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The Hopeful Hydrogen

Scientists Advocating Their Matter of Concern

Thesis for the degree of Philosophiae Doctor

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Preface

The topic of this dissertation is a 'matter of concern'; something which is held together by a combination of what someone knows about it and the ways in which they care about it, a hybrid. This preface is also a kind of hybrid, as it is supposed to answer some factual questions about the document that follows, while at the same time allowing me to express the ways in which I care about the people who helped me write it.

First, the formalities: This dissertation consists of three papers in addition to the overview paper. The first paper is currently under review in Minerva, and the second paper will be submitted to Science, Technology and Human Values. For the second paper, I did the document search, the interviews and the field work that together makes up the data the paper is based on. Knut Holtan Sørensen and I then wrote the paper together.

Then, the recognitions. Science is at its heart a collective effort, and it goes without saying that I could not have written this dissertation without help and support. The Department of Interdisciplinary Studies of Culture has been a great place to work. The combination of different theoretical and disciplinary approaches, and a wide variety of topics, has been a joy to be a part of. Furthermore, I have been lucky enough to have colleagues who go out of their way to be friendly and have fun together in between the hard work. I am grateful to all of you. In particular, I would like to thank Sunniva, Kristine, Stine, Elisabeth and Maggi for reading and commenting on various drafts to what in the end became this thesis. Maggi also stepped in as secondary advisor, for which I am especially grateful. Last but not least, Knut was my main advisor throughout the process, providing an endless source of ideas and fruitful discussions. I do not think I can adequately thank you in this preface, and hope that the following 138 pages do the job.

I would also like to thank the Dutch WTMC Research School for allowing me to attend several of their workshops and a summer school – I am grateful to all my fellow PhD students for making me feel welcome, and to coordinators (at my time in the WTMC) Els Rommes and Sally Wyatt for their friendliness and thorough work in preparing the different sections. Furthermore, the Institute for Transportation Studies at University of California, Davis, welcomed me as a guest researcher. I learned much both from their seminars and from more informal discussions, and would like to thank professor Joan Ogden for extending me an invite to stay with them.

I have chosen to not use full names for the informants in this thesis (although some of them will be fairly easy to recognize for those who know Norwegian research on hydrogen). However, it goes without saying that without their cooperation, my research would not have been doable. Some went out of their way to be helpful, and I am very grateful for the friendly and open attitude that they all showed towards my requests, and for the time they set aside.

Finally, I am lucky enough to have had the help of both friends and family when working with this PhD. Writing a thesis has its ups and downs, and I am very grateful for all the times you supported me, be it by listening to my enthusiastic recollections, or by convincing me that I was smart and capable when I was in a more doubting mood. In short, thank you for your words of encouragement and love.

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Chapter 1 (Overview paper): Hydrogen scientists as policymakers?

"For several years, the IEA has been presenting the case that an energy revolution, based on widespread deployment of low-carbon technologies, is needed to tackle the climate change challenge." (International Energy Agency (IEA) 2010)

Climate and energy issues are often listed among the major challenges of our world. Together with descriptions of the problems at hand, it is common to see development of new, more efficient technologies listed as a major part of the solution (for Norwegian examples see e.g. *Climate for Research. Summary in English: Report no. 30 to the Storting (2008-2009)*, 2009, *NOU 2012:9 Energiutredningen*, 2012). Hydrogen energy is one of the proposed technological answers to the climate and energy issues. The most optimistic hydrogen visions, like *The Hydrogen Economy* (Rifkin 2002), suggest that hydrogen energy heralds a new epoch in human history – connecting it to renewable energy production, energy security, local production and increased democracy, and last but not least clean city air: "A decentralized, hydrogen-energy regime offers the hope, at least, of connecting the unconnected and empowering the powerless. When that happens, we could entertain the very real possibility of "reglobalization," this time from the bottom up, and with everyone participating in the process." (Rifkin, 2002:10). The calls for scientific and technological solutions, and the visionary statements about technological potential, actualize the question of in what ways scientists interact with and shape politics? This thesis is a study of how and to what extent Norwegian hydrogen scientists engage with politics and policymakers to promote hydrogen energy.

In his book *De nasjonale strateger [The National Strategists]* (Slagstad 1998), Norwegian sociologist Rune Slagstad portrays the building of Norway as a modern nation by following central actors through the nineteenth and twentieth century. From the group he terms professor-politicians – like Anton Martin Schweigaard, Frederik Stang and Ole Jacob Broch - to what Slagstad calls the societal engineers of the post-World War II era, different ways in which scientists and academics have played a part in shaping Norway is described. In the earliest cases, the link between academia and politics was made partly by one person successfully participating in both worlds, as was the case with professor and MP Schweigaard (Slagstad, 1998:14-15). Schweigaard served as an MP in a time where parliament only were in session 3 months every 3rd year (this lasted until 1869) – one person being a part of both academia and politics might still be an option today, but perhaps less simultaneously now that national politics is a full-time occupation.

Slagstad's post World War II-story is about scientists cooperating closely with and having ties to the political elite. Minister of Defense Jens Chr. Hauge was essential on the political side, wishing to put the expertise gained by scientists who had worked in exile during the occupation to use in rebuilding the country. With a background from the exile government's committee FOTU (The Technical Committee of the Defense Central Command [Forsvarets Overkommandos Tekniske Utvalg]), scientists like Helmer Dahl and Gunnar Randers were eager to contribute to a modernizing of Norwegian industry and defense (Slagstad, 1998:252-253). Dahl argued that "Regardless of what kind of economic activity we are running, in modern times increased scientific effort will be profitable". Science was how society could ensure growth (Slagstad, 1998:295-296).[1] For a number of years, Randers managed a larger share by far of the budget of the Norwegian Science and Technology Research Council (NTNF) than anyone else (Slagstad, 1998:297). He combined research with visionary ideas about the opportunities offered by a specific technology – nuclear power.

Gunnar Randers was later characterized by Hauge as "a kind of czar of the development of nuclear energy in Norway. […]Who made him a czar? He did himself

[1] This, and the following quotes from Slagstad 1998, are my translations.

by virtue of a combination of qualities that unfolded in front of our eyes: A gifted scientist paired with an entrepreneurial and society-building instinct, a disrespectful, almost rude contempt for any practical difficulty and an unscientifically large drive. And lots of high spirits. It would be incorrect to say that it was a combination so far unknown in nature – even if it was and is very rare – but it is right to say that Norway after the liberation, at the dawn of the new day and the reconstruction, was very receptive to this kind of czar" (Slagstad 2006).[2]

One common point for the time of professor-politicians and the time of nuclear czars is that scientists were also involved with the public through articulating visions of what opportunities the new technologies were bringing. Broch wrote about the telegraph that "Electricity, that until now had the bringing of lightning and thunder as its most important role, is now like a mailman bringing news from one side of Europe and America and to the other." (Illustrert Nyhedsblad nr 1-2, 1851, as quoted by Slagstad, 1998:69). Randers wrote several books for the general public on nuclear issues arguing that nuclear technology represented hope rather than doom for the world (Randers 1946), partly due to the technology making war an unthinkable option and partly due to the incredible benefits for peacetime use both for medical science and energy. "It cannot be denied that power supply and consumption is essential to material progress. Repeatedly, we hear alarming messages about the world's oil supply running dry. The same is said about coal. Even though these messages have mostly been false alarms, they still contain a reality, since the reservoirs of oil and coal in the world without a doubt have a limit. […] It is thus reasonable that humans from time to time address the question of what will replace these dwindling supplies. This is where atomic energy is looked to – and doubtlessly deservedly so" (Randers, 1950:56)[3].

[2] As quoted by Slagstad in his obituary for Hauge – my translation

[3] My translation

The limit to fossil fuels, and the hope for a different future, is echoed by Rifkin 50 years later: “We find ourselves on the cusp of a new epoch in history, where every possibility is still an option. Hydrogen, the very stuff of the stars and our own sun, is now being seized by human ingenuity and harnessed for human ends. Charting the right course at the very beginning of the journey is essential if we are to make the great promise of a hydrogen age a viable reality for our children and a worthy legacy for the generations that will come after us” (Rifkin, 2002:12). Comparing the statements of Rifkin and Randers, the parallels between atomic energy in the 1950s and hydrogen energy in the 2000s are easy to make: Both were proposed technological solutions to a set of energy-related issues. But while Randers combined the role of scientist and technological visionary, Rifkin’s background is in economics and international affairs[4] rather than natural sciences. While technology visions could be described as a meeting point of politics and science, scientists apparently do not have any monopoly when it comes to formulating such visions. At the same time, when hydrogen energy became an issue for politics in Norway in the 2000s, it is reasonable to ask if and how the scientists contributed to the making of hydrogen policy. Did they act as professor-politicians, shifting between the role of scientist and the role of politician, or did they take on a kind of vision making like Gunnar Randers? Or did they pursue other strategies and practices?

This thesis employs a combination of interviews, field work and document studies to explore Norwegian hydrogen policies and scientists’ roles in regards to the making of these policies. In the following sections, I give a brief summary of the papers which are the main body of the thesis, followed by an overview of social science studies on hydrogen energy and a theoretical section focused on scholarship addressing how science and policy interact. Employing this theory, I discuss the common threads of the papers – what can they tell us when viewed as a whole? Finally, the methodology

[4] http://www.foet.org/JeremyRifkin.htm accessed 111012

section with appendixes address some overarching questions of the methodology of the thesis work as a whole.

Hydrogen as a field, as an idea and as relevant – a summary of the papers in the dissertation

The first paper, *Adaptable scientists? Features of interdisciplinary research*, provides a suitable starting point for the discussion in this overview paper through its addressing the fundamental questions of what makes someone a hydrogen scientist and of what kind of science hydrogen science is. Embarking from a definition of hydrogen scientists as scientists who somehow – through e.g. writing research papers or newspaper feature articles or attending conferences – have connected their research to hydrogen as an energy carrier, the paper employs different theories on interdisciplinarity to simultaneously explore if interdisciplinarity is indeed a fitting label for hydrogen science, and what it means for the hydrogen scientists to be involved in an interdisciplinary field.

The paper starts out with four hypotheses on what kind of interdisciplinary science hydrogen science is, based in different threads of the interdisciplinarity literature: a discipline (in the making), a legitimizing rhetorical construct, a kind of curiosity-driven border crossing, or transdisciplinary science focused on problem-solving in context. Differences in the backgrounds of the hydrogen scientists and a lack of other indicators of a discipline lead to the conclusion that hydrogen science is interdisciplinary and not a discipline in the making. Being engaged with hydrogen is shown to have an observable effect on research agendas, making hydrogen more than a legitimizing rhetorical construct. At the same time hydrogen is rhetorically important through its influence of scientist's self-understanding – the scientists describe working with hydrogen science as meaningful because it enables them to help address important challenges for future energy needs and for the environment. Moving on to the border crossing and transdisciplinary science hypotheses, the paper shows how hydrogen science is connected to a personal sense of meaning and achieving societal relevance at the same time – while scientific curiosity is downplayed as a reason to specifically engage with hydrogen science.

What holds hydrogen science together as a field? The scientists' focus on meaning suggests that one cornerstone is an agreement that working with it is the right thing to do. At the same time, it was made possible by financing, in a way that calls to mind what was pointed out by Peter Weingart: "'externally' defined subject matters, research problems, and values or interests can trigger sustained research" (Weingart, 2010:12). Thus, hydrogen science seems to be held together through the combined efforts of funders and scientists.

The paper argues that financing is not the only way in which hydrogen science is dependent on non-scientists. Through the concept of hydrogen, scientists have a platform for communicating the relevance of their research both to other scientists and to non-academic actors. Comparing hydrogen science with transdisciplinarity thus highlights what it may entail for scientists to engage with problems that they cannot solve without the participation of others: While the upside of being relevant is that someone is interested in what you are doing, the downside is that you are dependent on them. Transdisciplinarity implies that scientists are simultaneously asked to allow problems not defined by academia to be the ordering principle for their work, and to accept that the actual solution of the problem may not be in their hands. Thus, the paper concludes, scientists may gain an increased sense of meaning through relevance, and at the same time face the threat that this sense of meaning can be undermined.

The second paper, *The Rise and Fall of 'Hydrogen Society': Scientific advice and policy learning*, shows how 'hydrogen society' made its way into Norwegian energy policy discourses, and how it after first receiving significant political attention, lost prominence. The policy discourses are mainly observed through a document study, while a combination of documents and interviews are used to illuminate the role of scientific advice in the process.

Hydrogen entered government documents in 1997-1998 in a modest way under headings related to research and future technology opportunities – a potentially emission-free energy carrier that could reduce local pollution, but in a fairly distant future. Compared to the international attention given to broader hydrogen society scenarios – which included the local emissions issue but above all emphasized more wide-ranging visions of hydrogen as the basis of a new, sustainable energy regime – hydrogen was not really on the radar of policy makers as late as 1999. The paper describes how scientists tried to intervene, by lobbying through the Norwegian Hydrogen Forum and through producing a comprehensive report titled "The hydrogen society – a national opportunity review" (Kvamsdal and Ulleberg 2000). The proposed hydrogen society scenario now included both new renewable energy and – intermittently – the exploitation of Norwegian gas resources. This link proved popular among policymakers. By the end of 2001, interaction between scientists and policymakers had thus produced a Norwegian version of hydrogen society. Hydrogen seemed to be established as an energy carrier most immediately linked to natural gas, while a renewable energy system was more of a future vision. To the extent that an expectation was articulated, it was concerned with natural gas and industrial issues.

The fairly broad support hydrogen had gained, led through the production of an Official Norwegian Report about hydrogen published in 2004. The commission behind the rapport had members from industrial, political and scientific backgrounds. While hydrogen for stationary uses was judged as being in the fairly distant future due to lack of energy efficiency, the commission suggested an increased focus on hydrogen research and on hydrogen for transportation. From 2004 onwards, this understanding of hydrogen became dominant in the making of hydrogen policies.

What was the role of hydrogen scientists with respect to the fate of 'hydrogen society' as an energy policy concept in Norway, and what may we learn more generally concerning the relationship between scientists and policymakers? The analyzed policy documents display clear examples of scientific advice, in the form of providing descriptions of hydrogen's potential as an energy carrier, and of existing challenges with respect to developing appropriate hydrogen technologies. The scientists communicated a clear message that the government needed to increase its investment in hydrogen R&D, which resembles what Sheila Jasanoff (2011) calls the linearity-autonomy model. However, the context of these documents, in particular the making of Norwegian Official Reports, indicates that scientists exceeded the simple role of advisor. The paper thus suggests that hydrogen scientists participated in the making of broader energy policy proposals, closer to what Jasanoff (2011) calls virtuous reason. This virtuous reason was practiced through committees that were hybrid in the sense that the members came from different quarters: science, industry, public sector and policy-making. Thus, scientific proposals were negotiated with industrial and public sector interests as well as policy-making concerns – the advice provided through these hybrid institutions was itself a hybrid. There is little in the interviews that suggest that the hydrogen scientists felt uncomfortable with this transformation from, to use the terms of Bruno Latour (2004), matters of fact into matters of concern. Rather, they were also concerned with the value aspects of hydrogen science, the potential of hydrogen technologies to contribute to a more sustainable world.

The paper concludes that energy policy, like many other policy areas, is too complex to produce a lot of issues where scientific facts can be expected to settle disagreements. This means that the emphasis on quality assurance with respect to scientific advice (e.g., Lentsch & Weingart, 2011) may have a limited validity. Or, rather, in line with the virtuous reason model the issue of relevance needs to be emphasized. Clearly, when hydrogen gained some popularity in energy policy discourses, this was facilitated by observations that hydrogen had become a priority area in many other countries. Also the linking-in with natural gas should be seen as an effort to make hydrogen relevant to particular Norwegian energy policy concerns.

Thus, rather than focusing on scientific advice as an activity in itself, we should focus more broadly on the interaction between scientists and policymakers. The analysis of the second paper thus suggests, first, that this interaction should be studied on the premise that both parties have some autonomy and pursue their own agendas. Second, scientists and policymakers may be interdependent, at least with respect to scientists' need of funding and policymakers' need of scientific expertise. Third, there is a need to study in greater detail the hybrid forums where scientists and policymakers interact, and where diverse social interests may participate.

The third paper, *Advising or advocating? Funding applications as policy advice*, suggests that funding applications may be a case of such interaction. The paper analyzes hydrogen-related applications which have successfully achieved funding from the Research Council of Norway (RCN) through the Clean Energy for the Future (Renergi) program (which funds a majority of listed Norwegian hydrogen research projects at hydrogenplattformen.no). The focus of the analysis is on how the applications describe the relevance of their projects. A successful application is required to argue its own case not only as scientifically interesting, but also as socially relevant. When arguing the societal relevance of an individual project, applicants may also be seen as arguing the relevance for science as such, and thus the applications may become a channel for a kind of policy advice.

The research application process is potentially two-sided – while it may represent an opportunity for scientists to engage in making science policy through a dialogue with the research council, it is also an occasion where scientists may be disciplined to consider the need of being useful in a way compliant with the wishes of the funder. The paper gives an overview of Renergi policy documents and application forms before looking at the applications. The relevance arguments of the applications are then grouped into five different argument families; politics (references to explicit or implied political goals), environment (both general statements about the environment and references to two specific environmental issues, climate and local pollution), economy (arguments about relevance to the national economy and national interests, as well as more company-oriented arguments), international and safety. The first three categories were present in around 90% of the applications, while the last two were present in less than 50% of the applications. While the arguments are in accordance with the goals of Renergi, the comparison shows that the Renergi goals cannot be directly copied into the text of a successful application – instead, the scientists are invited to translate extensive policy goals into definite research proposals.

To make their arguments, the scientists writing the applications employ a repertoire which resemble a combination of three of Pielke's (2007) roles for scientists interacting with policy; issue advocacy, science arbitrage and honest brokering. Rather than dealing with these roles as mutually exclusive, the scientists take on a role with two major components: on the one hand, they presented their arguments in a fashion that proposes their approach as the right way to address challenges posed by the RCN (advocacy); on the other hand, they also describe problems, either explicitly recognized by the RCN or through identifying wider problem contexts, which they promise their research will contribute to solve (arbitrage/brokering). This seamless combining of elements from Pielke's separated roles may indicate that the available roles for scientists interacting with policy are dependent on the situation in which the interaction takes place. A successful application merges advocacy for a solution with promises of usefulness for a wider set of problems.

The variations between and within the categories reinforced the impression that the goals outlined by the RCN must be adapted to specific projects by the applicants. At the same time, the similarities between the applications show that it has been established an understanding that a relevant Renergi application should argue its case with (at least) arguments from the political, economic and environmental category. The scientists propose incremental rather than radical visions: translation strategies are applied to show how the existing visions of the RCN can be deepened, broadened or strengthened by the technologies the applicants represent, but no alternative overarching vision is presented. The presented visions were not only hydrogen visions, attempts at portraying hydrogen as essential for Norway's future as an energy nation – be that future founded on renewables, natural gas or a combination of the two – were more prevalent than references to a future hydrogen society, although the latter also were present. The paper suggests that this incremental improvement of existing visions may be a reflection of a kind of 'business as usual'-stage for the involved technology – hydrogen technologies have a foothold in public policy documents, and thus refining existing visions is a more logical bridging between a specific proposal and policy goals than an introduction of a radically different vision. These refinements also work as an employment of Latour's (1987) first translation strategy, with the researchers joining with the goals of the Norwegian government, and thus providing arguments for why hydrogen energy research should be given priority in current science policy. Without arguing against any other possible technologies that may apply for funding from the Renergi program, hydrogen is presented in a way that fulfills its goal of 'environmentally friendly, economical and rational management of the country's energy resources' (Research Council of Norway 2004) without having to decide between founding such a resource management on renewables or on natural gas resources. Within the fairly strong formatting that an application is exposed to, the scientists argue the case of hydrogen technology. Thus the paper concludes that funding applications are used as a channel for a specific, not too radical, form of policy advice.

