to a possible hydrogen economy. The group was invited 'to formulate a collective vision on the contribution that hydrogen and fuel cells could make to the realisation of sustainable energy systems in future', and of course a vision on the possible leading role of the EU (Commission 2003, 5). In the report they summarise the main characteristics of this future opportunity and assign the main action strategies. In my assessment of the report I reveal the hidden power that may have influenced future expectations and their acceptance through some strong rhetorical elements of the text that may be characterised as 'overuse' of rhetoric.

In their foreword to the report Palacio and Busquin state that the HLEG persuasively argued that 'hydrogen based energy systems can build bridges to the future' (Commission 2003, 7). Let us examine the structure and the dynamic of the narrative of the report. One must first assess the rhetorical function of the report beginning with the very basic fact that the expert assessment does not compare the HE with its alter-

natives. The report only summarises the arguments for 'why' and repeats previous US and European expert assessments that the hydrogen economy represents a unique possibility. With this the HLEG joins the already existing queue of supporters while also claiming the credit for themselves. A special European answer to 'why' is that there is a threat of losing economic competitiveness by failing to take a part in developing a HE.

Hydrogen is first referred to as 'clean energy'. Using the term 'clean energy' as an *epitheton ornans*² for hydrogen energy strengthens the usual confusing supposition that appears in so many visions and advertisements. One of the aims – aims of the EU, aims of developed countries – is to create a sustainable energy system in a clean way. This report emphasises that hydrogen is the solution to climate change, because it is clean when burned as a fuel. In international communication there are several clichés referring to hydrogen as clean energy because at the end of its utilisation there is no other end product than pure water. With this the reader is led to focus on this part of the story as if the clean production of hydrogen had already been solved. This influential symbol, *clean energy*, has been established to function as a 'magic word' that can possibly help to hide the small and even the bigger problems surrounding this new technology. In contrast to this, choosing the right primary energy source is another crucial point that requires broad environmental, economic and political consideration. It is thus not acceptable that the authors of the report would like us to see this as the solution to the greenhouse gas emission problem when it is not made fully clear that hydrogen can be produced both in a 'black' and a 'green' way. The report formulated 'immediate actions [are necessary] to promote greenhouse gas emissions-free energy sources such as renewable energy sources, alternative fuels for transport and to increase energy efficiency' (Commission 2003, 6). Indeed, the next paragraph is about hydrogen as the unique, clean energy that 'holds great promise for meeting in a quite unique way, our concerns over security of supply and climate change' (Commission 2003, 6). Together these two paragraphs suggest hydrogen is the solution to these problems. On the one hand, it must be made clear to the reader that immediate action is required and it appears as though hydrogen is the ideal solution, not least because no mention is made that in fact the

176 *Ágnes Fésűs*

recent 'hydrogen technology' is not able to offer this solution right now, and that a relatively long transition term is necessary, during which even more CO₂ is going to be produced in the beginning. Furthermore, stating as a fact that fuel cells are very efficient energy conversion devices might also be problematic.

Weaknesses are the challenges to overcome

The text defines the enormous difficulties I referred to above as challenges to be solved by serious further research. This rhetoric leads readers to believe that the possible solution is definitely achievable or has nearly been achieved already. The text emphasises one of the great advantages of hydrogen, namely that the production of hydrogen is flexible enough to use different energy sources. This is a real advantage from a purely energetic point of view. But we know that this advantage is more than questionable when we speak about reformation processes from hydrocarbons from the point of view of climate change. The problem that CO₂ sequestration is also a strategic task still to be solved is mentioned only as a challenge. Indeed recent production methods using non-renewables may be necessary for a long time to come in the production of hydrogen and this may cause an enormous additional problem. At the same time moreover, it is slightly misleading to suggest that hydrogen might be produced by using different energy sources. Most of the alternatives are just concepts, but the report simply puts them next to each other.

The expert report is at least ambivalent when discussing the possible future 'benefits of hydrogen and fuel cells' that 'are wide ranging, but will not be fully apparent until they are in widespread use' (Commission 2003, 11). This sentence states that these benefits obviously exist and people will be able to feel them once hydrogen is in widespread use. I urge the reader to consider that one of the main drivers for realising a HE is that hydrogen fuelling of cars meets the climate change requirements, provided that hydrogen is produced in a clean way. However, even the most optimistic scenarios do not suppose that there might be around 10 million hydrogen cars by 2030, given the fact that there are now only around 170 million cars in the USA. The problem of the lack

of technology comes up in the text repeatedly. It is fully clear that a series of breakthrough innovations are required in every part of a HE. This means it is highly uncertain that these technologies can really be effectively developed at all, at least in good time. By contrast, however, this lack of technology is presented as being no more than a (normal) challenge. It is also highly misleading that other preconditions are not questioned either. For example: '[hydrogen has] the flexibility to adapt to the diverse and intermittent renewable energy sources that will be available in the Europe of 2030' (Commission 2003, 11).