As this summary of the papers indicates, together they display scientists that engaged with policy and policymakers in several ways and on different arenas. How may we understand this? What kind of practices is observed? The next section will outline and discuss previous social science research concerned with hydrogen and pertinent theoretical perspectives drawn from science and technology studies, in order to situate and analyze the engagement of scientists with policy and policymakers with respect to the role of hydrogen as an element in Norwegian policy. What kind of lessons may we draw from the three papers when we do a cross-cutting analysis?

Understanding hydrogen science – policy interaction

There are two different sets of literature that may help shed light on how hydrogen scientists interact with policy: previous research on hydrogen energy from a non-technical perspective, and research concerning the different ways in which scientists engage with policy and the interaction of science and policy. The following sections give an overview.

Social science perspectives on hydrogen

What does social science scholarship find in regard to hydrogen as an energy carrier? What we find is a fairly diverse literature, suggesting that hydrogen has been approached from several social science angles. Kårstein (2005) provides a general bibliography of social science research on hydrogen, McDowall and Eames (2006) gives a review of the hydrogen futures literature, and Sovacool and Brossmann (2010) employ a methodology similar to McDowall and Eames to identify papers on the hydrogen economy, thus offering a supplement to the 2006 review in addition to giving an account of the continued interest shown by scholars towards the hydrogen economy. Visions, expectations and utopias are well-represented themes in the social science literature on hydrogen (Bakker, Van Lente, and Meeus 2011; van Lente and Bakker 2010; Eames et al. 2006; Hodson and Marvin 2009; Hultman 2009).

Several papers focus on what the hydrogen economy/society is, and why it may be a good idea to work towards it (Goltsov and Veziroglu 2001; Bockris 2002; Ogden 2002; Blanchette 2008) or why it may be less of a good idea than it might seem at first glance (Romm 2007). Related to these discussions of the hydrogen economy as a potential political goal are writings on policies and transitions (Bleischwitz and Bader 2010; Park 2011). Solomon and Banerjee (2006) give an overview of hydrogen energy research and policies. Some studies combine an interest in policy with innovation (Nerdrum and Godoe 2006; Vasudeva 2009; Godoe and Nygaard 2006), or focus more specifically on innovation (Madsen and Andersen 2010), technology diffusion (Meyer and Winebrake 2009), transition management (McDowall, 2011) or technological forecasting (Y.-H. Chen, Chen, and Lee 2011). Several papers address the hydrogen efforts and opportunities of specific countries (Árnason and Sigfússon 2000; Murray, Hugo Seymour, and Pimenta 2007; Zhang and Cooke 2010). Norway is no exception to this, with three PhD theses written addressing respectively the HyNor project (Kårstein 2008; Kårstein 2010), the co-evolution of technologies, markets and institutions (Nygaard 2008) and the hydrogen efforts of a specific company (Koefoed 2011). Klitkou, Nygaard and Meyer (2007) use scientometrics to track the techno-science networks of fuel cells and related hydrogen technologies in Norway.

Some scholars relate hydrogen more closely to sustainability, or try to appraise the sustainability and possible greenhouse gas emission effects of hydrogen (Andrews and Shabani 2011; Mcdowall and Eames 2007; Dougherty et al. 2009). This can also be approached via life-cycle assessment (Karimi and Foulkes 2002). Last but not least, public understanding of science (Cherryman et al. 2008; Rob Flynn, Bellaby, and Ricci 2009; M Ricci, Bellaby, and Flynn 2008) and stakeholder perspectives (Seymour, Murray, and Fernandes 2008) are addressed by several papers.

It is undoubtedly true that “the hydrogen economy continues to attract significant attention among politicians, the media, and some academics” (Sovacool & Brossmann, 2010:1999). However, while some of the aforementioned papers focus on energy policies and try to make sense of the implications of a focus on hydrogen as an energy carrier, they say less about the interaction between scientists and policy-making. A broader theoretical background is needed to shed light on the overarching question of this thesis: How the scientists working on hydrogen technologies in Norway have interacted with and contributed to the making of policy.

Perspectives on the science-policy interaction

According to Jasanoff (1990:4-5), the literature concerning the relationship of science and government tends to make a conceptual distinction between "science in policy" and "policy for science", as originally introduced by Harvey Brooks in his text *The Scientific Adviser*:

"The first is concerned with matters that are basically political or administrative but are significantly dependent on technical factors – such as the nuclear test ban, disarmament policy, or the use of science in international relations. The second is concerned with the development of policies for the management and support of the national scientific enterprise and with the selection and evaluation of substantive scientific programs" (Brooks, 1964:76 as quoted by Jasanoff, 1990:5).

Pielke (2007) also observes that Brooks' distinction between science for policy – "the use of knowledge to facilitate or improve decision-making" – and policy for science – "decision-making about how to fund or structure the systematic pursuit of knowledge" – has been defining how we think about science policy. He contends that this reinforces "a perception that science and policy are separate activities that are subject to multiple interrelations, rather than activities that are instead inextricably interconnected" (Pielke, 2007:79). This perception, argues Pielke, will often lead to an understanding of the science-policy relation in accordance with the linear model: "To the extent that our thinking about science policy separates decisions about knowledge from decisions with knowledge in decision-making, it reinforces a practical separation of science from policy, and implies that we can make these two types of decisions independently of one another" (Pielke, 2007:79).

Rather than understanding the science-policy relation as always linear (science produces facts, facts compel actions), Pielke contends that a stakeholder model might be more suitable (users of science has a role in the production of science) (Pielke, 2007:13-14). Combining different conceptions of democracy and science, Pielke describes four idealized possible roles for scientists in decision-making: the 'Pure Scientist,' the 'Issue Advocate,' the 'Science Arbiter,' and the 'Honest Broker.' The Pure Scientist is characterized by the fact that he/she has no interest in the decision-making process, but simply wants to share fundamental information about facts. The Issue Advocate is characterized by his/her trying to limit choice and convince others about a particular choice. The Science Arbiter is characterized by his/her attempt to be a resource for the decision-maker, standing ready to answer factual questions that the decision-maker thinks are relevant, but not to tell them what to prefer. The Honest Broker tries to expand (or clarify) the scope of choice for decision-making in a way that allows for the decision-maker to make a choice based on his/her own preferences and values (this is, Pielke holds, often best achieved through a collection of experts working together with a range of views, experiences and knowledge, and not necessarily something that one scientist alone can manage).

In Pielke's account, there are two critical factors to consider when a scientist (or any other expert or scientific organization) faces a decision about how to engage with policy and politics: the degree of value consensus and the degree of uncertainty about the issue at hand. At the core of Pielke's argument about these two factors and the employment of his four roles is the understanding that "[o]ne way beyond the apparent limitations on the role of science in decision-making presented by conflicts over values and inherent uncertainties is to recognize that in situations of gridlock, policymakers frequently need new options, and not more science" (Pielke, 2007:140), something which implies that we often need more honest brokers – "[e]xpanding the options available to policymakers is contrary to the approach most scientists have taken in the policy process when they associate themselves with a particular political agenda" (Pielke, 2007:140), but "[f]or the protection of science and the constructive role that it can play in policy, we desperately need organizations and individuals who are willing to expand the range of options available to policymakers by serving as Honest Brokers of Policy Alternatives" (Pielke, 2007:141).

Pielke's book tries to give scientists advice about the different roles they may take on, and represents "an attempt to connect scholarly understandings of science in society with the practical world of scientists who increasingly face everyday decisions about how to position their careers and research in the context of policy and politics" (Pielke, 2007:8-9). In *STS Perspectives on Scientific Governance*, Alan Irwin (2008) gives an overview of some such scholarly understandings of science in society, what he chooses to call scientific governance. "Characteristically, STS research into scientific governance has emphasized a number of general points:

- That knowledge cannot be separated from the contexts of its development, and implementation. Instead, it should be seen as contingent, situated, contextualized, and open to different framings and perspectives (Collins and Pinch 1998; Latour and Woolgar 1979; Wynne 1989)
- That policy-making must be seen as much more than the simple addition of "values" to objective expertise (e.g., Gonçalves, 2000). Instead, the interaction between politics and the natural world should be viewed as a more active (if often implicit) process of defining the boundaries between the public and the private, the nature of citizenship, and the role of the state (Jasanoff 2004; Parthasarathy 2004).
- That claims to "democracy" and to "public opinion" should similarly be viewed in contextual and contingent themes. Rather than simply advocating "democracy", the question instead is "what form of democracy?" and "from whose perspective?" Equally, STS research has considered the political and cognitive constraints on "democratization" (Irwin 1995; Irwin 2001; Hagendijk 2004; Rayner 2003).
- That governance processes are often characterized by uncertainty, doubt, and indeterminacy (Beck 1992; Nowotny 2003; Wynne 2002). In this situation, STS

research has emphasized the importance of public trust in institutions and the need for political agencies to recognize alternative framings of policy dilemmas (e.g., Zavestoski et al., 2002).

- That the study of scientific governance is not concerned with the interaction between two separate processes ("expertise" and "power") but precisely the manner in which knowledge of the natural world and political action have become mutually embedded and co-constituted" (Irwin 2008).

Of the STS perspectives Irwin emphasize, two are especially useful when addressing the issues of this overview paper: the notion of boundary work and the concept of co-production. Writing about the U.S. Science Advisory Board (SAB), Sheila Jasanoff (1990) describes how the SAB has "been able to maintain its scientific authority on the one hand, and on the other to avoid being labeled as captive to EPA's mission" through "the very successful boundary work by which the Board and its committees have held themselves aloof from the appearance of making policy" (Jasanoff, 1990:95). "The SAB's own contributions to boundary work," Jasanoff writes, "are particularly in evidence when its advice is closely related to policy" (Jasanoff, 1990:97). One example of such boundary work is when the SAB makes it clear that it will only be involved in the "science" of risk assessment and not in the "policy" of rulemaking in regards to the drawing up of the Safe Drinking Water Act. Even if there, as Jasanoff notes, is "little support for the existence of such a boundary in the literature on risk assessment"(Jasanoff, 1990:97), drawing such a boundary was clearly a useful exercise for the SAB.

In some cases, according to Irwin, "we appear to be discussing a more fundamental and mutual embedding between science and politics than the concept of boundary work necessarily conveys. In Macfarlane's terms, 'scientific knowledge cannot be separated from politics and associated policies. Rather they co-evolve in response to each other' (Macfarlane, 2003:789)" (Irwin, 2008:589). This co-evolution is what some scholars have tried to describe through the idiom of coproduction. According to

Jasanoff, "co-production is shorthand for the proposition that the ways in which we know and represent the world (both nature and society) are inseparable from the ways we choose to live in it" (Jasanoff, 2004:2). Furthermore, co-production "occurs along certain well documented pathways. Four are particularly salient [...]: making identities, making institutions, making discourses and making representations. [...] [T]o acknowledge and briefly describe these, [...] help connect the science studies literature to work on similar topics in political and social theory" (Jasanoff, 2004:38).

Identity is "one of the most potent resources with which people restore sense out of disorder" (Jasanoff, 2004:39). Co-productionist accounts often draw attention to the identity of the expert, but at the same time "collective identities are also contested or under negotiation in the working out of scientific and technological orders. What does it mean to be "European" [...], "African" [...], "intelligent" [...] or a member of a research community, learned profession or disease group [...]? And what roles do knowledge and its production play in shaping and sustaining these social roles or in giving them power and meaning?" (ibid.) Similarly, institutions are a powerful ordering instrument in the description of Jasanoff; "stable repositories of knowledge and power"(ibid.) that can be employed to put "things in their places at times of uncertainty and disorder" (Jasanoff, 2004:40). Equally important in the context of this thesis, they also serve as "sites for the testing and reaffirmation of political culture. […] When environmental knowledge changes, for example, new institutions emerge to provide the web of social and normative understandings within which new characterizations of nature – whether climate change, endangered elephants or agricultural science [...] – can be recognized and given political effect. In other policy settings, institutions are required to interpret evidence, make law, standardize methods, disseminate knowledge or ratify new identities" (ibid.). This kind of solving problems of order "frequently takes the form of producing new language or modifying old ones so as to find words for novel phenomena, give accounts of experiments, persuade skeptical audiences, link knowledge to practice or actions, provide reassurances to various publics, and so forth. […] Discursive choices also form an important element in most institutional efforts to shore up new structures of scientific authority" (Jasanoff, 2004:40-41). Finally, Jasanoff lists three aspects of representation that have so far received attention within co-productionist scholarship: "[1] historical, political and cultural influences on representational practices in science; [2] models or human agency and behavior that inform representation, especially in the human and biological sciences; and [3] the uptake of scientific representations by other social actors" (Jasanoff, 2004:41).

Co-production is one possible approach when trying to make sense of the different meanings attributed to hydrogen (science). However, there are two other approaches that also may be useful for answering questions about what hydrogen is. One such approach is found in the study of boundary objects. A boundary object "holds different meanings in different social worlds, yet is imbued with enough shared meaning to facilitate its translations across those worlds" (McSherry, 2001:69 as quoted by Strathern, 2007:131), it "may be approached from different directions" (Strathern, 2007:131), it is "a sort of arrangement that allow[s] different groups to work together without consensus" (Star, 2010:602). Could hydrogen be a case of one such object that is "weakly structured in common use, and become strongly structured in individual-site use" (Star & Griesemer, 1989:393)?

Related to considering hydrogen as a potential facilitator of cooperation without consensus, is the rich literature concerning controversies and how consensus is reached about what an object (or a scientific finding) is. From the studies of the social construction of technology (SCOT), one angle that has been employed is to follow the developmental process of an artifact, enabling one to "see growing and diminishing degrees of stabilization of the different artifacts" (Pinch & Bijker, 1987:39). This line of analysis places emphasis on the interpretative flexibility of scientific findings and/or technologies, meaning that "scientific findings are open to more than one interpretation" up until a consensus about the truth emerges (ibid. p 27). Social mechanisms that limit this interpretative flexibility thus allowing the terminating of controversy are referred to as closure mechanisms. After such a closure, the artifact is described as stabilized – the essential 'ingredients' of the artifact are taken for granted (Pinch & Bijker, 1987:39).

A slightly different take on interpretative flexibility and the closing thereof is found in what Latour describes as translating interests: "at once offering new interpretations of these interests and channeling people in different directions" (Latour, 1987:117). Translation is a matter of connecting with other actors, and linking their goals to your goals – either by joining in with their goals (Latour's strategy 1), convincing them that they want what you already want (strategy 2), convincing them to do what they already plan to do in a slightly different way (that can possibly solve some other problems on the way) (strategy 3), or by creating new goals, displacing goals, finding new groups of actors with an interest in what you can offer (strategy 4) (Latour, 1987:115-117). While translation theory mainly has been used to study how techno-scientists can go about producing actor networks centered on their research results and/or new technologies, a translation perspective could also be employed more directly on the interactions of scientists with politics. Together with the co-production approach, translation theory underlines that at the heart of studies of science in society – and science in politics – are questions of how science simultaneously helps shape our world and appears as non-political. In the words of Jasanoff; "Published accounts of science in policy thus deepen the paradox of advice and legitimacy, for by questioning whether technical advisers can ever be dispassionate, decisive, or value neutral, they cut at the roots of the conventional justification for scientific advice" (Jasanoff, 1990:9).

How can these different takes on science and policy be used to understand the data of this thesis? In the following, I will first employ Pielke's roles and perspectives on scientists providing policy advice, combined with Jasanoff's concept of boundary work, to examine what kind of advisor role the scientists take on. I will then examine how the concept of co-production, combined with boundary object and interpretative flexibility, can answer the question of what hydrogen science is. Finally, I will use Latour's translation theory to look at how this comes together – what kind of policy advice are the scientists providing?

The making of a hopeful hybrid

Previous research on scientists giving advice to policymakers has focused on particular institutions established for this purpose (see e.g. Lentsch and Weingart 2011). In my study, scientists used a variety of channels. They were members of commissions drafting white papers; they took part in establishing an interest group; they wrote newspaper articles and spoke at meetings in the parliament, and their funding applications provided a form of policy advice. Furthermore, they had a fairly broad repertoire of arguments that they brought to the table. Hydrogen was connected to environmental issues like climate change and local pollution; to industrial policy issues like domestic use of natural gas and the development of technology for potential export; to policy goals as formulated in other energy policy documents; and to the policies of other countries and international organizations with a suggestion that Norwegian policy needed to keep up with the international development related to hydrogen. The scientists appeared as competent policy actors, and they used this competence to simultaneously advocate the expansion of hydrogen science and to promote an understanding amongst policymakers for the need for hydrogen in the development of a – hopefully sustainable – Norwegian society.

How can we understand the policy advisor role played by the scientists? One way to start is to look at the noted absence of boundary work in light of Pielke's suggested roles for scientists in decision-making. At the foundation of Pielke's suggested roles is the understanding that the greater the uncertainty – both scientific and political – the more important it is for science to focus on policy options rather than scientific results (alone), and relatedly, that the two critical factors to consider for scientists when deciding how to approach an issue is the degree of value consensus and the degree of uncertainty.

However, it is not a given what the issue in question is when looking at hydrogen scientists. As the second and third papers show, hydrogen has been connected to a number of issues – energy use, climate change, domestic use of natural gas, local pollution and opportunities for new business. Should we understand what the hydrogen scientists do as providing a policy option in light of these issues? And would that make them issue advocates due to their attempts to convince others about a particular choice, or would it be more appropriate to view them as honest brokers because they are trying to bring a new policy option to the table? It is not unreasonable to argue that the hydrogen scientists are trying to expand the scope of choice for decision-making (and the third paper in particular highlights that their argument cannot be interpreted as a suggestion to focus all efforts related to climate and energy issues on hydrogen). Thus, in this case, Pielke's differentiation between honest brokers as actors who expand the options available for policy, and issue advocates as actors who limit the number of options, does not seem to fit. Nevertheless, the concepts behind the categories highlight something essential about what kind of policy advice the hydrogen scientists provide: A suggestion that hydrogen is a policy option, an argument that something should be an issue.

How does this relate to the notable absence of boundary work in the material? In Jasanoff's study of the SAB, boundary work provided the scientists with a way to avoid being "labeled as captive to EPA's mission" (Jasanoff, 1990:95). Just like it can be questioned what the issue at hand is in the case of hydrogen, it is questionable who would capture the hydrogen scientists. If the issue is taken as suggesting hydrogen as such – and hydrogen scientists are seen as issue advocates for hydrogen as an issue – what kind of boundary work would be possible? The first paper suggests that hydrogen scientists are defined by that they make a connection to hydrogen energy as a concept. This implies that drawing a strict boundary between hydrogen science and the suggesting of hydrogen as a policy issue would remove the "hydrogen" from the science. However, there are no cases in the material where the scientific authority of the scientists has been questioned in the sense that it has been questioned if their research was in accordance with good scientific practices. Thus, it is also possible that the lack of any noticeable boundary work is an effect of another side of the hydrogen issue: If the scientists have been viewed as someone bringing a policy option to the table, it is possible that hydrogen energy has been treated as one among many policy options (and thus that arguments against hydrogen energy have been framed not as questions about scientific certainty, but rather about political priorities). To further examine if this is a good understanding of the policy advice provided by hydrogen scientists, we need to look more closely at this seeming inextricability we find between hydrogen science and hydrogen as a policy option. In the words of Alan Irwin, we need to look at the "more fundamental and mutual embedding between science and politics than the concept of boundary work necessarily conveys" (Irwin, 2008:589) – in other words, at the possibility of hydrogen science as co-produced.

As we saw, Jasanoff suggests four particularly salient pathways of co-production: "making identities, making institutions, making discourses and making representations" (Jasanoff, 2004:38). When looking at the empirical basis of my thesis – a set of data collected to describe hydrogen science – it is noteworthy how attempting to understanding hydrogen science also led to these pathways: the identities of scientists in relation to working on hydrogen being integral to the first paper, with their efforts to make institutions (conferences) and the lack thereof (efforts to create a discipline) also playing an important part. The second paper examines Norwegian hydrogen policy discourses, while the third paper could be seen as dealing with a specific form of representations. The first paper shows how hydrogen science for the scientists is connected to a sense of meaning and usefulness. The second paper studies hydrogen scientists who are concerned with the value aspects of hydrogen science, and who are comfortable with dealing with matters of concern as well as matters of fact (Latour 2004). The third paper observes scientists who argue the case of hydrogen as an object of research funding while connecting it to a wider set of problems. When taken together, the papers reveal that hydrogen science is indeed a case of "natural and social orders as being produced together" (Jasanoff, 2004:2). In other words, hydrogen science cannot be understood as either purely scientific or just political. The amalgamation of diverse scientific efforts to a set of political issues is what creates hydrogen science as simultaneously a proposed solution and a program for research – with part of the proposed solution being to fund said research.

Saying that hydrogen science is a co-product partly answers our question about what hydrogen science is. However, from the summary of the papers we also know that what hydrogen science is seems to be shifting from one context to the other: While the second paper suggests that hydrogen science is currently mainly a transportation issue, the first and third papers connect hydrogen to a wider set of issues (similarly to what the second paper shows happened in 2002-2004). Does this mean that hydrogen is "weakly structured in common use, and become strongly structured in individual-site use" (Star & Griesemer, 1989:393), in other words, that hydrogen plays the role of a boundary object? Immediately this seems like an interesting concept to apply to hydrogen science, as it highlights that there is some kind of cooperation going on despite that there is no consensus on what hydrogen (science) is. Arguably, hydrogen plays the role of boundary object at, e.g., the Norwegian Hydrogen Seminar. However, it is worth noticing Star's cautioning that "I think the concept of boundary object is most useful at the organizational level" (Star, 2010:612). It may be a better description to say that hydrogen has retained its interpretative flexibility – it is certainly not taken for granted across sites what connections (or which technologies) "hydrogen energy" entails.

What facilitates this continued interpretative flexibility, while simultaneously allowing what seems like a closure in one site (the policy documents as shown in paper two)? One possible answer is found in Latour's concept of translating interests, which with its focus on linking your own goals with those of others draw our attention to what kind of different goals are linked through hydrogen. If we compare these goals, we find at least three different kinds: The overarching goals of a climate friendly society or hydrogen society are fairly general long-term goals. The goal of building a hydrogen road in Norway, when specified to building a set of fuelling stations, is a more concrete and short-term goal. The third kind of goal we find is increased funding for hydrogen research – motivated by the overarching long-term goals, it could nevertheless also be seen as a fairly concrete, short-term goal in its own right if we view it as a goal for science policy (or for scientists). When looking at the different timeframes implied in these goals, it is tempting to suggest that time itself serves as a kind of closure mechanism (or opening mechanism) in our case. For the short term, hydrogen is interpreted in terms of what policy currently addresses: transportation and science funding. However, the long-term dimension is an essential part of the reasons given for short term action, at least in the case of science funding and the scientists' arguments in favor of it. One interpretation of the relation between these goals is that the scientists have joined with the long-term goal of the politicians (Latour's strategy 1) while convincing the politicians that they want what the scientists already want, i.e. science funding (Latour's strategy 2). This leads to the conclusion that the hydrogen scientists provide two kinds of policy advice: A science policy suggestion of funding for hydrogen research is combined with the scientists contributing to broader energy policy proposals.

In her introduction to *States of Knowledge*, Sheila Jasanoff argues that "in broad areas of both present and past human activity, we gain explanatory power by thinking of natural and social orders as being produced together" (Jasanoff 2004:2). The case of hydrogen science shows how this explanatory power may be further expanded when we combine a co-production perspective with translation theory. Translation theory originates from studies of scientists and traditionally sets their goals in the center of attention. Co-production shifts the focus towards the interaction between science and politics. When combined, they inform each other. Thinking in terms of translation theory clarifies what we may look for when we gather data along the four pathways Jasanoff describe as particularly effective for co-productionist studies (the making of identities, institutions, discourses and representations).Thinking in terms of co-production makes it easier to avoid making assumptions of who is winning whom over to their way of thinking as scientists interact with policy. When scientists employ Latour's translation strategy 1 and join with the long-term goals of the politicians, this may simultaneously be a case of politicians successfully using Latour's second translation strategy – that it is politicians who are convincing scientists that the scientists want what the politicians want. Taken together, these perspectives can thus deepen our understanding of the interplay taking place when science and policy interacts.

In the beginning of this paper, I briefly introduced the concept of professor-politicians (Slagstad, 1998), which describes an important role scientists took on by shifting between working at the university and taking on political offices or tasks where they – at least partly – drew upon their scientific expertise when making policy. I also described atomic physicist Gunnar Randers as an example of a scientist who engaged in vision work as a way of gaining support for a large techno-scientfic project. Were any of these models present in my study?

The quick response is in the negative. The professor-politician model did not appear in the analysis, and to follow in Randers' footsteps is obviously very demanding. However, as is evident from my discussion of the concept of translation above, vision-making was a part of what (some) hydrogen scientists did in order to make hydrogen interesting for policymakers. Still, from the analysis in my three papers, it becomes clear that the translation concept place too much emphasis on the role and strategies of the scientists. While the scientists engaged in translation, they did so in a context where the translation work was – so to speak – commissioned. Put in another way, while the scientists were offering advice, policymakers were also asking for it.

Two phenomena seem particularly pertinent in this respect. First, as we learn from the third paper, policymakers may set up particular channels for getting advice from scientists, channels that involve formatting. While funding applications may not have traditionally been thought of as an arena for policy advice, the scientists were instructed to explain the relevance of their proposed projects by addressing identified and potentially important policy areas. Thus what was requested from them was that they make it possible for policymakers to make sense of their proposals in policy terms. Second, as we learn from the second paper, in other channels like governmental commissions, scientific advice is negotiated with policy, administrative experiences and values through the work of hybridly composed committees.

Thus, this dissertation means to add to the theoretical perspectives discussed above the need to focus more on the interaction of scientists and policymakers and place greater weight on what policymakers do. This focus extends a bit beyond the co-construction type of analysis, which is concerned with the way scientific knowledge and policy may be co-produced as stable entities. When policymakers are given more concern, this adds new dynamic elements that we have to consider (Latour, 2007 have also suggested that STS studies may need to explore this further).

Finally, what image of hydrogen science and the hydrogen society discourse is provided by my papers? Several scholars have commented that the increased interest in hydrogen in the early 2000s resembled a hype (see e.g. Bakker, 2010). However, this thesis suggests that while there may have been a hydrogen society hype, it is not obvious that hydrogen science is dependent on it. While hydrogen loses visibility in politics and the public sphere, it remains a considerable activity within R&D and to some extent also industry. Thus, as seen from the perspective of hydrogen scientists, it is more fitting to characterize hydrogen as something hopeful. That it still has challenges that need to be solved, does not subtract from this – on the contrary, this simultaneously serves as a reason for funding and as a provider of meaning.

Methodology

The following papers give their own accounts of method and data. This methodology section will repeat some of those to create an overview. Furthermore, I will address two issues that did not fit in the format of the papers: ANT as a methodological inspiration for choices made when working with this thesis, and how my different data collecting strategies have informed each other.

ANT as methodological inspiration: Where to start, where to stop and what to do in-between

The methodological starting point of this study has been Actor-Network Theory. In his 2005 introduction book to this approach, Bruno Latour addresses at least three important aspects of method: Where to start, where to stop and what to look for in-between these two points. Latour provides the following seemingly simple advice on beginnings: "Where should we start? As always, it is best to begin in the middle of things, *in medias res*. Will the reading of a newspaper do? Sure, it offers a starting point as good as any. As soon as you open it, it's like a rain, a flood, an epidemic, an infestation. With every two lines, a trace is being left by some writer that some group is being made or unmade. […]If we simply follow the newspapers' cues, the central intuition of sociology should be that at any given moment actors are made to fit in a group – often in more than one" (Latour, 2005:27-28).

For this thesis work, two possible starting points were given from the project description: Hydrogen (as an energy carrier) with its technologies and the contributions of scientists to hydrogen policy. Attempting to trace actors leads to employing a broad set of methods, and so both documents, places, people and devices were possible sources of data. The starting points also included two cases of what Latour referred to as actors being made to fit in a group: A set of technologies and an element[5] being made into “hydrogen energy”, and scientists being made into “hydrogen scientists”.

From the very beginning, I was aware that hydrogen as an energy carrier was a specific kind of hydrogen. What I did not fully understand before I started collecting data was the inextricability of the hydrogen I was interested in and politics. Starting from political documents, the traces of “my” hydrogen were clear and observable, the few traces of other hydrogens (e.g. as part of Heavy Water) easy to distinguish. However, when looking for hydrogen scientists, it soon became clear that (as the previous sections of this paper describe), hydrogen science is not a discipline. I could certainly find scientists who had engaged with “my” hydrogen. But the only possible way of defining a hydrogen scientist in the context of my study turned out to be in the connections they had made. Thus, as I use the term, a hydrogen scientist is not only doing research on themes relevant to hydrogen as an energy carrier, but also links her research to hydrogen, for example by attending hydrogen conferences, by applying for support from hydrogen funding sources, or by presenting her work towards the public under a hydrogen heading through speaking on hydrogen in the media or on a research group website. Following this definition, a scientist could be a hydrogen scientist and for example a battery scientist at the same time. Attempting

[5] Hydrogen is the lightest and most abundant chemical element, constituting roughly 75% of the Universe's chemical elemental mass (see http://imagine.gsfc.nasa.gov/docs/ask_astro/answers/971113i.html , accessed 2011-10-12). The sun’s fusion of hydrogen into helium is the originating source of the vast majority of energy available at earth. Together with carbon (as hydrocarbons) hydrogen is a central building block in all fossil fuels; combine with oxygen and you will get water, add oxygen and carbon both and you will have the nutrients we call carbohydrates. In short, hydrogen is more omnipresent than the air we breathe (and there is hydrogen in air, too).

to build on the traceable connections made by the scientists rather than making a clear definition of what a "hydrogen scientist" is, is another way in which this study has been inspired by ANT perspectives (see Latour, 2005:150-151). The insight that the actors know more, not less, than the scientists studying them about themselves is certainly not unique to ANT, but nevertheless ANTs combined focus on the actor and their traces were important for my fully realizing what this implied for how I should define the scope of my study.

Last but not least, an ANT perspective has helped me balance my wish for a complete description, at the very least a text that does justice to all the information I have been allowed to access during my work with this thesis, with a certain level of pragmatism. I still recall reading the quote below at the start of my thesis work, thinking it rather unhelpful for making my plans, as "it is finished when it is done" seemed a rather tricky instruction to follow:

"Student: But that's exactly my problem, to stop. I have to complete this doctorate. I have just eight more months. You always say 'more descriptions' but this is like Freud and his cures: indefinite analysis. When do you stop? My actors are all over the place! Where should I go? What is a complete description?

Professor: Now that's a good question because it's a practical one. As I always say: a good thesis is a thesis that is done. But there is another way to stop than just by 'adding an explanation or 'putting it into a frame'.

Student: Tell me it then.

Professor: You stop when you have written your 50,000 words or whatever is the format here, I always forget.

Student: Oh! That's really great. So my thesis is finished when it's completed. So helpful, really, many thanks. I feel so relieved now.

Professor: Glad you like it! No seriously, don't you agree that any method depends on the size and type of texts you promised to deliver?

Student: But that's a *textual* limit, it has nothing to do with method.

Professor: See? That's why I dislike the way doctoral students are trained. Writing texts has *everything* to do with method. You write a text of so many words, in so many months, based on so many interviews, so many hours of observation, so many documents. That's all. You do nothing more" (Latour, 2005:148).

However, after having made my attempt at making a thesis, I think these instructions do full justice to what it is actually about. There is no absolute limit I can draw around my actors – while I would argue that the following chapters contain important insights about how scientists interact with policy, there are other stories that could be told that did not fit within my textual limit. Some actors told me beautiful stories about coincidentally interacting with politics – situations where they "just did it" – that have passed through the cracks in my making of this account, partly because hydrogen did not play much of a part in these stories, but also because I had reached the point where I had written a text that fulfilled the formal requirements this thesis was to fulfill, and my time was up. And "that's all".

Fieldwork and snowballing as complementary points of departure

The data described in the papers of this thesis is mainly interview data and documents. Nevertheless, a kind of field work has been an important basis for my work. I have attended 12 conferences and seminars, some with hydrogen included as one of several topics and some being purely hydrogen conferences. As well as attending presentations, excursions and social events in connection with the conferences, I have also used the conference programs to gain insight in what themes Norwegian hydrogen scientists focus on. I have written notes from the conferences. I have talked to attendees, about both my own and their research. I have shared a room with a fellow PhD student and discussed how it feels to present on conferences. I have laughed along with the rest of the group when a professor jokingly commented how bad our compressibility was at a conference group picture taking session (the hydrogen context made it quite funny). I have stood at the back with a State

Secretary watching her Minister open a session, whispering comments and questions about hydrogen versus battery cars.

When an anthropologist does a long-term fieldwork, there is plenty of room for both getting to know people and clarifying the role of the scientist as an observer. With my study, it was less obvious how to do this. I could have done the kind of study of one laboratory that were one of the starting points of science and technology studies (see Latour & Woolgar, 1979). However, there is no obvious "hydrogen lab" which I could have studied – the researchers become hydrogen scientists when they come together from a set of different laboratories. I thus found it more useful to my study to be present at these gathering places. With fairly short time frames in which to get to know people, I decided on an approach where I asked for an interview (on a few occasions they were as short as 5 minutes, sometimes an observation at a conference was what made me ask for a longer interview at a later date) to get statements confirmed and use quotes from these interviews as basis for further analysis. I believe a strength in this approach was that it allowed me to be not overly intrusive at the conferences I attended, while simultaneously not quoting anyone without their awareness. On more than one occasion, asking an interviewee if I had understood them correctly also resulted in the interviewee reflecting on their statement in a way that provided valuable analytical insights. Thus the fieldwork strengthened the interviews as "a dynamic, meaning-making occasion" (Holstein & Gubrium, 1995:9). The interviews were with one exception conducted at the workplace of the interviewees, giving additional opportunities for observation (two interviewees graciously gave me a guided tour of their labs).

I believe that snowballing is the term that best fits my strategy for choosing both informants and conferences – but this expression should then be understood as applying to the conferences and informants together. The interviewees were selected based on observations at the conferences and from suggestions made by other interviewees (snowballing). The conferences to attend were selected based on suggestions from interviewees and on conference announcements from the Norwegian Hydrogen Forum – some conferences were recurring events. I am especially grateful to my initial two interviewees who were with scientists also in some way involved with organizing hydrogen science or giving hydrogen energy advice to the authorities.

Altogether, 32 interviews were conducted in Norway, with scientists representing five different universities and research institutions, representatives of funding agencies, industry, authorities, and NGOs. One scientist was interviewed twice, and one interview had two interviewees. In addition, three interviews were conducted during a stay as a visiting scholar at UC Davis, Institute for transportation studies, with two scientists and one former scientist now working for a government agency, and I attended several hydrogen-related presentations and seminars while in California. This provided valuable additional insight in hydrogen science internationally, but has not been part of the final analysis. A list of interviews is attached as Appendix A. The 19 interviewed Norwegian scientists came from two different universities, one university college and two research institutes.

The documents analyzed in this thesis were gathered in three different ways. One set of data were the hydrogen-related applications submitted to the Clean Energy for the Future program (Renergi), see chapter 3 for details. The boundary of this set of data was decided by what the Research Council of Norway (RCN) was able to allow access to. The first analysis of these documents was done on the premises of the RCN. I was given a temporary workplace there, and the opportunity this gave for questions and conversations with people working with the Renergi program was very helpful to my work. The second source of written material was a number of websites that were used as a starting point supplementing conferences and interviews in my attempt at gaining an overview of Norwegian hydrogen research. This includes hydrogenplattformen.no, which is run by the Research Council of Norway listing ongoing hydrogen projects, the websites of involved research groups.

www.cristin.no, a national Norwegian database for science publications, was used to gauge the focus on hydrogen energy as a theme and publications in specific hydrogen journals amongst the interviewed scientists. The last set of written data was policy documents, based on a search that is detailed in chapter 4. Some documents were added to the first set of findings based on references to them in the other documents. The fieldwork mentioned above was also helpful when trying to decide if there were documents that should be paid extra attention, as were the interviews. On several occasions interviewees provided written material. Some of this was fairly informal (like copies of e-mails and power-point presentations), but some of it has been more formal and more directly related to the policy documents (like a lobby-letter to a member of parliament). The latter documents I have used to supplement the analyzed policy documents when appropriate.

Addressing issues regarding the interaction of scientists with policy, in a case such as mine without one obvious committee that could be followed more closely, called for a broad approach. Together, the 35 interviews, 12 conferences and seminars, 55 research funding applications and numerous policy documents comprise an extensive, and I believe satisfactory, basis for the analysis done in this thesis.

An active interviewer

In their book *The New Language of Qualitative Method*, Gubrium and Holstein examine different ways in which qualitative social scientists talk about method. Summarizing some common threads which simultaneously work as excellent guidelines for qualitative inquiry, they write that "shifting between *what* and *how* questions keeps the analysis of interpretive practice self-consciously attentive to both the world researched and the researcher. […] Because the dual approach emphasizes the emergent and contingent nature of social reality, it underscores the traditional "antitotalizing" spirit of qualitative inquiry, retaining a role for both individual agency and circumstantial evidence. This, in turn, encourages a theoretical minimalism that guards against both a priori assumptions and deterministic modeling" (Gubrium &

Holstein, 1997:212). In trying to figure out how to approach the interview situation, I am indebted to Gubrium and Holsteins work, and especially their concept of the active interviewer: “The active interviewer is responsible for inciting respondents’ answers. But the active interviewer does far more than dispassionate questioning; he or she *activates narrative production*. Where the standardized approach attempts to strip the interview of all but the most neutral, impersonal stimuli, the consciously active interviewer intentionally, concertedly provokes responses by indicating – even suggesting – narrative positions, resources, orientations, and precedents for the respondent to engage in addressing the research questions under consideration” (Holstein and Gubrium 1995).

Consciously allowing that the interviewer suggests narrative positions highlights how the interview is dependent on both interviewer and interviewee. This approach has been especially important for me when it comes to how to utilize my own background in regards to the research process. I have worked within politics (as an MP) before I became a PhD student, and my master’s degree is in applied physics. Thinking of myself as part of the meaning-making occasion that the interview is, has been enlightening several times, for instance when interviewing a politician who gave answers building on what she saw as our shared insights, or when one (chemistry) professor immediately (and correctly) suggested that I was the kind of person who would want to study physics, and went on to explain challenges in interdisciplinary work by building on what we by then had established could be seen as different personality traits of physicists and chemists. In including these notes on myself as part of the interviews towards the end of this method section, I keep hoping I manage to stay “self-consciously attentive to both the world researched and the researcher” (Gubrium and Holstein 1997).

References

Andrews, John, and Bahman Shabani. 2011. "Re-envisioning the role of hydrogen in a sustainable energy economy." *International Journal of Hydrogen Energy* 37 (2) (October): 1184-1203.

Bakker, Sjoerd. 2010. "The car industry and the blow-out of the hydrogen hype." *Energy Policy* 38 (11) (November): 6540-6544.

Bakker, Sjoerd, Harro Van Lente, and Marius Meeus. 2011. "Arenas of expectations for hydrogen technologies." *Technological Forecasting and Social Change* 78 (1) (January): 152-162.

Beck, Ulrich. 1992. *Risk Society: Towards a New Modernity*. London: Sage.

Blanchette, Stephen. 2008. "A hydrogen economy and its impact on the world as we know it." *Energy Policy* 36 (2) (February): 522-530.

Bleischwitz, Raimund, and Nikolas Bader. 2010. "Policies for the transition towards a hydrogen economy: the EU case." *Energy Policy* 38 (10) (October): 5388-5398.

Bockris, J. 2002. "The origin of ideas on a Hydrogen Economy and its solution to the decay of the environment." *International Journal of Hydrogen Energy* 27 (7-8) (August): 731-740.

Brooks, Harvey. 1964. The Scientific Advisor. In *Scientists and National Policy Making*, ed. Robert Gilpin and Christopher Wright, 73-96. New York: Columbia University Press.

Chen, Yu-Heng, Chia-Yon Chen, and Shun-Chung Lee. 2011. "Technology forecasting and patent strategy of hydrogen energy and fuel cell technologies." *International Journal of Hydrogen Energy* 36 (12) (June): 6957-6969.