According to the strategic research agenda part of the report (Commission 2003, 17) the plan is to solve the 'remaining technical barriers to the introduction of hydrogen and fuel cells' (Commission 2003, 17). The phrasing 'remaining technical barriers' urges the reader to believe that most of the barriers have already been eliminated and that we are at the end or at least the middle of the process and merely a few barriers remain. Having read these confusing arguments that concentrate purely on the possible benefits and underrate the difficulties, readers might still expect a clear detailed summary that balances the positive and negative aspects of this future economy based on well-founded research. The authors do not neglect this justified demand and give a 'Summary of hydrogen production technologies' (Commission 2003, 25) in a table, which unfortunately is not exhaustive. It lists hydrogen production technologies but not all of them and does not separate the techniques or the energy source used for production. On the other hand the authors collect possible benefits and barriers, but sometimes these are not even on the same level. Electrolysis must compete with the direct use of renewable electricity, but this barrier is not valid for this production method only, since every other method of energy generation has the same problem. Once again the authors mix the strengths and opportunities. Using biological production methods has the opportunity of providing a large resource, but this is not a strength as the most appropriate organisms for the task had simply not been found in 2003, a fact which the authors see as a barrier.

Confusing the different technologies for better representing the opportunity

To reduce the SWOT analysis to barriers and benefits is just one way to cover the biggest unsolved problem of the hydrogen future: the problem of 'black hydrogen'. The expert material leaves aside the concept of 'black hydrogen' and just talks about the cleanliness and effectiveness of hydrogen and fuel cells. 'Hydrogen and fuel cells are seen by many as key solutions for the 21st century, enabling clean efficient production of power and heat from a range of primary energy sources' (Commission 2003, 5). Or in another case the emphasis is on the possibility of using a broad range of primary energy sources. 'Hydrogen opens access to a broad range of primary energy sources' (Commission 2003, 12). The question is why hydrogen specifically opens this access? The only answer may be because it might be a good storage material, but this is an opportunity not really solved yet, and because of the clean nature of hydrogen end use. Research and trials on how hydrogen might function as a storage medium have been and are being carried out, but the winning technology has not yet emerged. It is again stated later that easy storage is a prime advantage of hydrogen over electricity, but once again this is oversimplifying the issue. Through the use of an adverb the statement changes from a possibility to an unquestionable fact. 'The ability to store hydrogen more easily than electricity can help with load levelling and in balancing the intermittent nature of renewable energy sources' (Commission 2003, 13). The notion that hydrogen can be stored more easily than electricity must clearly be taken as a hypothesis until proven one way or the other and this proof is not yet available. The presumption made here is that if every technological innovation can be materialised in future then hydrogen might well function as a better energy carrier than electricity does at present. Starting from this we can question what exactly is meant here by 'easily'?

More functional alternatives still need to be demonstrated. Contrarily, the text gives the impression that demonstration projects will already solve the fundamental problems of a HE. A similar problem is that the text gives the impression that the promised land of clean energy is very close at hand; we are on the verge of the production phase, or at least there is no

question that we are going to reach it. 'It should generate a critical mass (...) to solve the remaining technical barriers to the introduction of hydrogen and fuel cells' (Commission 2003, 17). What this implies is that we have already taken a long development track but we still have a short way ahead of us and we must now solve the few 'remaining problems'.

Promising breakthrough innovations as business as usual

Another way to give the impression that the basic problems of a HE can be solved easily is to present the series of necessary breakthrough innovations as business as usual, or in other words simply as the small remaining steps of a research that will be tackled more or less as a matter of routine. The authors emphasise the obvious possible advantages of hydrogen by pointing out that its use may compensate regional differences. 'The introduction of hydrogen as an energy carrier, alongside electricity, would enable Europe to exploit resources that are best adapted to regional circumstances' (Commission 2003, 12). The problem is that they skip a step: the task of making hydrogen an acceptable mass energy carrier has to be solved before it might enable Europe to exploit resources. We find the same approach in the example that has already been mentioned in another context: 'hydrogen can be produced in many different ways, using a wide range of technologies. Some of these involve established industrial processes while others are still at the laboratory stage' (Commission 2003, 25). The impression is given here that it is not a crucial problem that some of the technologies are still at the laboratory stage – a stage involving the implied risk that they may not necessarily prove suitable for further development. The strong hype surrounding technologies seduces the authors into thinking the future opportunities are already present fact or they turn the tables on uncertainty by presenting an emerging technology as a signpost for the necessary direction of development. The same goes for the following statement: '[A] breakthrough in on-board vehicle hydrogen storage technology is still required' (Commission 2003, 26). Without the temporal adverb *still*, this sentence describes the current situation, the lack of innovation, the lack of adequate technology, although *still* does not emphasise the distance from the goal but gives the impression

180 *Ágnes Fésűs*

that the goal will definitely be attained in the future. This presentation, however, is largely wishful thinking. On the one hand, as is only too well known, breakthrough innovations are still required, but this requirement does not by any means provide an automatic guarantee that they can be realised. The authors also imply that the transition to hydrogen technologies will be quite a normal process compared to other technologies.