Cherryman, S.J., S. King, F.R. Hawkes, R. Dinsdale, and D.L. Hawkes. 2008. “An exploratory study of public opinions on the use of hydrogen energy in Wales.” *Public Understanding of Science* 17 (3) (May): 397-410.

Climate for Research Summary in English: Report no. 30 to the Storting (2008-2009). Oslo.

Collins, Harry M., and Trevor Pinch. 1998. *The Golem at Large*. Cambridge, MA: Cambridge University Press.

Dougherty, William, Sivan Kartha, Chella Rajan, Michael Lazarus, Alison Bailie, Benjamin Runkle, and Amanda Fencl. 2009. “Greenhouse gas reduction benefits and costs of a large-scale transition to hydrogen in the USA.” *Energy Policy* 37 (1) (January): 56-67.

Eames, Malcolm, William Mcdowall, Mike Hodson, and Simon Marvin. 2006. “Negotiating contested visions and place-specific expectations of the hydrogen economy.” *Technology Analysis & Strategic Management* 18 (3-4) (July): 361-374.

Flynn, Rob, Paul Bellaby, and Miriam Ricci. 2009. “The ‘value-action gap’ in public attitudes towards sustainable energy: the case of hydrogen energy.” *The Sociological Review* 57: 159–180.

Godoe, Helge, and Stian Nygaard. 2006. “System failure, innovation policy and patents: Fuel cells and related hydrogen technology in Norway 1990–2002.” *Energy Policy* 34 (13) (September): 1697-1708.

Goltsov, Victor .A., and T. Nejat Veziroglu. 2001. “From hydrogen economy to hydrogen civilization.” *International Journal of Hydrogen Energy* 26 (9): 909–915.

Gonçalves, Maria Eduarda. 2000. “The importance of being European: The science and politics of BSE in Portugal.” *Science, Technology & Human Values* 25 (4): 417-448.

Gubrium, Jaber F., and James A. Holstein. 1997. *The New Language of Qualitative Method*. Oxford: Oxford University Press.

Hagendijk, R.P. 2004. "The public understanding of science and public participation in regulated worlds." *Minerva* 42 (1): 41-59.

Hodson, Mike, and Simon Marvin. 2009. "Cities mediating technological transitions: understanding visions, intermediation and consequences." *Technology Analysis & Strategic Management* 21 (4) (May): 515-534.

Holstein, James A., and Jaber F. Gubrium. 1995. *The Active Interview*. Thousand Oaks, CA: Sage Publications, Inc.

Hultman, Martin. 2009. "Back to the future: The dream of a perpetuum mobile in the atomic society and the hydrogen economy." *Futures* 41 (4) (May): 226-233.

International Energy Agency (IEA). 2010. *Energy Technology Perspectives 2010*. Paris: OECD/IEA.

Irwin, Alan. 1995. *Citizen Science: A Study of People, Expertise and Sustainable Development*. London: Routledge.

———. 2001. "Constructing the scientific citizen: Science and democracy in the biosciences." *Public Understanding of Science* 10 (1): 1-18.

———. 2008. STS Perspectives on Scientific Governance. In *The Handbook of Science and Technology Studies, Third Edition*, ed. Edward J. Hackett, Olga Amsterdamska, Michael Lynch, and Judy Wajcman, 583-607. Cambridge, MA: The MIT Press.

Jasanoff, Sheila. 1990. *The Fifth Branch - Science Advisers as Policymakers*. Cambridge, MA: Harvard University Press.

———. 2004. *States of Knowledge: The Co-production of Science and Social Order*. Ed. Sheila Jasanoff. London: Routledge.

———. 2011. Quality control and peer review in advisory science. In *The Politics of Scientific Advice - Institutional Design for Quality Assurance*, ed. Justus Lentsch and Peter Weingart. Cambridge: Cambridge University Press.

Karimi, S., and F. R. Foulkes. 2002. "Fuel Cell Cars: Panacea or Pipe Dream?" *Bulletin of Science, Technology & Society* 22 (4) (August 1): 283-296.

Klitkou, Antje, Stian Nygaard, and Martin Meyer. 2007. "Tracking techno-science networks: A case study of fuel cells and related hydrogen technology R&D in Norway." *Scientometrics* 70 (2) (February): 491-518.

Koefoed, Anne Louise. 2011. *Hydrogen in the making – how an energy company organises under uncertainty*. PhD Dissertation (BI Norwegian School of Management). Oslo.

Kvamsdal, Hanne Marie, and Øystein Ulleberg. 2000. *TR A5197 Hydrogensamfunnet - en nasjonal mulighetsstudie*. Teknisk rapport, Sintef Energiforskning A/S. Trondheim.

Kårstein, Asbjørn. 2005. Samfunnsvitenskapelig forskning om hydrogen: En bibliografi. STS-arbeidsnotat 04/05. Norwegian University of Science and Technology, Trondheim.

———. 2008. *HyNor – den norske hydrogenveien? En studie av en stor tekno-politisk hybrid.* PhD Dissertation (Norwegian University of Science and Technology, NTNU). Trondheim.

———. 2010. "Stumbling blocks on the Hydrogen road in Norway." *Proceedings of the ICE - Urban Design and Planning* 163 (4) (December 1): 177-183.

Latour, Bruno. 1987. *Science in action: how to follow scientists and engineers through society*. Milton Keynes: Open University Press.

———. 2004. "Why Has Critique Run out of Steam? From Matters of Fact to Matters of Concern." *Critical Inquiry* 30 (2): 225-248.

———. 2005. *Reassembling the Social: an Introduction to Actor-Network-Theory*. Oxford: Oxford University Press.

———. 2007. “Turning Around Politics: A Note on Gerard de Vries’ Paper.” Social Studies of Science 37 (5) (October): 811-820.

Latour, Bruno, and Steve Woolgar. 1979. *Laboratory Life*. Princeton: Sage Publications, Inc.

van Lente, Harro, and Sjoerd Bakker. 2010. “Competing expectations: the case of hydrogen storage technologies.” *Technology Analysis & Strategic Management* 22 (6) (August): 693-709.

Lentsch, Justus, and Peter Weingart (ed). 2011. *The Politics of Scientific Advice - Institutional Design for Quality Assurance*. Cambridge: Cambridge University Press.

Macfarlane, Allison. 2003. “Underlying Yucca Mountain: The Interplay of Geology and Policy in Nuclear Waste Disposal.” *Social Studies of Science* 33 (5): 783-807.

Madsen, Anne Nygaard, and Per Dannemand Andersen. 2010. “Innovative regions and industrial clusters in hydrogen and fuel cell technology.” *Energy Policy* 38 (10) (October): 5372-5381.

McDowall, Will. 2011. “Technology roadmaps for transition management: The case of hydrogen energy.” *Technological Forecasting and Social Change* 79 (3) (October): 530-542.

McDowall, William, and Malcolm Eames. 2006. “Forecasts, scenarios, visions, backcasts and roadmaps to the hydrogen economy: A review of the hydrogen futures literature.” *Energy Policy* 34 (11): 1236–1250.

McSherry, Corynne. 2001. *Who Owns Academic Work? - Battling for Control of Intellectual Property*. Cambridge, MA: Harvard University Press.

Mcdowall, William, and Malcolm Eames. 2007. “Towards a sustainable hydrogen economy: A multi-criteria sustainability appraisal of competing hydrogen futures.” *International Journal of Hydrogen Energy* 32 (18) (December): 4611-4626.

Meyer, Patrick E., and James J. Winebrake. 2009. “Modeling technology diffusion of complementary goods: The case of hydrogen vehicles and refueling infrastructure.” *Technovation* 29 (2) (February): 77-91.

Murray, M. Luke, E. Hugo Seymour, and Rui Pimenta. 2007. “Towards a hydrogen economy in Portugal.” *International Journal of Hydrogen Energy* 32 (15) (October): 3223-3229.

Nerdrum, Lars, and Helge Godoe. 2006. “Industry cycles, market ideology and innovation policies: Fuel cells and hydrogen industries.” *VEST-Journal for Science and Technology Studies* 19 (1-2): 7–29.

NOU 2012:9 Energiutredningen. Oslo.

Nowotny, Helga. 2003. “Democratising expertise and socially robust knowledge.” *Science and Public Policy* 30 (3): 151-156.

Nygaard, Stian. 2008. Co-Evolution of Technology, Markets and Institutions - The Case of Fuel Cells and Hydrogen Technology in Europe. Phd Dissertation (Lund University).

Ogden, Joan M. 2002. “Hydrogen: The fuel of the future?” *Physics Today* (April): 69-75.

Park, Sangook. 2011. “Iceland’s hydrogen energy policy development (1998–2007) from a sociotechnical experiment viewpoint.” *International Journal of Hydrogen Energy* 36 (17) (August): 10443-10454.

Parthasarathy, Shobita. 2004. “Regulating Risk: Defining Genetic Privacy in the United States and Britain.” *Science, Technology, & Human Values* 29 (3) (July 1): 332-352.

Pielke Jr., Roger A. 2007. *The honest broker: making sense of science in policy and politics*. Cambridge: Cambridge University Press.

Pinch, Trevor J., and Wiebe E. Bijker. 1987. The Social Construction of Facts and Artifacts: Or How the Sociology of Science and the Sociology of Technology Might Benefit Each Other. In *The Social Construction of Technological Systems - New Directions in the Sociology and History of Technology*, ed. Wiebe E. Bijker, Thomas P. Hughes, and Trevor Pinch, 17-50. Cambridge, MA: The MIT Press.

Randers, Gunnar. 1946. *Atomkraften Verdens håp eller undergang*. Oslo: J. W. Cappelens Forlag AS.

———. 1950. Atomer og sunn fornuft. Oslo: H. Aschehoug & Co.

Rayner, Steve. 2003. "Democracy in the age of assessment: reflections on the roles of expertise and democracy in public-sector decision making." *Science and Public Policy* 30 (3) (June 1): 163-170.

Research Council of Norway. 2004. Programplan 2004-2013. RENERGI: Clean Energy For The Future. Oslo: Research Council of Norway.

Ricci, M, P Bellaby, and R Flynn. 2008. "What do we know about public perceptions and acceptance of hydrogen? A critical review and new case study evidence." *International Journal of Hydrogen Energy* 33 (21) (November): 5868-5880.

Rifkin, Jeremy. 2002. *The Hydrogen Economy*. New York: Penguin Putnam Inc.

Romm, Joseph. 2007. Energy Myth Four - The Hydrogen Economy is a Panacea to the Nation's Energy Problems. In *Energy and American Society - Thirtheen Myths*, ed. Benjamin K. Sovacool and Marilyn A. Brown, 103-124. Springer.

Seymour, E, L Murray, and R Fernandes. 2008. "Key Challenges to the introduction of hydrogen—European stakeholder views." *International Journal of Hydrogen Energy* 33 (12) (June): 3015-3020.

Slagstad, Rune. 1998. *De nasjonale strateger*. Oslo: Pax Forlag A/S.

———. 2006. “Motet til å ta det store ansvar.” *Aftenposten*, October 31.

Solomon, Barry D., and Abhijit Banerjee. 2006. “A global survey of hydrogen energy research, development and policy.” *Energy Policy* 34 (7) (May): 781-792.

Sovacool, Benjamin K., and Brent Brossmann. 2010. “Symbolic convergence and the hydrogen economy.” *Energy Policy* 38 (4) (April): 1999-2012.

Star, Susan Leigh. 2010. “This is Not a Boundary Object: Reflections on the Origin of a Concept.” *Science, Technology & Human Values* 35 (5) (August 10): 601-617.

Star, Susan Leigh, and James R. Griesemer. 1989. “Institutional ecology,translations’ and boundary objects: Amateurs and professionals in Berkeley's Museum of Vertebrate Zoology, 1907-39.” *Social studies of science* 19 (3): 387-420.

Strathern, Marilyn. 2007. “Interdisciplinarity: some models from the human sciences.” *Interdisciplinary Science Reviews* 32 (2) (June 1): 123-134.

Vasudeva, Gurneeta. 2009. “How national institutions influence technology policies and firms’ knowledge-building strategies: A study of fuel cell innovation across industrialized countries.” *Research Policy* 38 (8) (October): 1248-1259.

Weingart, Peter. 2010. A short history of knowledge formations. In *The Oxford Handbook of Interdisciplinarity*, ed. Robert Frodeman, Julie Thompson Klein, Carl Mitcham, and J. Britt Holbrook. Oxford: Oxford University Press.

Wynne, Brian. 1989. Frameworks of Rationality in Risk Management: Towards the Testing of Naïve Sociology. In *Environmental Threats: Perception, Analysis and Management*, ed. J. Brown, 33-47. London: Belhaven Press.

———. 2002. “Risk and Environment as Legitimatory Discourses of Technology: Reflexivity Inside Out?” *Current Sociology* 50 (3) (May 1): 459-477.

Zavestoski, Stephen, Phil Brown, Meadow Linder, Sabrina McCormick, and Brian Mayer. 2002. “Science, policy, activism, and war: defining the health of Gulf war veterans.” *Science, Technology & Human Values* 27 (2): 171-205.

Zhang, Fangzhu, and Philip Cooke. 2010. “Hydrogen and Fuel Cell Development in China: A Review.” *European Planning Studies* 18 (7) (July): 1153-1168.

Árnason, Bragi, and Thorsteinn I. Sigfússon. 2000. “Iceland - a future hydrogen economy.” *International Journal of Hydrogen Energy* 25 (5): 389–394.

Appendix A – interviews

Role (yymmdd)	Date interviewed
Research advisor A	080303
Professor B	080405
Research Scientist C	080519
Research Scientist D	080519
Professor E	080505
PhD student F	091217
Professor G	080604
Postdoc H	091217
Research leader I	080526
Researcher J	090513
PhD student K	091217
Senior researcher L	070815
Researcher M	091209
PhD student N	091217
PhD student O	091217
Postdoc P	091217
Research scientist Q	070816, 090514
Research Leader R	080527
Research Leader S	080118
Professor T	091204
State Secretary	080117
Former MP	080102
Leader of government agency	090526
Leader of NGO	080104
Two Ministry of Transportation bureaucrats	080519

Member of committee that wrote NOU 2004:11	080303
Consultant who worked on hydrogen report	080104
Employee 1 of electric car company	090515
Employee 1 of large energy company 1	080102
Employee 1 of large energy company 2	090513
Employee 2 of large energy company 2	080603
Californian scientist 1	100525
Californian scientist 2	100608
Californian government agency worker	100528

Appendix B

Conferences, meetings and seminars attended as part of the data collection process

Meetings for members of the Norwegian Hydrogen Forum: March 2008, June 2009

Seminar at the Parliament with hydrogen researchers and politicians April 2008

HyNor conference December 2007

Energiuka February 2008 (dedicated hydrogen seminars as part of the program)

Zero emission conference 09, September 2009 (dedicated hydrogen seminars as part of the program)

EVS 24 (including one-day separate hydrogen seminar before the actual conference) May 2009

SFFE Lunch Colloquium 27th of February 2008: Suistainable Road Transport v/Ann Mari Svensson

SFFE Lunch Colloquium 15th of September 2009: Battery and fuel cells – key technologies for zero emission transport v/Magnus Thomassen

Norwegian Hydrogen Seminar 2008 including excursion to the Utsira Hydrogen demonstration project, September 2008

Hydrogen and Fuel Cells in the Nordic Countries Conference, November 2009

Career day at NTNU, September 2008 (with visits at the stands of research institutions represented in the interview material)

Nordic SME and OEM Fuel Cell Workshop June 2009

Appendix C
Overview of documents and web pages referred to or used as background for the thesis

St. meld. nr. 58 (1996-97) Miljøpolitikk for en bærekraftig utvikling

St. meld. nr. 29 (1997-98) Norges oppfølging av Kyotoprotokollen

NOU 1998:11 Energi- og kraftbalansen mot 2020

Written materials and minutes from the NOU committee (as provided by a member)

Hearing responses to NOU 1998:11

Stortingsmelding nr 29 (1998-99) Om energipolitikken

Inst. s. nr 122 (1999-2000)

St. meld. nr. 46 (1999-2000) Nasjonal transportplan 2002-2011

Hydrogensamfunnet – en nasjonal mulighetsstudie. Sintef-rapport TR A5197, 2000

Sem-erklæringen (the agreement between the parties in Government 2001-2005 that was the basis of their common policies)

St. meld. nr. 15 (2001-2002) Tilleggsmelding til st. meld. nr. 54 (2000-2001) Norsk klimapolitikk

Ta naturgassen i bruk! Report from a joint committee of the Labour Party and the Confederation of Trade Unions, July 2001

NOU 2002:7 Gassteknologi, miljø og verdiskaping

Hearing responses to NOU 2002:7

St. meld. nr. 9 (2002-2003) Om innenlands bruk av naturgass mv.

Inst. S. nr 167 (2002-2003)

Letter sent by the Norwegian Hydrogen Forum to a member of parliament regarding St. meld. nr. 9 (2002-2003) as provided by an interviewee

Bellona-rapport 6-2002 Hydrogen – status og muligheter

St. meld. nr. 47 (2003-2004) Om innovasjonsverksemda for miljøvennlege gasskraftteknologiar mv.

St. meld. nr 24 (2003-2004) Nasjonal transportplan 2006-2015

FoU og innovasjonsvirksomhet innen brenselsceller og relatert hydrogenteknologi i Norge (Helge Godø, NIFU arbeidsnotat 1/2004)

NOU 2004:11 Hydrogen som fremtidens energibærer

Hearing responses to NOU 2004:11

Hydrogen & Fuel Cells – Review of National R&D Programs. OECD/IEA, 2004

Energi 2020+ - Sluttrapport fra et foresight-prosjekt. Norges Forskningsråd, 2005

Strategi - Satsing på hydrogen som energibærer innenfor transport og stasjonær energiforsyning (as published by the Ministries of Transportation and of Oil and Energy on 050826)

Strategi for tele- og transportforskningen 2006-2009 (as published by the Ministry of Transportation, 2005)

Soria Moria-erklæringen (the agreement between the parties in Government 2005-2009 that was the basis of their common policies)

Hydrogen and Fuel Cells in Norway - Who's who (Dag Sanne, May 2006)

Norsk storstasting på hydrogen – Handlingsplan for perioden 2007-2010 (as drawn up by the Hydrogen Council, December 2006)

NOU 2006:18 Et klimavennlig Norge

St.meld. nr. 34 (2006-2007) Norsk klimapolitikk

Coordination of Norwegian Hydrogen Related Activities within Safety, Regulations and Standards – report from Det Norske Veritas, published 071221

Energi21 – Final report, 2008

Letters from the Ministries of Transportation and of Oil and Energy to the Research Council of Norway concerning the Ministries' respective science funding (as sent yearly providing guidelines to the RCN on how to best employ the Ministries' funds)

Hydrogen-related funding applications that gained support from the Renergi program

Web pages:

Norsk hydrogenforum – www.hydrogen.no
HyNor – www.hynor.no
Hydrogenplattformen -
http://www.forskningsradet.no/servlet/Satellite?c=Page&cid=1234130625668&pagename=hydrogen%2FHovedsidemal
Zero – www.zero.no
Bellona – www.bellona.no
Forskningsrådet – www.forskningsradet.no
IEA – www.iea.org
Ministry of Transportation – www.sd.dep.no
Ministry of Petroleum and Energy – www.oed.dep.no

Appendix D Interview guides

This is the interview guide that was used in a generalized form. Some questions were added to this interview guide related to specific sides of the institution the interviewee belonged to, sides of hydrogen policy they were known to have worked on, or statements they had made on hydrogen conferences that I wanted them to clarify.

Interview guide in Norwegian:

Intro: Jeg arbeider med et prosjekt som søker en bedre forståelse av hvordan forskning – i dette tilfellet forskning knyttet til hydrogen – bidrar til å skape visjoner og politikk/policy i forhold til den teknologien det forskes på.

1) Først, kan du fortelle litt om din utdannings- og yrkesbakgrunn?

2) Når ble du interessert i å jobbe med hydrogen? (Mulig oppfølging her: Var det bestemte personer/en bestemt tekst etc som spesielt vekket interessen?)

3) Hva slags arbeid har du vært involvert i knyttet til hydrogen utenom det rent vitenskapelige? (Forskningsråd/Hydrogenråd/nettverksbygging etc?)

4) Kan du si litt mer om fagmiljøet du jobber i her? Hvem er dere (navn/antall personer/faglig bakgrunn og kompetanse), hvilke hydrogenrelaterte problemstillinger arbeider dere med?

5) Hvordan er arbeidet deres finansiert?

6) Hvilke andre fagmiljøer er de viktigste samarbeidspartnerne deres? På hvilke områder samarbeider dere?

7) Om dere lykkes med forskningen dere gjør her, hva vil resultatet være (kort sikt/lang sikt)?

8) I hvilken grad tror du hydrogen vil bli tatt i bruk som energibærer (angi gjerne ulike tidshorisonter)?

9) Hva må til for at dette skal bli virkeliggjort? (Si noe om faglige utfordringer/politiske utfordringer/utfordringer i forhold til industrien/folk flest).

10) Enkelte har brukt begrepet ”hydrogensamfunnet” for å få fram hvor sentralt hydrogenteknologi kan bli i framtida. Tror du vi noen gang vil leve i ”hydrogensamfunnet”? Hva innebærer det?

11) Hvilke miljøer og/eller personer utenom de rent vitenskapelige er viktige for dere i forhold til arbeidet deres med hydrogen? Hvordan samarbeider dere?

Interview guide in English

The list of questions is shorter than the Norwegian list because questions 4-6 and 11 in the Norwegian list are all mentioned in question 4 in the English list. The reason I have not just done a direct translation is that some of the interviews were conducted in English, and this is the interview guide that was actually employed. The changes made to the interview guide was based on the experience from earlier interviews that the questions 4-6 and 11 were often addressed at the same time by interviewees.

Introduction: I'm working on a project aiming for a better understanding of how science – in this case hydrogen research – is a part of creating visions and politics/policy for the technology research is done on. To what extent do these kind of visions matter for research(ers)?

1) Firstly, could you please describe your educational background/your research career? (places you have worked, subjects you have worked on, what kind of education you have, what was important when you chose a project/place to work with) What brought you to Norway?

2) Who/what made you interested in doing research on hydrogen? (And if you are no longer doing so, what made you quit?)

3) Have you taken part in any work with hydrogen that is not directly research? (Eg Research Council, Hydrogen Council..)

4) Could you say a little about your research group? Who are your closest colleagues, how is your work financed, which other research groups/institutions are most central for your work?

5) If your research succeeds, what is the impact/result?

6) To what degree do you believe that hydrogen will be used as an energy carrier? (please feel free to add a timeframe as you see fit)

7) What is missing today to reach that level of use? (Scientific/political/industry/people..)

8) Some have talked about ”the hydrogen economy” or ”the hydrogen society” to emphasize how important hydrogen might become in the future. Do you think we will ever live in a “hydrogen society”? What would that mean? Is it a useful term?

Chapter 2: Adaptable scientists? Features of interdisciplinary research

Abstract

Hydrogen as an energy carrier is a proposed solution to a set of pressing issues like facilitating new renewable production of energy, climate friendly transport, energy security, and reducing local air pollution. Hydrogen is closely related to energy security and environmental challenges, issues that have been quoted as examples of the world's need for interdisciplinary solutions. This paper employs different theories on interdisciplinarity to simultaneously explore if interdisciplinarity is indeed a fitting label for hydrogen science, and what it means for the hydrogen scientists to be involved in an interdisciplinary field, showing that hydrogen science provide the scientsts with a sense of meaning and simultaneously a way of communicating the relevance of their efforts. This highlights the inherent riskiness for scientists engaging in transdisciplinary work: A sense of meaning is gained through increased relevance, but at the same time this sense of meaning can be undermined. While you can come to the agora wishing for a problem-solving collaboration, you cannot force the attendance of others.

Keywords: transdisciplinarity, interdisciplinarity, hydrogen, materials science, chemistry, physics

Supposedly, scientific knowledge is becoming increasingly interdisciplinary due to "pressing weight of social and technological problems, breakthroughs in research, new scholarship, and new demands on the curriculum" (Klein 1996: 1). Interdisciplinarity is without a doubt a buzzword in modern science policy, coveted by funding sources as well as scientific journals (Moran 2010: iix). It is implied that people should aim for more integration, that "the greater the degree of interdisciplinarity the better" (Strathern 2007:125). But what does it mean for scientists to engage in research considered to be interdisciplinary? In this paper I use theories on interdisciplinarity to examine the practices of hydrogen scientists, simultaneously exploring the interdisciplinarity of hydrogen science and asking what this interdisciplinarity entails for the scientists involved.

Hydrogen as an energy carrier (shortened to hydrogen hereafter) is a proposed solution to a set of pressing issues like facilitating new renewable production of energy, climate friendly transport, energy security, and reducing local air pollution (see Veziroglu 2000 for a review of the rise of hydrogen as a topic for policy and research). The grander of these proposals are sometimes put forward as visions of a Hydrogen Economy or a Hydrogen Society. Hydrogen is closely related to energy security and environmental challenges, issues that have been quoted as examples of the world's need for interdisciplinary solutions (Nowotny et al. 2001: 213). Hydrogen is "promoted by a broad range of actors with diverse and often conflicting agendas and interests, as well as differing degrees of power and influence" (Eames et al. 2006: 361). For instance, the car industry is essential for production of hydrogen-related knowledge and (technological) expectations (Bakker 2010). This raises the question of whether hydrogen science fits the new "Mode 2" kind of knowledge production, characterized by its taking place in a context of application, rather than within the borders of the university (Nowotny et al. 2003:179).

However, the existence of problems that cannot readily be said to belong to only one scientific discipline is hardly new. As Sarewitz (2010:65) points out, "[r]eality is not divided up along disciplinary lines,"nevertheless "[d]isciplinary, reductionist science and its embodiment in technology are the most powerful sources of social transformation in the world today" (Sarewitz 2010:67). If science is now becoming increasingly interdisciplinary, what is causing this development? According to Nowotny et al. (2001:4-5) "[t]here appears to have been a remarkable coincidence between the development of more open systems of knowledge production on the one hand and on the other the growth of complexity in society - and the increase of uncertainty in both.” Klein (2010:26) cites a US National Academy of Sciences report from 2004 identifying four primary drivers of interdisciplinarity: the inherent complexity of nature and society, the desire to explore problems and questions that are not confined to a single discipline, the need to solve societal problems, and the power of new technologies. While the first, third and fourth of these drivers correspond closely to the development Nowotny et al. (2001) describes, it is worth noting that scientific curiosity is also cast as a motive to engage in interdisciplinary studies.

Another possible motive, according to Weingart (2000:38-39), is legitimation. Weingart presents a more cynical view where interdisciplinarity is seen as a case where “scientists re-label their research projects in order to ‘fit in,’” and concludes that “Interdisciplinarity may best be described as a result of opportunism in knowledge production” – on the side of scientists as well as policymakers. These conflicting perceptions have quite different implications as to if and how interdisciplinarity affects the scientists working within a field. In this paper, I use these different perceptions to simultaneously explore if interdisciplinarity is indeed a fitting label for hydrogen science, and what it means for the hydrogen scientists to be involved in an interdisciplinary field.

Interdisciplinarity as theory and practice

What is interdisciplinarity? Strathern (2006) chooses to “refer to interdisciplinarity in the abstract because its most powerful grip lies in the very idea of it,” due to the compelling combined suggestion of creative crossing of boundaries and “the practical sense of addressing issues that cannot be handled by one approach alone” (Strathern 2006:196). However, just like there are many divergent takes on what interdisciplinarity may mean for the scientists working within a field, numerous answers have been proposed to the questions of what interdisciplinarity is (see Klein 2010 for an overview).

Weingart (2010:12) claims that disicplines are still the principal organizational unit of knowledge production, and that “[t]he thesis of a new mode of knowledge production has been based on impressionistic evidence only.” He nevertheless lists two possible theoretical explanations for a development where inter- and transdiscplinarity become more dominant: “First, with the continuously growing number of specialties (i.e. research fields below the level of disciplines) the probability increases that, due to the proximity of such fields, new recombinations will occur which will result in new 'interdisciplinary' research fields. The organizational status of these fields, however, still follows the model of ' internal' specialization. After a period of emergence they form into another specialized field. Second, inter- and transdisciplinary research fields are promoted by funding agencies in the interest of directing research to politically desired goals. This process is conditioned by the fact that the 'externally' defined subject matters, research problems, and values or interests can trigger sustained research” (Weingart 2010:12). Weingart also lists legitimation as a possible driver towards interdisciplinary fields (Weingart 2000:37).

What does Weingart’s take on interdisciplinarity imply for the scientists involved? The first kind, specialization-driven recombinations, does not involve any permanent changes in scientific practice. The second, interdisciplinarity as driven by political goals external to science with the promise of legitimacy (and financing) as reward, offers a range of possible implications. On one end, disciplines or subdisciplines will be “joined in research centers, journals and funding programs but […] remain intellectually independent and continue to develop individually” (Weingart 2010:13), thus enlarging the group of people scientists work or communicate with. On the other end of the spectrum, interdisciplinarity could also become a discursive instrument producing legitimization, rather than a different strategy for production of knowledge. This kind of interdisciplinarity as merely a rhetorical construct could lead to scientists responding with either an opportunistic acceptance focused on financing options or with resentment towards political steering of science.

According to Klein (1996), understandings of interdisciplinarity tend towards instrumentalism or epistemology, where “[s]olving social and technological problems and borrowing tools and methods exemplify instrumentalism. The search for unified knowledge and critique exemplify the other end of the spectrum” (Klein 1996:10-11). While instrumentalism fits well with Weingart’s take on interdisciplinarity, the other side of Klein’s spectrum highlights a different possible take on interdisciplinary efforts: scientists’ curiosity and search for answers. This view of interdisciplinarity is connected to seeing scientists as boundary crossers (Klein 1996) – traders who work out a pidgin language in order to communicate (Galison 1996), or construction workers building bridges or restructuring (Klein 1996:10-11). Bridge building is described as something happening between established disciplines, often with an applied orientation, while restructuring involves changing parts of disciplines. While this take provides us with a possible different driver towards interdisciplinarity, it remains true that “disciplinarity is the precondition for interdisciplinarity” (Frodeman, 2010:xxxvi).

However, within the idea of interdisciplinarity “there is also a great pull to imagine that disciplinary boundaries can be transcended altogether” (Strathern 2006:196). This transcendence is highlighted by the transdisciplinarity perspective. Here, “[t]he old paradigm of scientific discovery (‘Mode 1’) – characterized by the hegemony of theoretical or, at any rate, experimental science; by an internally-driven taxonomy of disciplines; and by the autonomy of scientists and their host institutions, the universities,” (Nowotny et al. 2003:179) is being superseded by a new paradigm of knowledge production (Mode 2), which, contrary to the old paradigm is “socially distributed, application-oriented, trans-disciplinary, and subject to multiple accountabilities” (Nowotny et al., 2003:179). The new kind of knowledge production happens within a context of application, as opposed to generation within the borders of the university. This leads to a “much greater diversity of sites at which knowledge is produced, and in the types of knowledge produced” (ibid). Other characteristics of Mode 2 production of knowledge are reflexivity, novel forms of quality control involving more than the traditional focus on scientific peers, and perhaps most importantly transdisciplinarity – “by which is meant the mobilization of a range of theoretical perspectives and practical methodologies to solve problems” (Nowotny et al. 2003:186-187). Transdisciplinarity puts scientists in a position where they, rather than being privileged gatekeepers of knowledge, are in a continuous dialogue with non-academian actors about both the questions asked and how the answers should be understood. The organization of knowledge production around problems, rather than institutions or disciplines, implies that the latter may become less important to scientists when it comes to practices as well as professional identities.

As we can see, at least four distinct meanings of interdisciplinarity emerge from the literature: interdisciplinarity as a temporary step in the formation of a new discipline; interdisciplinarity as legitimization, a rhetorical exercise; interdisciplinarity as a curiosity-driven movement across disciplinary borders; or interdisciplinarity as a Mode 2, problem solving in context, being shaped by the expectations from and dialogue with society at large rather than from within the sciences. From this, we can consider the following four hypotheses about hydrogen science, with their respective implications for the meaning of hydrogen science to hydrogen scientists:

1) Hydrogen science is a new discipline or discipline in the making, being temporarily interdisciplinary but headed towards single-discipline science. Indications of this would be the degree of institutionalization – separate conferences, education programs, hydrogen science journals, and people identifying themselves primarily as hydrogen scientists.

2) Hydrogen science is mainly a rhetorical construct, an effort of legitimizing science and gaining funding, a kind of science policy discourse. We should see scientists responding with either an opportunistic acceptance focused on financing options or a resentment towards political steering of science.

3) Hydrogen science is an exploration mainly driven by scientific curiosity, involving boundary crossing. If this characteristic is true, scientists would express a strong interest in cooperating with scientists from other disciplines.

4) Hydrogen science is transdisciplinary, engaging with problem-solving in context, defined by citizens, industry, or society at large. If this characteristic is correct, the research objectives should be spoken of in terms of practical challenges to be overcome in collaboration with non-academic actors.

These hypotheses are not exhaustive – it may be that none of them are good characterizations of hydrogen science. Nevertheless, they offer a starting point for exploring what kind of scientific effort hydrogen science is, and thus what it means for the scientists involved to be doing hydrogen science.

Studying hydrogen scientists

The label “hydrogen scientist” was not clearly defined among the actors. As I use the term, a hydrogen scientist is not only doing research on themes relevant to hydrogen as an energy carrier, but also links her research to hydrogen, for example by attending hydrogen conferences, by applying for support from hydrogen funding sources, or by presenting her work towards the public under a hydrogen heading through speaking on hydrogen in the media or on a research group website. Following this definition, a scientist could be a hydrogen scientist and for example a battery scientist at the same time.

This paper is based on several sources of data. First, I have analyzed a number of websites to gather information about hydrogen research in Norway. Particularly important is hydrogenplattformen.no, which is run by the Research Council of Norway listing ongoing hydrogen projects. The report *Who's Who in Hydrogen Norway* (Sanne 2006) also helped to identify active research groups. The websites of these research groups have been analyzed to provide an understanding of who works together, and to assess the relative importance of hydrogen energy research to the group. www.cristin.no, a national Norwegian database for science publications, was used to gauge the focus on hydrogen energy as a theme and publications in specific hydrogen journals amongst the interviewed scientists.

A second source of data has been conferences and seminars. I have attended 12 conferences and seminars, some with hydrogen included as one of several topics and some being purely hydrogen conferences. As well as attending presentations, excursions and social events in connection with the conferences, I have also used the conference programs to gain insight in what themes Norwegian hydrogen scientists focus on.

The third source of data is interviews with scientists. The interviewees were selected based on observations at the conferences and from suggestions made by other interviewees (snowballing). The initial two interviews were with scientists who were also in some way involved with organizing hydrogen science or giving hydrogen energy advice to the authorities, and their suggestions provided a valuable starting point. 18 interviews were conducted with scientists representing five different universities and research institutions. An additional 14 interviews were done with representatives for funding agencies, industry, authorities, and NGOs, which provided background information.

The analysis was inspired by a grounded theory approach (Charmaz 2006; Corbin and Strauss 2008). Based on the data, I identified six main hydrogen research groups in Norway, and in the following I will refer to these as Group 1-6. The groups varied somewhat in size, from about 5 to 50 research scientists including Ph.D. students.

Neither the group with 5 nor the group with 50 was working exclusively with hydrogen energy. In the words of Professor B[6] of Group 1: "It would not be right to say that hydrogen is a core business, other things are our core business. Hydrogen could more accurately be characterized as a side activity." When asked about the size of Norwegian hydrogen science, an advisor to the Research Council of Norway stated, "I'd estimate that there are somewhere between 50-100 full-time equivalent [hydrogen scientists] within academia. There are not too many communities."[7] Three groups were located at universities, two at applied research institutes, while one group was an institutional collaboration. (I have chosen to treat these scientists as one group due to an extensive cooperation, with one professor being a part-time employee at the research institute as well as being one of the leaders of the university group. They could also be seen as two groups cooperating closely.)

After having sorted the interviewed scientists in accordance with the found research groups, the interviews were read closely to indentify what parts related to (disciplinary) identity, cooperations with other scientists, funding applications, career plans, motivations to do scientific work, and hydrogen. I identified different narratives the scientists offered when accounting for their engagement with hydrogen science. Narratives of meaning, relevance, and community were identified and used in coding of the data.

Towards a new discipline?

Is hydrogen science merely temporarily interdisciplinary, in the process of becoming a new discipline? Do the involved scientists see themselves primarily as hydrogen scientists, and are the research groups mainly organized around hydrogen? When asked to describe their professional background, the scientists mainly referred to

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[6] Interviewed 080405, my translation

[7] Research advisor A, interviewed 080303, my translation

having a background in chemistry or physics (the main exception being a few who worked with explosions, safety, and computer simulation). Typical answers were “My education is from […] NTNU, physics. So I am a physicist”[8] or “I’m a civil engineer in physical chemistry from NTH [now NTNU], then I did my PhD, and that was also physical chemistry, but specializing on polymer fuel cells.”[9] The same could be seen when examining the groups as a whole. Groups 2, 4, 5, and 6 were dominated by chemists (mainly electrochemistry, materials and chemical engineering). The scientists in Group 3 had a mix of modeling and engineering backgrounds, and Group 1 consisted of physicists and chemists in a disciplinary mix. This mix was however not attributed to hydrogen science but rather to the well-established speciality of materials science: “[by the time their center was established] it was a little physics and a little chemistry. It was the first small attempt to try to be a little together, chemists and physicists, because you see, that is not so easy. But after a while it turned out… I mean, materials science was already then starting to… it was plain to see that it would be and was already a large field”[10] (see Klein 1996:6 for a discussion on the many interdisciplinary meetings happening on the border between chemistry and physics).

While this look at the groups clearly shows that hydrogen science is performed by scientists with different disciplinary backgrounds, neither the groups nor the self-descriptions of the scientists give the impression that hydrogen science is a discipline in the making. Are there any other indicators that suggest this may nevertheless be the case? Using Group 1 to take a closer look at the scientists’ publications, I found that hydrogen was an important part of many publications as a theme, but that the publications were most of the time in journals relevant to another specialization than

[8] Research Scientist C, interviewed 080519, my translation

[9] Research Scientist D, interviewed 080519, my translation

[10] Professor E, interviewed 080505, my translation

hydrogen (like materials science or electrochemistry). Of the 50 most recent published articles by the three most senior interviewed Group 1 scientists, only one was published in a hydrogen-specific journal.[11] There are conferences focused on hydrogen, like the (bi) annual Norwegian/Nordic hydrogen and fuel cell conference,[12] but still the combination of publications and conferences does not leave the impression of scientists primarily involved in a dialogue with other hydrogen scientists. Finally, while recent years have seen the establishment of educational programs related to materials science in Norway,[13] no hydrogen specific program/degree exists. All in all, the first hypothesis does not seem to be a satisfactory description of hydrogen science – hydrogen science is not on its way to becoming a discipline.

Rhetorics without substance?

With the conclusion made that hydrogen science is not a case of disciplinary formation, the second hypothesis offers a different angle: does hydrogen science affect the actual work of the involved scientists? Is it influencing what scientists do to an observable extent, or is it mainly a legitimizing rhetoric? Do we see scientists reacting with distaste to attempted political steering, or perhaps a cynical acceptance of the offered funding opportunities?

Achieving funding is part of what scientists do, and this usually involves making an argument in favor of the research you want to do: "You present solutions to the

[11] The 50 latest publications of each scientist as listed in www.cristin.no , a national Norwegian database for science publications, August 19th 2011. The journal in question is The International Journal for Hydrogen Energy, http://www.sciencedirect.com/science/journal/03603199

[12] See http://www.malmokongressbyra.se/hydrogen_and_fuel_cells_conference for information on the latest of these conferences, held in October 2011. Site accessed 20120124

[13] http://www.uio.no/studier/program/mena/index.xml is one such program. Site accessed 20120124

problems and let's say you present the solution of hydrogen. And you have to hype it. I mean you're not going to get funding unless it's an area that's topically popular."[14] Moreover, "hydrogen science" provides a common label to a diverse set of research efforts. It clearly plays a rhetorical role.