Only time and money and the commitment of the public authorities are the problems

Other barriers arise parallel to the technological issue. The impression is given as shown above that the technological issue is not itself a problem and all that needs to be done is that special conditions need to be realised to see it through successfully. Another interesting line pursued in the text is how these prerequisites of time, money and commitment of the public authorities are presented. The time issue arises either implicitly only or as an estimate. For example the report finds that hydrogen-based energy systems will require 'many years before coming to fruition' (Commission 2003, 7). This statement again shows the assessment that reaching the aim is not in question since we are proceeding in the right direction, it must merely be clear that many years of effort are required. 'At present, hydrogen and fuel cells do not offer sufficient short term end-user benefits to justify their higher costs compared to conventional technologies' (Commission 2003, 19). On the one hand it is beyond question that at present these technologies are too expensive for broad use, but the essential point is that it is not only a time barrier that stands in the way of a satisfactory development – radical innovations are also necessary. The reader here encounters a special technique for how the time factor becomes a proof itself instead of proving the possibility for long- or short-term realisation. 'Moving from the fossil fuel economy of 2003 to a hydrogen and fuel cell-based economy will not happen immediately' (Commission 2003, 19).

It would seem as though the issue of money, the necessity for enormous investments should be mentioned only tangentially. The rhetoric of the whole text gives the impression that the hydrogen economy is so prom-

ising that the issue of how much it will cost in the near future is of no concern. However no plan for the potential costs is presented. The first place referring to cash amounts is the comparison between the leaders (USA, Japan). Unfortunately this data does not permit real comparisons to be drawn. 'The US Administration responded in January 2003 by proposing a total of \$1.7 billion (including \$720m of new funding) over the next five years to develop hydrogen fuel cells, hydrogen infrastructure and advanced automotive technologies. (...) Japan is also aggressively pursuing the research and demonstration of hydrogen and fuel cells with a 2002 budget estimated at around \$240m. The Japan Fuel Cell Commercialisation Conference will commission six hydrogen fuelling stations in Tokyo and Yokohama in 2002–3. The Japanese have announced initial commercialisation targets of 50 000 fuel cell vehicles by 2010, and 5m by 2020, and installed stationary fuel cell capacity of 2 100 MW by 2010, with 10 000 MW by 2020' (Commission 2003, 15). Furthermore, readers have no idea about the source of these estimates nor more significantly, about the costs involved in developing the hydrogen economy the authors are talking about.

It makes a difference whether we say that fuel cells are not commercialised because of the current high price or whether we also emphasise that even the fuel cell technology that can be commercialised at an acceptable price has not been invented yet. 'All types of fuel cells are expected to have roles in a future energy economy, especially a hydrogen economy. But for the moment the costs are too high to be competitive with conventional systems in most applications' (Commission 2003, 30). On the one hand the text says that at the moment the costs of a possible hydrogen economy are too high, while on the other hand it gives the impression that the costs will decrease and make HE cost-efficient.

Summary

Following the introduction of HE as a multi-dimension, multi-actor field the reader rightly expects to receive suggestions about which way forward can lead to a sustainable energy future. Whose interests and capabilities will be integrated? May it be the case that not one but many

182 Ágnes Fésűs

possible hydrogen economies are together the real alternative for the long-term transformation of the world energy system? Remember: recent climate damage mainly derives from the traditional coal, oil, and natural gas-based economy and transport system, which will continue through the 2020s. The main challenge is to radically shift this fossil-fuel based system towards environmentally more benign utilisation as quickly as possible. Alternative technological paths should be kept alive: e.g. hybrid electric cars, synthetic fuels and repeated ‘rethinking’ of hydrogen R&D priorities.

Notes

- ¹ In 1807 Francois Isaac de Rivaz of Switzerland invented an internal combustion engine that used a mixture of hydrogen and oxygen for fuel. It was one of the first internal combustion engines, but the design of the new car was not successful (<http://www.alternative-energy-resources.net/hydrogenfuelcar.html>).
- ² *Epitheton ornans* is a descriptive word or phrase that has become a fixed formula applied to real or fictitious people, divinities, objects.

References

- Bossel, Ulf, Eliasson, Baldur, and Taylor, Gordon (2005), *The Future of the Hydrogen Economy: Bright or Bleak?*, Final Report of 15 April 2003 with foreword, European Fuel Cell Forum, Luzern, Switzerland.
- Commission, European. (2003), Hydrogen Energy and Fuel Cells – A Vision of our Future, https://www.hfpeurope.org/uploads/59/hydrogen-vision-report_HLG_2003_en.pdf. [30 October 008].
- Stirling, Andy (2006), ‘Precaution, foresight and sustainability: Reflection and reflexivity in the governance of science and technology’, in Jan-Peter Voß, Dierk Bauknecht and René Kemp, *Reflexive Governance for Sustainable Development*, Cheltenham: Edward Elgar, 225–272.
- Yergin, Daniel (2008), ‘How different will tomorrow be? Thinking about the energy future’, <http://oilenergysource.com/> [30 October 008].