However, in several ways, hydrogen science is also substantial. First of all, doing hydrogen science changes what the scientists are topically engaged with. The extent of this change is easier to see in some cases than others – generally, the more applied the research, the fewer other possible uses could be imagined for the same research, as can be exemplified by a project that aimed to "provide decision support for introduction of Hydrogen as energy carrier in the Norwegian energy system."[15] Even if some of the modeling work done in the project has relevance for energy planning in general, it seems unlikely that the same work would have been done if hydrogen did not receive interest from funders and scientists did not engage with hydrogen. Thus, in this case hydrogen science changed the work of the scientists by introducing new research questions.

In other cases, the effect of hydrogen science was an accentuation of existing interests. Professor B described it this way when listing the different ways in which Group 1 engaged with hydrogen energy: "All these [hydrogen projects] […] originate from long-time work of ours. They are not areas we have entered due to hydrogen currently being popular. But, when hydrogen now has become popular, that has made it easier to get financing for projects we would have been interested in doing regardless."[16] Again we see that hydrogen science changes what researchers do, not

[14] Researcher M, interviewed 091209

[15] http://www.ntnu.no/ept/norways Acessed 110818

[16] Professor B, interviewed 080405, my translation

by steering them towards something they are uninterested in, but by changing which of their interests they currently pursue.

A third way in which hydrogen science influenced the work and practices of scientists was by affecting the ways in which they cooperated with others. Hydrogen was used to argue that there was a meaningful connection between different bodies of work and actors, and to suggest that further cooperation between groups would be beneficial. The aforementioned hydrogen conferences are one example of this. Another is found among the materials scientists of Group 1, where hydrogen as a research theme provided additional arguments for their combination of physics and chemistry: “We are fighting to make the chemists’ ionconductors, electrolytes, and electrochemistry speak with the physicists’ PV cells [these PV cells are to be used to decompose H_2O for hydrogen production]. […] It is an enjoyable challenge, to get the physicists and chemists to communicate and work together on this problem.”[17]

Hydrogen serving as a bridge between applied and basic research was seen in the case of one research institute, where one group did basic physics research and another more applied group worked on energy issues. In the words of the leader of the basic research group, his motivation was connected to increasing basic understanding of materials and their properties: “We were of the opinion that there still was a lot one could understand. And that can – that is something I often come back to, I always say that… if you understand something, then you can also manage to find something new.”[18] According to a leader in the applied group, hydrogen became a way in which the basic research group could be enlisted in working with something the applied group saw as practical and useful: “So hydrogen came here kind of through the back door, because the physics section doesn’t want to work practically, they want to be able to work theoretically and experimentally with small

[17] Professor E, interviewed 080505, my translation

[18] Research Scientist C, interviewed 080519, my translation

samples."[19] While there was a clear tension between the two approaches to research, hydrogen provided a way in which they could benefit from and appreciate each other's work.

Meaningful rhetorics

Hydrogen science is clearly not merely rhetoric. As we have seen, engaging with hydrogen science can affect research question, research agendas and priorities, and strengthen collaborations. However, the second hypothesis also invites questions on whether the scientists experience hydrogen science as (unwelcome) political steering. None of the interviewed scientists expressed such sentiments. However, the scientists were not blind to the political implications of their work. On the contrary, such implications turned out to be a reason why working with science was not only interesting, but also important.

For some of the interviewed, hydrogen energy was connected to a larger picture of moving away from fossile fuels and the way they shape society: "I think petroleum was always going to the government, at least in my country. And then it was a kind of barrier to let people have their own rights. […] So it's not only about energy, it's about wealth and all the abilities that petroleum and fossil fuels can make for these kinds of governments. So in my mind it was always like: Let's get rid of petroleum somehow. And then when I went through some articles and found this fuel cell in my bachelor, so I was thinking that: Ok, this is something really different."[20] In this case, hydrogen and fuel cell technology offered both meaning and direction, leading to a substantially different choice of education and career.

For another scientist, choosing to work on hydrogen provided a way to help address global warming, and thus doing something that had a positive impact in the world:

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[19] Research leader I, interviewed 080526, my translation

[20] PhD student F, interviewed 091217

“it’s kind of maybe a little bit childish but you know from the age I was – I don’t know – ten, I always wanted to do something like important, you know. Something which makes something good. […] I kind of believe that we are responsible for this global warming which happens. Not many people… well, I think like a lot of people don’t believe that, at least I know a lot of people. But I believe that and hope I can contribute to like a small extent, at least. So that’s nice about this job.”[21]

However, for some hydrogen affected the meaningfulness of their work not due to choosing it as a career or changes in their research, but due to changes in the applications that could be imagined for it. Thus, hydrogen science could imbue the same practice with a different set of meanings: “In a way we’ve always worked with hydrogen, for the last 25 years I’ve been involved in some kind of technical role connected to use and production of hydrogen, and to hydrogen technology. But then, about 15 years ago, the hydrogen society started to become an issue. […] My field is petrochemistry and refining. That’s where I come from and it is about fossile raw materials, but hydrogen is very important for this field. So hydrogen production, the fundamental technical stuff, it does not care if this is connected to an old-fashioned or a modern industry. It is pretty similar. So our gateway to this is from the fossile side, but the end use is now completely different. The motivation now is another than what it was originally.”[22]

Rather than connecting hydrogen science to some sort of unwelcome politicization of science, the scientists seemed to start from an assumption of science as useful, and when this usefulness could be harnessed for what was perceived as a good cause, being a scientist was more meaningful. The scientists might emphasize their practical and factual approach, but simultaneously approached meaning as a basic human need: “So you know, I’m kind of a simple engineer, so I have some difficulties when it

[21] Postdoc H, interviewed 091217

[22] Professor G, interviewed 080604, my translation

comes to having these grand visions about what the hydrogen society is, and such stuff… But I also need to have a meaning with what I do, and in a way that is that we will have energy for a long time yet to come, and then hydrogen is one of the important solutions, maybe."[23]

Curiosity-driven exploration?

We have seen that hydrogen science plays both a substantial and a rhetorical role for the hydrogen scientists. The way in which hydrogen science can serve as a bridge between applied and basic research, and as a validation of the need for materials science as a collaborative effort between physicists and chemists, actualize the postulate of the third hypothesis; that hydrogen science is an exploration mainly driven by scientific curiosity, involving boundary crossing, and that the scientists thus will emphasize an interest in cooperation with scientists from other disciplines.

One of the interviewed scientists related a story of working together with social scientists to better evaluate hydrogen demonstration projects: "I have tried to work with social scientists, amongst others. […] In 1999-2000 we saw a need to have a look at demonstration projects. We wanted to learn from the experiences of such projects worldwide to define success criteria, and identify pitfalls. This became a project we did in collaboration with social scientists."[24] Thus, we do find the kind of border crossings proposed by the third hypothesis amongst the Norwegian hydrogen scientists. However, this was the only case in which hydrogen was so explicitly connected to the need to cross such borders.

As mentioned above, the materials scientists work together with a background in physics or chemistry, and belong to both a university and a research institute. They explicitly stated in interviews that they wished to cooperate to do work that was

[23] Senior researcher L, interviewed 070815, my translation

[24] Research scientist Q, interviewed 070816, my translation

relevant and complementary: “It is also rather important, we feel, that one doesn’t have to compete, but try to grow strong by having complementary specialities. […] So in this area we are in a close and good partnership and [research institute] are internationally recognized within this field and also in a strong partnership with [university].”[25] The earlier quote from professor E about the desire to get the physicists’ and chemists’ work to talk to each other also points to a desire to work together regardless of background. But are these scientists drawn together by a desire to understand basic properties of materials, by a desire to understand basic properties of hydrogen energy, or by a desire to solve the (applied) problem of hydrogen? It is unclear if hydrogen plays a decisive role for their border crossings.

What if we look at curiosity as a potential deciding factor for the scientists’ actions? Some of the interviewed scientists pointed to curiosity as important for their work, like when Research scientist C explained the background for his group’s work by saying that “We were of the opinion that there still was a lot one could understand.”[26] PhD student N explained his desire to do a PhD within hydrogen energy as a matter of wanting a stimulating job: “To me, research and development is what is exciting. […] So, I want to work with research and then I need training as a scientist.”[27]

Did hydrogen play an important role in regards to this expressed curiosity? Some of the interviewees connected their feeling of being intrigued to specific, hydrogen-relevant technologies like fuel cells. Finding something exciting or interesting could also be a reason to work with a specific technology. One scientist remembered that “I

[25] Professor B, interviewed 080405

[26] Research Scientist C, interviewed 080519, my translation

[27] PhD student N, interviewed 091217

actually started to be interested in fuel cells as early as high school,"[28] while another compared his fascination to reading, expressing a need to fully understand: "I like fuel cell. Is like when… like a book. When you start the first page you need to read at the end. You need to read a book from the beginning to the end. […] This is my good book. And I starting, ok I need to follow it till the end. When I finished the last page, then another book."[29]

Still, it was a lot more common for the interviewees to connect hydrogen energy to questions of personal meaning and to the research being useful for something (and implicitly, relevant for someone), than to describe hydrogen energy in terms of scientific curiosity and something that required specific collaborations. Should we from this conclude that the third hypothesis does not fit as a description of hydrogen science? A possible alternative to this conclusion is proposed by Crease, who argues that it is less a question of the degree of border crossing and more a question of (a lack of) need for extensive reflection: "What's distinctive about interdisciplinary research in the sciences, I said above, is that they do it more and theorize about it less. Scientists are accustomed to redrawing their disciplines, and live and work with their boundaries under reconstruction. The practical, goal-oriented focus of the researchers allows them to bypass the need for reflection and intersubjective inquiry. Moreover, theorizing about scientific practice is the task of other kinds of scholars" (Crease 2010:92). In the end, what can be said about the third hypothesis is that the material does not lend itself to a very strong argument in support of it as the major explanation of hydrogen science – regardless of if this is due to (scientific) border crossings and (scientific) curiosity not being major motivations for hydrogen science, or if it is just a matter of these being taken for granted by the scientists in question.

[28] PhD student O, interviewed 091217

[29] Postdoc P, interviewed 091217

Problem-solving in context?

As we saw when looking at the second hypothesis, hydrogen science is meaningful to the contributing scientists because it connects their research to a proposed solution for a set of important problems. Thus, while our exploration of the third hypothesis gave a few examples of scientists finding a motivation in scientific curiosity, hydrogen science seems to mainly connect motivation – which could have been perceived as an inner, personal drive – to a more externally oriented idea of being useful and moving the world in the right direction. This focus outward from academia actualizes the fourth hypothesis: Is hydrogen science transdisciplinary science?

Transdisciplinary science engages with problem-solving in context, building on the realization that "science needs to enter into a new relationship with society, and its openness to social issues and to demands for public accountability include the ability to break down disciplinary barriers. Interdisciplinarity here becomes a marker of communicational success" (Strathern 2007:125). Connecting transdisciplinarity to communication is one way of accentuating its relational aspect. Transdisciplinary science is inherently relevant to someone besides the involved scientists. Looking for transdisciplinarity in the practices of hydrogen scientists involves looking for claims of (societal) relevance and meeting places, as well as looking for scientific efforts that address practical challenges to be overcome in collaboration with someone outside of academia.

The aforementioned (bi)annual Norwegian/Nordic hydrogen and fuel cell conferences invite participants to "meet with researchers, industrial actors and decision makers working within this field."[30] Thus, the most important (physical) meeting place for hydrogen science is a meeting place where non-scientists are welcome. Furthermore, several of the research groups connect descriptions of their work to challenges society needs to overcome. One university-based group writes, "The research

[30] http://www.malmokongressbyra.se/hydrogen_and_fuel_cells_conference. Site accessed 20120124

activities in the group include photo-electrochemical research, fuel cells, and water electrolysis. These research areas are related to the needs for a sustainable energy system based on renewable energy."[31] Another university-based group explains the importance of their work by stating [in a presentation tailored towards students], "Catalysts are the key to energy efficient and environmentally friendly chemical processes. The activity focuses towards catalytic processes in chemistry and petrol chemistry industry, at gas conversion, oil refining and in connection with energy and enviornmental technology." [32] A group based at a research institute writes that "In view of the global challenges related to green house gas (GHG) emissions and energy supply, electrochemical energy conversion technologies, such as capacitors, fuel cells and batteries are becoming increasingly important in the energy system."[33]

There are several similarities between the challenges pointed out by the scientists and challenges identified by public authorities. One example of this can be found if examining how the Research Council of Norway (RCN) describes its reasons to fund hydrogen research. In a recent report on their funding of research related to energy and environment, RCN describes greenhouse gases and other pollution as important drawbacks to the current transportation system, giving this as reasons why they have spent substantial funds on research and development related to hydrogen storage and to fuel cells (Coldevin 2011:11). Thus, there are external actors proposing hydrogen as a research theme and possible solution (and the RCN does so with backing from the Government).

However, there are a few counter-arguments to seeing the dialogue between RCN and hydrogen scientists as transdisciplinary. Firstly, scientists being in a dialogue

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[31] Website of group 4, acessed at 110715

[32] Website of group 5, acessed at 110715

[33] Website of group 6, acessed at 110818

about scientific goals with the Government and with funding agencies can hardly be said to represent a science "subject to multiple accountabilities" (Nowotny et al. 2003:179). Secondly, the RCN clearly states that their strategy is to contribute with pieces needed to solve the hydrogen puzzle, but that it is not possible for Norway to do all the needed research, and that international cooperation is thus needed (Coldevin 2011:12). This resembles a classic analytical approach to problem-solving (dividing a problem into smaller, more manageable problems to enable a solution), and raises the question of whether an ambition to assemble the proposed solution is required for something to qualify as problem-solving in context. The scientists are not in a position to do this (and nor should they be, if they are no longer in a privileged position in regards to knowledge) – but nevertheless, some assembly is required. This is not something the scientists deny: "…it is very dependent on political incentives. […] business as usual will not give us an environmentally friendly energy system, an environmentally friendly future. Even the European Parliament states that openly. Political steering is needed here."[34] Thus, implicit in the proposition that transdisciplinary science addresses problems that cannot be solved by scientists alone, is the realization that it may not be up to the hydrogen scientists if their work is transdisciplinary or not.

A possible stricter definition of transdicisplinary problem-solving in a context of application would be to require that the proposer of the problem to be solved is a (non-academic) actor that wants to build something concrete, in which case the problem would be related to making this something come into being. There were examples of this kind of problem-solving amongst the interviewees. One described a project where they were "making hydrogen from their biogass from the landfill."[35] The same project is described in further detail in Kårstein (2008:155), where a

[34] Research scientist Q, interviewed 070816

[35] Research leader S, interviewed 080118

funding application related to this project is quoted. It describes how preliminary results are made a basis for further development of "a reactor on 30 kW for continuous production of hydrogen at [industry partner]." Some of the research done within Norwegian hydrogen science fits this understanding of transdisciplinarity. However, it is questionable if this is a satisfactory conceptualization of transdiciplinarity, considering that transdisciplinarity supposedly represents a new paradigm of knowledge production (Nowotny et al. 2003:179) – it is something more than applied research.

Is hydrogen science transdisciplinary science? Perhaps more interesting than giving a simple yes or no answer to this question, is what the comparison with transdisciplinarity highlights when it comes to hydrogen science. Societal relevance through addressing issues of environment and energy is one clear common thread amongst the hydrogen scientists. Moreover, the scientists are simultaneously trying to be useful to the solution of these problems and realizing that they cannot solve them alone. Hydrogen becomes a way to bind their research efforts together in a way that makes a dialogue with the other needed participants possible. Thus, starting from Strathern's remark of transdisciplinarity as a marker of communicational success (Strathern 2007:125), we see that hydrogen science can be understood as a platform for communication.

Precarious meaning

What kind of science is hydrogen science? Departing from the idea that it could be interdisciplinary, we started out with four hypotheses on what kind of interdisciplinary science hydrogen science was: a discipline (in the making), a legitimizing rhetorical construct, a kind of curiosity-driven border crossing, or transdisciplinary science focused on problem-solving in context. We have seen that hydrogen science has an observable effect on research agendas and scientist's self-understanding, and that it is closely connected to achieving societal relevance. At the same time, we did not find any strong indicators of hydrogen science being on its way to becoming a discipline, and there were differences in the backgrounds of the involved scientists. Thus, if we apply the term interdisciplinarity to all scientific efforts that go beyond the disciplines, it fits hydrogen science. However, the empirical data did not lend itself to unconditional support of any of the hypotheses as complete descriptions of hydrogen science. It is tempting to join Strathern (2006:196) in referring to interdisciplinarity "in the abstract because its most powerful grip lies in the very idea of it."

What does it mean for scientists to be connected to the interdisciplinary field of hydrogen science? By looking at the possibility of hydrogen science as mainly a rhetorical construct, we discovered that for the scientists, working with hydrogen science was meaningful because it enabled them to help address important challenges for future energy needs and for the environment. It could thus be said that hydrogen science is held together by an agreement that working with it is the right thing to do. At the same time, it was made possible by financing, in a way that calls to mind what was pointed out by Weingart: "'externally' defined subject matters, research problems, and values or interests can trigger sustained research" (Weingart 2010:12). Thus, hydrogen science seems to be held together through the combined efforts of funders and scientists.

However, financing is not the only way in which hydrogen science is dependent on non-scientists. Through the concept of hydrogen, the relevance of their research can be communicated, both to other scientists and to non-academic actors. Comparing hydrogen science with transdisciplinarity highlighted what it may entail for scientists to engage with problems that they cannot solve without the participation of others: While the upside of being relevant is that someone is interested in what you are doing, the downside is that you are dependent on them. Transdisciplinarity implies that scientists are simultaneously asked to allow problems not defined by academia to be the ordering principle for their work, and to accept that the actual solution of the problem may not be in their hands. This may in turn both allow scientist an increased sense of meaning through relevance, and at the same time contain the threat that this sense of meaning can be undermined: while you can come to the agora wishing for a problem-solving collaboration, you cannot force the attendance of others.

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References

Bakker, Sjoerd. 2010. "Hydrogen patent portfolios in the automotive industry – The search for promising storage methods." *International Journal of Hydrogen Energy* 35 (13) (July): 6784-6793.

Charmaz, Kathy. 2006. *Constructing Grounded Theory. A Practical Guide Through Qualitative Analysis*. Los Angeles: Sage Publications.

Coldevin, Grete Håkonsen, ed. 2011. *Lange spor Energi*. Oslo: Forskningsrådet.

Corbin, Juliet M, and Anselm L Strauss. 2008. *Basics of qualitative research: techniques and procedures for developing grounded theory*. Thousand Oaks, Calif.: Sage Publications, Inc.

Crease, Robert P. 2010. Physical sciences. In *The Oxford Handbook of Interdisciplinarity*, ed. Robert Frodeman, Julie Thompson Klein, Carl Mitcham, and J. Britt Holbrook. Oxford: Oxford University Press.

Eames, Malcolm, William Mcdowall, Mike Hodson, and Simon Marvin. 2006. "Negotiating contested visions and place-specific expectations of the hydrogen economy." *Technology Analysis & Strategic Management* 18 (3-4) (July): 361-374.

Galison, Peter. 1996. Computer simulation and the trading zone. In *The disunity of science: Boundaries, contexts, and power*, ed. Peter Galison and David Stump. Stanford: Stanford University Press.

Klein, Julie Thompson. 1996. *Crossing Boundaries: Knowledge, Disciplinarities, and Interdisciplinarities*. Charlottesville: University Press of Virginia.

———. 2010. A taxonomy of interdisciplinarity. In *The Oxford Handbook of Interdisciplinarity*, ed. Robert Frodeman, Julie Thompson Klein, Carl Mitcham, and J. Britt Holbrook. Vol. 2. Oxford: Oxford University Press.

Kårstein, Asbjørn. 2008. HyNor – den norske hydrogenveien? En studie av en stor tekno-politisk hybrid. PhD diss., Norwegian University of Science and Technology (NTNU).

Moran, Joe. 2010. *Interdisciplinarity*. 2nd ed. New York: Routledge.

Nejat Veziroglu, T. 2000. "Quarter century of hydrogen movement 1974–2000." *International Journal of Hydrogen Energy* 25 (12) (December): 1143-1150.

Nowotny, Helga, Peter Scott, and Michael Gibbons. 2001. *Re-Thinking Science*. Cambridge: Polity Press.

———. 2003. "Mode 2 Revisited: The New Production of Knowledge." *Minerva* 41 (3): 179-194.

Sanne, Dag. 2006. *Hydrogen and Fuel Cells in Norway – Who's who?* Oslo: BBU.

Sarewitz, Daniel. 2010. Against holism. In *The Oxford Handbook of Interdisciplinarity*, ed. Robert Frodeman, Julie Thompson Klein, Carl Mitcham, and J. Britt Holbrook. Oxford: Oxford University Press.

Strathern, Marilyn. 2006. "A community of critics? Thoughts on new knowledge." *Journal of the Royal Anthropological Institute* 12 (1): 191-209.

———. 2007. “Interdisciplinarity: some models from the human sciences.” *Interdisciplinary Science Reviews* 32 (2) (June 1): 123-134.

Weingart, Peter. 2000. Interdisciplinarity: The Paradoxical Discourse. In *Practising interdisciplinarity*, ed. Peter Weingart and Nico Stehr, 25-43. Toronto: University of Toronto Press, Toronto; Buffalo; London.

———. 2010. A short history of knowledge formations. In *The Oxford Handbook of Interdisciplinarity*, ed. Robert Frodeman, Julie Thompson Klein, Carl Mitcham, and J. Britt Holbrook. Oxford: Oxford University Press.

Chapter Three: The Rise and Fall of 'Hydrogen Society': Scientific advice and policy learning

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Knut H. Sørensen

Abstract

This paper shows how 'hydrogen society' made its way into Norwegian energy policy discourses, and how it came to lose prominence in the first decade of the 21st century. Using a combination of a document study and interviews, we analyse the role of scientific advice in this process. We find clear examples of scientific advice in the form of providing descriptions of hydrogen's potential as an energy carrier and existing challenges with respect to developing appropriate hydrogen technologies. However, we also find indications that scientists exceeded the simple role of advisor. Rather than acting according to the linearity-autonomy model, the practice seems to have been much closer to what Sheila Jasanoff (2011) calls virtuous reason; i.e., that hydrogen scientists participated in the making of broader energy policy proposals. At the same time, some of the scientists also acted in a manner closer to translation theory, invoking 'hydrogen society' as a scenario to successfully elicit political support of increasing the funding for hydrogen science.

The brief summer of hydrogen

During the first years of the new millennium, the concept of 'hydrogen society' (or 'hydrogen economy') gained some prominence in scientific as well as public debates. While the idea that hydrogen might be used as a clean energy carrier and with considerable social impact was not new (see, e.g., Bockris 2002), rather suddenly it was placed on the agenda of sustainable energy policy. Most authors linked the use of hydrogen to the emergence of fuel cell technology with a wide range of potential applications (e.g., Johnston et al. 2005, McDowall and Eames 2006). Thus, hydrogen emerged as a non-polluting energy carrier but also a potential solution to the problem of storing energy from new sustainable sources. For a while ‘hydrogen society’ became a policy buzz-word. In Rifkin’s (2002) version, it even became a broad social vision on par with ‘knowledge society’ and similar concepts of social changes (see also Sovacool and Brossmann 2010).

In this paper, we study how hydrogen and ‘hydrogen society’ became part of the wider energy policy discourse, with an emphasis on the role of scientific advice. How were hydrogen and the idea of ‘hydrogen society’ articulated and received? Our analysis is focused on energy policy debates in Norway. Given Norway’s role as a leading exporter of oil and gas as well as a country where nearly all electricity come from sustainable hydro-electric sources, it may seem a particular case. However, with its abundant supply of natural gas that could be reformed into hydrogen, Norway could arguably have pursued a strategy of becoming a hydrogen society as much as Iceland (Park 2011).

Sovacool and Brossman (2010) who have analysed hydrogen discourses more broadly, identify many arguments in support of hydrogen, including sustainability, social progress and decentralised production of energy. A main hope was that hydrogen could be used to store and transport renewable energy. In the Norwegian context, the concept of ‘hydrogen society’ was never developed other than as a loose vision of a future sustainable way of life that was supposed to make substantive use of hydrogen as an energy carrier. Hydrogen society stakeholders were a varied group of actors – scientists, industrialists, environmentalists and politicians. How did these groups of actors interact in the making of hydrogen society discourses as part of Norwegian energy policy? In particular, how important were scientists in establishing ‘hydrogen society’ as a vision of the future to energy policy-makers?

We use three sets of approaches in the analysis. First, studies exploring the various roles of scientific expertise in providing advice to or otherwise interacting with policy-makers (e.g., Jasanoff 1990, Pielke 2007, Bijker et al. 2009, Lentsch and Weingart 2011, Latour 1987). From this perspective, we ask if the hydrogen society entered into energy policy discourses due to scientists engaged in hydrogen research, offering their expertise to and/or persuading policy-makers to prioritise hydrogen-related science. Second, we use what has been called the sociology of expectations (Borup et al. 2006) to analyse the role of 'hydrogen society' in energy policy. Did the concept work to coordinate energy policy efforts through the establishment of expectations with respect to hydrogen as an energy carrier or did it remain a less clearly articulated vision? Third, we engage with Ulrich Beck's (2006) ideas related to reflexive governance and the concept of policy learning (Bennett and Howitt 1992) to analyse the role of policy-makers. When 'hydrogen society' failed to retain prominence in energy policy discourses, was that caused by experience and learning among policy-makers, discovering weaknesses in the concept? Or did 'hydrogen society' fall prey to energy policy controversies?

Policy from science

Callon et al. (1986) argue with Alain Touraine that increasingly, science has gained influence as a critical resource to modern society. Increasingly, they claim, science is made use of to discuss and decide social and political issues. In turn, this raise questions about how science has achieved such a position and what institutions and activities that are involved. For example, to what extent is this situation a product of scientists' to promote science and make scientific results available? More specifically, how do scientists interact with policy-makers?

Several studies focus on the potential role of scientists as providing advice to policy-makers and the institutions set up to facilitate such advice and provide quality assurance (e.g., Jasanoff 1990, Pielke 2007, Bijker et al. 2009, Owens 2010, Lentsch and Weingart 2011). This research suggests considerable diversity with respect to the format of the advice, the way scientists relates to policy-makers, and the institutions providing scientific advice. In some contexts, much effort is made to secure that the best available facts are made accessible to policy-making (e.g., Bijker et al. 2009).

In fact, there are several critical issues to explore. First, Owens (2011:73) claims that "We do not have a well-developed theory of policy advice", indicating that the practice of providing advice is in need of further exploration. Second, there has been (and still is) a widespread belief in what Jasanoff (2011) terms the linearity-autonomy model of scientific advice, where the ideal is scientists 'speaking truth to power'. This model assumes that knowledge may be linearly moved from autonomous (read: disinterested) scientists into policy, making a distinction between science and policy that may be difficult to uphold. Jasanoff proposes as an alternative what she calls the model of virtuous reason, where science and politics are integrated to advance public ends in the best way. But what is involved in such integration, and what does it mean for the status of scientific expertise? Third, and related; a basic tenet of science and technology studies is that the boundaries between science and society increasingly have become blurred (Irwin 2008, Nowotny et al. 2001). On what grounds may then scientific knowledge be framed as policy advice?

The influence of science may follow from other strategies than the giving of advice. A related approach is to focus on the ability of scientists to translate social interests to become aligned with particular scientific results or research programmes (e.g., Callon 1987, Latour 1987). Translation may result in support of fact claims or particular technological designs, but scientists may also aim to achieve economic support for further research by proposing scenarios that describe attractive future developments. When a concept like 'hydrogen society' makes its way into policy, this could be the outcome of scientific advice taking place through institutions established for the purpose of making results from hydrogen science available to energy policy-makers. If so, we would expect the hydrogen society discourse to be focused on facts about hydrogen as an energy carrier. However, 'hydrogen society' could also be seen as a scenario proposed by scientists to get more funding for hydrogen-related research. If 'hydrogen society' made its way into energy policy discourses in this manner, we should anticipate that arguments would be more generic and less concerned with singular facts. 'Hydrogen society' would then be a R&D programme rather than a set of strategies for implementing hydrogen technologies in society.

Scenarios represent expectations in the sense that they articulate promises about what is going to be achieved through future development of, e.g., hydrogen technologies. The attractiveness of scenarios, often achieved through what David Nye (1996) calls the technological sublime, is what motivates actors to engage with R&D, innovations, etc. needed to meet the promises. In this manner, expectations are important to mobilise resources through national policy as well as sectorial initiatives (Borup et al. 2006). Moreover, expectations motivate individual actors as well as providing a basis for coordination of activities. This means that expectations may need to be concretely formulated with respect to patters of development and outcomes that more abstract and general visions. With respect to 'hydrogen society' this raises the potentially important issue of whether the idea, in the context of the Norwegian energy policy arena, was articulated in sufficient detail to work as an expectation in the way Borup et al. use the concept. Lack of such articulation may have made 'hydrogen society' a less influential vision.

Two concerns should be added. First, there may be competing expectations (van Lente and Bakker 2010). Thus, in the analysis of the role of 'hydrogen society' in the energy policy discourses we need to be sensitive to the potential role of other visions that may guide and coordinate energy policy actors. Second, Alkemade and Suurs (2012) claim that expectations for emerging sustainable technologies follow a pattern that indicates hype cycle dynamics. Actually, the number of hits for 'hydrogen society' in Norwegian news media follows a bell curve that rises in 2001, peaks in 2004 and recedes distinctly in 2008.[i] While this supports a claim that 'hydrogen society' only was a hype of limited influence in Norwegian energy policy, we need to look more closely at other actors than news media to draw such a conclusion.

We may understand the rising importance of 'hydrogen society' in Norwegian energy policy discourses as an outcome of scientists advising policy-makers or in other ways working to establish 'hydrogen society' as a realistic scenario or well-articulated expectation about a set of future developments in the energy area. Of course, we could also see the diminishing policy interest in the concept as an outcome of scientists changing their minds, but alternatively, we could ask if this failure of 'hydrogen society' to retain prominence in the energy policy discourses was due to policy-makers experiencing the concept as less appropriate and beneficial?

Latour (2007) usefully reminds us that policy-making definitely is a form of expertise in its own right. Thus, an alternative to see the appearance of 'hydrogen society' in energy policy discourses as an effect of scientists' advice or their efforts to argue the attractiveness of this scenario, is to consider it as an outcome of policy-makers' learning about sustainable energy. Of course, such learning may or may not involve interaction with scientists. With Bennett and Howitt (1992), we could look for traces of 'lessons drawing' in the relevant energy policy discourses, which could be suggestions that 'hydrogen society' was less useful as an energy policy scenario or that the underlying concerns were redefined. On the other hand, drawing on Beck's (2006) concept of reflexive governance, policy-makers may have found 'hydrogen society' to be a scenario too narrowly focused on hydrogen as an energy carrier, when they needed more inclusive, less boundary-drawing visions. Arguably, 'hydrogen society' might have appeared to policy-makers as a modernist construct, insufficiently open to the uncertainties and ambivalence that characterise the risk society of late modernity. If so, such considerations may be observable in policy documents and debates.

In this paper, we analyse how 'hydrogen society' made its way into Norwegian energy policy discourses, and how it came to lose prominence in the first decade of the 21st century. We use this to analyse the relative role of scientific advice, compared to the practice of articulating energy policy, but also to explore hydrogen scientists' interaction with politics in a broader fashion. Were Norwegian hydrogen scientists actively promoting hydrogen and hydrogen-related visions in political arenas, or were they suppliers of advice when asked for by policy-makers?

Method

To pursue the admittedly fairly broad research questions, we have used a comprehensive set of data with two main points. First, the first author has done fieldwork over a period from 2007 to 2009, in order to study the Norwegian hydrogen research community and their science policy and science advice activities. The fieldwork has included running observation of relevant web sites, observation at relevant Norwegian and Nordic conferences, analysis of grant applications from hydrogen scientists, and a number of interviews. Particularly important amongst the websites was hydrogenplattformen.no, which is run by the Research Council of Norway listing ongoing hydrogen projects. *Who's Who in Hydrogen Norway* (Sanne 2006) also helped to identify active research groups. The websites of these research groups were analysed to assess the relative importance of hydrogen energy research to the group. CRIStin, the national Norwegian database for scientific publications, was used to measure the focus on hydrogen energy as a theme and the frequency of publications in specific hydrogen journals amongst the interviewed scientists. Furthermore, 12 conferences and seminars were attended, some with hydrogen included as one of several topics and some with a purely hydrogen focus. Presentations, excursions and social events in connection with the conferences were attended, and the conferences also served as important sites to identify scientists engaging with the politics of hydrogen energy, to be approached for interviews later.

Thus, interviewees were selected based on observations at the conferences but also from suggestions made by other interviewees (snowballing). The initial two interviews were with scientists who were also involved with organizing hydrogen science or giving hydrogen energy advice to the authorities, and their suggestions provided a valuable starting point. 18 interviews were conducted with scientists representing five different universities and research institutions. An additional 14 interviews were done with representatives for funding agencies, industry, government, and NGOs. We believe these interviews provide a representative picture of the Norwegian hydrogen science engagement with policymaking.

The second main point of data consisted of documents concerning hydrogen in policy. The main body of texts analysed in this article was collected using the search function of the website of the Norwegian Parliament (www.stortinget.no) in March 2010. The search term used was hydrogen. Full-text document search was available from the 1998-99 parliamentary sessions and onwards, while shorter reference information was searchable from the 1986-87 sessions and onwards. Through this search function, we access all publications from the Government and the Parliament, including transcripts of all debates from parliament plenaries. Search hits from the reference information were explored with the help of the (non-electronic) parliamentary records and the Government database.

Furthermore, for Official Norwegian Reports 1998:11, 2002:7, and 2004:11, hearing responses were acquired from the Ministry of Oil and Energy, and for Official Norwegian Report 1998:11 the records of the committee that wrote the report were acquired from a committee member.

The findings from the search that referred to hydrogen in a non-energy context were disregarded, and a few documents were added based on references to them within the search results. A chronological document was then compiled containing all findings and documents, with relevant quotes. This document was then used as basis for the analysis. We believe we have made use of all major written documents relevant for the topic of the paper.

The paper quotes mainly from the interviews and from governmental documents. The other data has served as background information, used in the interpretation of interviews and documents. The analysis has been organised in a chronological manner, with an emphasis on the way and the extent to which 'hydrogen' and 'hydrogen society' were used in the articulation of Norwegian energy policy.

The rise of hydrogen in energy policy: Scientists' advice?

Except for one question raised in the Norwegian Parliament in 1988 about the possibilities of government support use of hydrogen as a fuel due to its emission reducing capabilities, hydrogen was uncharted policy territory when people from research and industry in 1996 founded the Norwegian Hydrogen Forum (NHF) to advance hydrogen as an environmentally friendly energy carrier. The Forum aimed to inform about hydrogen in Norway, organize workshops and seminars, publish a newsletter, and encourage hydrogen related science and innovation. Also, NHF wanted to become an active partner for the government and other organizations in the development of a future hydrogen based industry policy.[ii] Did they succeed?

No doubt, the NHF was the first public initiative by Norwegian hydrogen scientists to provide hydrogen society visions and provide policy advice about hydrogen. Hydrogen entered government documents quite late and in a modest way under headings related to research and future technological opportunities. A 1997 white paper on environmental policy noted in passing that hydrogen could become one of the fuels of the future due to the lack of local air pollution from hydrogen fuel cells (St. meld. no. 58 (1996-97) This observation was repeated in a 1998 white paper on Norway's follow-up of the Kyoto agreement (St. meld. no. 29 (1997-98). Thus, hydrogen entered policymaking primarily as a potentially emission-free energy carrier that could reduce local pollution but in a fairly distant future. The hydrogen society scenarios included the local emissions issue but emphasised above all more wide-ranging visions of hydrogen as the basis of a new, sustainable energy regime.

Also in 1998 came an Official Norwegian Report (Green paper) which reviewed the energy and power balance towards 2020. Here, with input from scientists at Institute for energy technology and Norwegian University of Science and Technology, hydrogen was used as an example of technologies that might gain importance closer to 2020. Particularly notable in our context was a figure outlining the renewable energy system of the future, leading to the conclusion that: "In the long run one can imagine an energy system fully based on renewable energy with hydrogen and electricity as energy carriers" (NOU 1998: 11, chapter 25.1). However, the report also noted that currently, the cheapest way to produce hydrogen was from natural gas.

The report was followed up by a white paper in 1999 that observed that hydrogen society would be a long time in coming: "There are still large development challenges for fuel cell technology. Building the needed infrastructure [for hydrogen] will also take relatively long time" (St. meld. no. 29 (1998-99, section 3.3.4). In the parliament's discussion of this white paper hydrogen was only mentioned by one small opposition party, which emphasized the greenhouse effect as "perhaps the most serious environmental issue the world is facing", that Norway due to its income from oil and gas has a special responsibility to show that greenhouse gas emissions can be reduced, and pointed to hydrogen as a solution and a way towards a society with decentralized and clean energy sources (Innst. S. nr. 122 (1999-2000)). Obviously, at this stage, hydrogen was not really on the radar of Norwegian policymakers, even if the National Transportation Plan 2002-2011 mentions fuel cell cars as a possible alternative to conventional cars in the not-so-near future (St. meld. nr. 46 (1999-2000), p. 32).

This lack of political attention was likely a frustration to scientists who believed hydrogen technologies to be important but seemed unable to change the mind of policymakers. A leading hydrogen scientist expressed in a later interview that: "When I worked in the US, I was employed by a hydrogen programme supported by Department of Energy. (…) That programme was in place from 1992-1993. Norwegian authorities have been very slow. While people in other places have produced strategies and plans to bring the technology to the market, in Norway, one has sat and looked at what other people have been thinking. It was the US, Japan and EU that finally opened the eyes of Norwegian politicians, I think"[iii]

This did not mean that scientists remained passive. Besides the activities of the Norwegian Hydrogen Forum, a comprehensive report was produced, titled "The hydrogen society – a national opportunity review" (Kvamsdal and Ulleberg 2000). A large number of scientists from all major energy research institutions in Norway contributed. The result was – unsurprisingly – a strong recommendation that Norwegian authorities should provide comprehensive support for R&D related to hydrogen to make Norway competitive in a 30 year time frame. Interestingly, the report also noted that "With our large natural gas resources Norway is in a unique situation, and could become the leading hydrogen manufacturer in Europe within a fairly short timeframe." Here, they picked a clue from the Official Norwegian report from 1998, trying to link a prioritising of hydrogen R&D with inland use of natural gas and thus with Norwegian industrial policy. The proposed hydrogen society scenario now included both new renewable energy and – intermittently – the exploitation of Norwegian gas resources. Did this help to make hydrogen attractive?

The move to make production of hydrogen from natural gas into a stepping stone to a renewable hydrogen society proved to be successful. Two important non-government documents from 2001 give evidence to this. First, the agreement between the Conservative Party, the Christian Democratic Party and the Liberal Party about forming a multiparty government after the 2001 election appropriated this scenario.[iv] Second, a report from a joint committee of the Labour party and the Norwegian Confederation of Trade Unions on increasing domestic use of natural gas gives substantial mention of hydrogen.[v] This report emphasised the importance of "Natural gas as the bridge to the hydrogen society" and proposed the establishment of a public company to promote innovation and infrastructure for natural gas and hydrogen. These views were picked up by Labour MPs in the parliament's discussion of the 2002 government budget. On behalf of the ruling coalition, Minister for Oil and Energy Einar Stensnæs stated that the government "will increase the public research funding related to use of natural gas and hydrogen".[vi] Arguably, by the end of 2001, interaction between scientists and policymakers had produced a Norwegian version of hydrogen society. Hydrogen seemed to be established as an energy carrier most immediately linked to natural gas, while a renewable energy system was more of a future vision. To the extent that an expectation was articulated, it was concerned with natural gas and industrial issues.

While not denying the importance of the advice given by hydrogen scientists, the role of hydrogen in energy policy increasingly bore the mark of policy-making handicraft with the short-term industry-oriented emphasis on natural gas as a source of hydrogen and reduced emissions as the main environmental argument. This helped to carry a hydrogen focus further. In 2002, an Official Norwegian Report on gas technology recommended that a sizable national hydrogen program should be established to coordinate hydrogen efforts. Hydrogen from renewables was seen as being in the far future, but "in a shorter perspective production of hydrogen from natural gas will be necessary" (NOU 2002:7, section 2.2). The making of hydrogen into a shorter term issue was based on the observation that "Important countries like the US, Canada, Japan and Germany are leading the development of hydrogen technologies, and their governments are making considerable effort to support research, development and commercialisation of hydrogen and fuel cell technology" (ibid.).

The report was soon used in energy and gas related discussions in the parliament, with Labour representatives arguing that the report strengthened the case for establishing a public company to deal with natural gas and hydrogen technologies and innovation.[vii] In this debate, the vision of natural gas as the bridge to the hydrogen society was repeated and elaborated, even if there were critical voices: "It is not true that a massive development of natural gas infrastructure is a necessary prerequisite for the hydrogen society".[viii] However, the main argument was that fossil fuels would be the cost efficient source of hydrogen in the near future, but with an afterthought. "For the establishment of the hydrogen society to happen within the bounds of a sustainable optimal energy development, the challenges of managing the CO_2 separated from hydrogen production must therefore be solved" (St. meld. nr. 15 (2001-2002), p. 49). Nevertheless, hydrogen was pushed forward. In the government's draft budget for 2003, hydrogen research was given increased mention as well as some increase in funding (St.prp. nr 1 (2002-2003), p. 29). This increase was interpreted by MPs representing the governing coalition as proof that the government "has visions to get closer the goal of using hydrogen as one of the most important and cleanest energy carriers of the future".[ix]

Towards the end of 2002 the Government also presented a white paper based on the Official Norwegian Report on gas technologies (St. meld. nr. 9 (2002-2003)). Here, it was stated that "A vision for the future energy system is that hydrogen becomes a substantial energy carrier". The white paper continued by observing that "Matters are well set for increased use of hydrogen in Norway". This was argued to be due to the good access to natural gas and renewable energy sources, possibilities for carbon capture and storage (CCS), industrial experience with production of hydrogen, and available technological expertise in industry and R&D. The main point was that in Norway, natural gas would be "a natural source for large scale hydrogen production in the coming years", and "environmental benefits related to gas power stations with CCS will make investments in hydrogen based energy systems more attractive."

In the discussions in parliament, all parties agreed that "hydrogen can become one of the most important energy carriers of the future and matters are well set for increased use of it in Norway" (Innst. S. nr. 167 (2002-2003)). All parties also agreed to ask the government to "create a broadly composed national hydrogen committee to draw up national goals and the measures needed for developing hydrogen as an energy carrier and as a tool for domestic value creation." Members of the Norwegian Hydrogen Forum later referred to this as one of the clearest signs that the Forum – and thus hydrogen scientists – had been heard by the policymakers: "I don't think there would have been an Official Norwegian Report (about hydrogen) without the Hydrogen Forum … Thus, early on, I think we were an important driving force".[x]

In retrospect, this was probably hydrogen's finest hour in the Norwegian context. Hydrogen earned more frequent and positive mentions in the subsequent parliamentary session than in any other debate in parliament before or after. The only controversial issue was domestic use of natural gas and the level of government support to increase such use. Also, during 2003, a committee was appointed to produce an Official Norwegian Report about hydrogen as a future energy carrier. This signalled that the government intended for hydrogen to become an important policy issue, since such reports usually form the basis of subsequent white papers. Thus, 'hydrogen society' was becoming important to Norwegian energy policy, at least with natural gas as a stepping stone to the hydrogen future. Moreover, the abovementioned committee and the appointment of two related expert advisory boards provided an – admittedly temporary – institution for hydrogen scientists to provide advice to policymakers.

As we have seen, hydrogen society became an important energy policy concept during a fairly brief period between 1998 and 2003. Clearly, this was in accordance with the hydrogen scientists' advice. They made an effort through the Norwegian Hydrogen Forum as well as other channels to argue that hydrogen was the energy carrier of the future. The linking of hydrogen society to natural gas proved particularly popular among policymakers, to the extent that the Norwegian version of 'hydrogen society' included natural gas as a stepping stone to a future where energy would come from renewable sources. Probably, 'hydrogen society' would not have made its way into Norwegian energy policy without hydrogen scientists' efforts. On the other hand, the rising popularity of hydrogen in the period clearly depended on the possibility seen by policymakers to weld hydrogen initiatives to a wished-for on-shore use of natural gas and thus to main concerns of Norwegian industrial policy.

The idea to produce hydrogen from natural gas was so tempting to policymakers that 'hydrogen society' remained a fairly fuzzy vision. In the period 1998-2003, it was not developed into an expectation in the sense of Borup et al. (2006) as a tool to coordinate actors and actions. This coordination, as well as the further development of a Norwegian hydrogen society vision, was left to the committee that was commissioned to produce the Official Norwegian Report about hydrogen as an energy carrier. What were the results?

From 'hydrogen society' to the Hydrogen Road

The Official Norwegian Report about the future of hydrogen as an energy carrier came in 2004 (NOU 2004: 11). This report represented a combination of scientific and industrial advice, tempered by political concerns. The committee behind it, as well as the expert groups providing input, should be described as hybrid institutions since we find representatives from relevant scientific institutions, industrial companies and policy-makers. However, there is no doubt that the scientific voice was clear and present. The message was also unambiguous. 'Hydrogen society', regardless of what the concept meant, would at best happen in a distant future. The report laconically states with respect to stationary applications that "A hydrogen initiative must have a long time-frame and will not directly represent any solution to the challenges one foresees for the Norwegian and Nordic electric power balance in the near future" (NOU 2004:11, p. 64). The main reason given was the low level of efficiency in transforming electricity to hydrogen, while the reforming of natural gas to hydrogen still would produce considerable emissions of CO_2. The vision of 'hydrogen society' was put on hold; actually, this vision more or less disappeared from later energy policy documents.

However, this did not mean that hydrogen was to be abandoned from science and industrial policy. On the contrary, the committee recommended that hydrogen should remain a priority area, with an emphasis on four areas: (1) Environmentally friendly production of hydrogen from Norwegian natural gas, (2) Early users of hydrogen vehicles, (3) Hydrogen storage, and (4) Development of hydrogen technology. Again, the possibility of finding on-shore use for natural gas was an important motive. In addition and in contrast to the advice with respect to stationary use, the committee found hydrogen to be a potentially important clean fuel for transport. A third motive was that many other countries pursued hydrogen. The committee thought that a large international market with respect to hydrogen could be emerging (NOU 2004:11, p. 70).

Further proof that 'hydrogen society' was in decline as an energy policy concept was the fact that the hydrogen report was not followed up by a white paper, as usually is the case with Official Norwegian Reports. Instead of becoming the object of a white paper, hydrogen was treated more modestly through a government strategy document, made by the Ministries of Transportation and of Oil and Energy in collaboration (*Satsning på hydrogen som energibærer innenfor transport og stasjonær energiforsyning*, 2005). The main proposal of this document was to establish a permanent national Hydrogen Platform with an advisory Hydrogen Council to coordinate resources. Despite noting that "most people see a hydrogen society, where hydrogen together with electricity are the dominant girders, as a distant future", the document motivated the need for coordination by noting that "today, there is internationally a comprehensive and increasing focus on hydrogen as an energy carrier" (ibid, p. 11). 'Hydrogen society was given no more mention in the strategy, which basically promoted the same the four areas proposed by the Official

Norwegian Report about hydrogen. This meant that R&D was argued to be the most prominent instrument to support the development of hydrogen – in the long run.

What then about hydrogen for transport purposes? This was the preferred area of application by the Official Norwegian Report: "The commission believes that a hydrogen programme above all should support research related to the development of hydrogen technology and demonstration projects. A main ambition of a Norwegian hydrogen initiative would be to become an early user of hydrogen vehicles" (NOU 2004:11, p. 21). However, in this respect the national strategy document was unclear. Nevertheless, already in 2003, an initiative had been taken "to build a first hydrogen infrastructure, as part of a future permanent infrastructure, from Oslo to Stavanger. (…) In the period from 2005 to 2008 it shall be possible to drive hydrogen fuelled vehicles between Stavanger and Oslo" (Buch, C., 2003, *Hydrogenveien i Norge – HyNor* quoted in Kårstein 2008, p. 82). The concept of the so-called Hydrogen Road formed the backbone of the HyNor project, established above all by industrial actors (Kårstein 2008), and it was mentioned specifically in the parliamentary proceedings about the 2005 budget for the Ministry of Transportation. Here, a parliamentary majority found it reasonable that the Government increased its support for the budget item meant to support rational and environmentally friendly transport aimed at demonstrations of hydrogen use (Budsjett-innst. S. nr. 13 (2004-2005)).

The focus on the budget item 'Rational and environmentally friendly transport', which historically had been used to fund public transport experiments, is significant. This item had increasingly been used to fund fuel research and demonstration projects. However, it was other actors than scientists who pursued this angle. A prominent NGO representative told in an interview that his organisation had chosen to approach the Ministry of Transport because the minister was believed to be concerned with environmental issues: "During the 1990s, there had been a budget item called 'alternative fuels' (…). And we worked hard to increase that item and to achieve that the money should be used for hydrogen projects and was quite successful in that respect”.[xi]

HyNor was the most frequently mentioned demonstration project in policy documents and parliamentary debates from 2004 and onwards, receiving substantial support from the Research Council of Norway, partly through the budget item ‘alternative fuels’ which the Ministry of Transportation channelled through the Research Council. As shown by Kårstein (2008), the HyNor project was an amalgamation of industrial, public and political interests. Scientific concerns were present but less articulated. In the 2004 Official Norwegian Report about hydrogen, the proposal to focus on the use of hydrogen in transport reflected both industrial and scientific advice. However, as also indicated by the interview with the NGO representative quoted above, the Norwegian focus on hydrogen for transport was rather a political achievement. Scientists advised the move, but it was carried through by policy-makers and industrial actors. In various ways, the HyNor project continued to be in the political limelight, as a clear indication that hydrogen for transport remained on the political agenda.

The ‘hydrogen society’ concept was for a brief period a loose vision that mobilised political interest in establishing initiatives to develop hydrogen technologies and demonstration projects. However, as we have shown, after 2004 the focus on hydrogen as an energy carrier became either something for a fairly distant future and thus not very pressing, or a transport issue. When an Official Norwegian Report titled “A climate friendly Norway” was issued in 2006, hydrogen was not given priority as a tool for climate mitigation: “The remaining technological and economic challenges regarding the production above all of fuel cells makes it less probable that this technology will contribute to significant reductions in climate gas emissions from the transport sector before 2020. The future will show if and when research … may lead to a hydrogen society without emissions of climate gases from the transport sector. What is for sure is that this will require long-term and focused research efforts on a global basis” (NOU 2006: 18, p. 57). ‘Hydrogen society’ was mentioned this one time throughout the report, which favoured ‘low carbon society’ as the concept to designate the vision of the future underlying the report. Probably, ‘hydrogen society’ was considered too specific with respect to technologies and not really catching the challenges of climate mitigation.

In 2008, the Ministry of Oil and Energy established a board to develop a national strategy with respect to stationary energy called Energy 21. Energy 21 quickly developed into an institution that became a meeting place for industrial, scientific and public interests regarding energy issues in order to provide advice to energy policy. The most recent strategy document was published in June 2011 and does not contain any reference to hydrogen (Energi 21, 2011). The society of the future is not a hydrogen society but a zero emission society. In Norway, hydrogen had become relevant only in the context of transport.

Scientific advice and policy learning

As we have seen, ‘hydrogen society’ enjoyed a fairly brief summer in Norwegian energy policy. What role did hydrogen scientists play in the rise and fall of this concept? How should we consider the importance of scientific advice relative to policy learning? As we have seen, there is no doubt that Norwegian scientists made considerable efforts to promote hydrogen to energy policy-makers. How should we understand these efforts, and what strategies were pursued?

As part of our study, a number of hydrogen scientists were interviewed in 2007-2009. Some retrospective information was offered, including strategies of giving advice or in other ways influencing policy-makers. Perhaps unsurprising, not everybody was engaged in such practices. However, there was broad agreement that some hydrogen scientists provided advice on an individual basis and also that the large R&D institutions in the field engaged with policy-makers. The Norwegian Hydrogen Forum and the Kvamsdal and Ulleberg (2000) report showed that hydrogen scientists collaborated to provide advice.

Scientific advice happened through a variety of channels, formal as well as informal. We have seen previously that scientists were invited to participate in policy-oriented expert committees. The R&D institutes found such participation valuable: "So by giving our committee members enough time to prepare and work we can achieve lots of influence".[xii] Hydrogen scientists also gave input to expert committees without being a member. They might write letters to the Research council of Norway or to individual politicians and meet with members of Parliament and other policy-makers.

Some scientists were described as skilled in communicating with policy-makers. One interviewee even described a colleague as "a very political person".[xiii] Another senior scientist stated that "We know what buttons to push and where to send our e-mails and things like that. We write articles in the newspapers [...] the politicians are very aware of those articles, of who writes what. [...] I think that we are not experts in politics, but we use the people we have - like here at [name of research institute] the manager of our information department … has been State Secretary in the Ministry for Oil and Energy … . He knows exactly who needs to be at which meetings and present what very briefly and why".[xiv]

Of course, we also heard that communicating with policy-makers was challenging: "(P)eople who try to make something new happen, they need to have frequent meetings with people in the relevant ministries. [...] And of course, the question is who should do it, right? [...] If one has the energy, and knows the right people, there are lots of things like that, but of course some are better connected and work more than others and then they get results".[xv] However, while frequent meetings with the right people were considered important, it was not sufficient. A common lesson seemed to be that for scientists to be heard by policy-makers, they needed to speak with one voice: "I think that Science-Norway, the experts, is in agreement about what is said now [about hydrogen]. That is very important. The politicians feel very safe when they hear something now, and if it is coming from [the main R&D institutions in the hydrogen field] then it is assumed to be coordinated. It used to be that they had to go to [name of institute] to hear what they had to say and then [name of another institute] said something else. That made them very uncertain: 'What are we supposed to believe?'".[xvi] Another challenge was that policy-makers frequently changed positions: "We try to influence all [hydrogen relevant] ministries (…). We try to work with all of them, but that also becomes a many-headed troll that you cannot really … they change their State Secretary at all times and suddenly, the guy who was interested in hydrogen isn't there any longer".[xvii]

What kind of message did they get across? What kind of advice was taken on board? If we return to the most important hydrogen-relevant policy documents of the period from 1998 and onwards, reviewed in the previous sections, we observe that facts about hydrogen and hydrogen technologies were made use of. However, hydrogen visions seemed even more influential, in particular the no-emissions quality of hydrogen technologies and their industrial potential. Above all, as we have seen, the idea that hydrogen could be supplied by reforming natural gas, was attractive and a main constituent of the Norwegian concept of 'hydrogen society'. Still, when considering the documents and the interviews, the main advice given was that the government needed to increase its investment in hydrogen R&D.

However, most of the channels through which hydrogen scientists provided advice should be considered as hybrid institutions, where scientists work together with representatives of industry, public sector and policy-makers. This was above all true for the expert committees that produced the reviewed Official Norwegian Reports. The advice provided through such hybrid institutions was itself a hybrid. Already in the committees, scientific facts and visions were amalgamated with articulated needs of industry and public sector – in Bruno Latour's (2004) terms – transforming matters of fact into matters of concern. There is little in the interviews that suggest that the hydrogen scientists felt uncomfortable with this. Rather, they were also concerned with the potential of hydrogen technologies to contribute to a more sustainable world.

Thus, clearly, hydrogen scientists contributed importantly to make hydrogen and 'hydrogen society' policy relevant and an important part of Norwegian energy policy discourses in the period 2000-2004. Their advice about hydrogen technologies and future prospects of using hydrogen as an energy carrier clearly provided opportunities for policy-makers to learn. This situation extends the categories proposed by Bennett and Howitt (1992), since policy learning is related to scientific advice rather than 'lessons drawing'. On the other hand, there is little doubt that 'the brief summer of hydrogen' owed to political handicraft. In particular, this is evident from the way political interest in hydrogen piggy-backed on onshore use of natural gas as we have seen throughout the preceding analysis.

The beginning of the brief summer of hydrogen could be seen as an outcome of scientific advice. However, that would be too simplistic. In the Norwegian context, as already indicated, this has to be understood even more as a bandwagon effect (Kårstein 2008). Norway was mainly following suit, observing how hydrogen was given priority in the US, Japan and EU. But how should we explain the end? The short time-frame of hydrogen as a central element in Norwegian energy policy seems inconsistent with the assumption that policy-makers had been able to do 'lessons drawing'. Thus, it seems more probable that the downturn also was due to scientific advice. If we return to the Official Norwegian Report about hydrogen (NOU 2004: 11), it is scientific facts about energy losses that is used to dismiss the vision of 'hydrogen society'. However, when we analyse the energy policy discourses more broadly, we observe some indications of reflexive governance (Beck 2006). Up till 2004, the arguments in support of hydrogen display a modernist outlook with hydrogen as a solution to pressing environmental concerns. Later policy documents do not privilege particular technologies but display a more pluralist approach to climate mitigation and sustainable energy. On the other hand, this change does not appear to be about ambivalences and ambiguities but rather a lack of will to give priority to particular technologies. We may be observing cautious rather than reflexive governance.

Quality or relevance?

How may we understand the role of hydrogen scientists with respect to the fate of 'hydrogen society' as an energy policy concept in Norway, and what may we learn more generally with respect to the relationship between scientists and policy-makers? To begin with, the analysed policy documents display clear examples of scientific advice in the form of providing descriptions of hydrogen's potential as an energy carrier and existing challenges with respect to developing appropriate hydrogen technologies. However, the context of these documents, in particular the making of Norwegian Official Reports, indicates that scientists exceeded the role of advisor. Rather than acting according to the linearity-autonomy model, the practice seems much closer to what Jasanoff (2011) calls virtuous reason; i.e., that hydrogen scientists participated in the making of broader energy policy proposals. We also saw that virtuous reason was practiced through committees that were hybrid fora in the sense that the members came from different quarters: science, industry, public sector and policy-making. Thus, scientific proposals were negotiated with industrial and public sector interests as well as policy-making concerns.

However, the interviews with hydrogen scientists showed that some of them also acted in a manner closer to translation theory. Initially, 'hydrogen society' was invoked as a scenario to elicit political support of increasing the funding for hydrogen science. A particular Norwegian version of 'hydrogen society' was made use of, which emphasised a potential role for natural gas as raw material for the production of hydrogen as a stepping stone towards a system based on renewable energy. While this vision after a short while lost out, arguably the hydrogen scientists succeeded in their aim to improve funding for their research.

Energy policy is, like many other policy areas, too complex to produce a lot of issues where scientific facts can be expected to settle disagreements. This means that the emphasis on quality assurance with respect to scientific advice (e.g., Lentsch and Weingart 2011) may have a limited validity. Or, rather, in line with the virtuous reason model, the issue of relevance needs to be emphasised. Clearly, when hydrogen gained some popularity in energy policy discourses, this was facilitated by observations that hydrogen was becoming a priority area in many other countries (see also Kårstein 2008). Also the linking-in with natural gas should be seen as an effort to make hydrogen relevant to particular Norwegian energy policy concerns.

Thus, rather than focusing on scientific advice as an activity in itself, we should focus more broadly on the interaction between scientists and policy-makers. Our analysis suggests, first, that this interaction should be studied on the premise that both parties have some autonomy and pursue their own agendas. Second, scientists and policy-makers may be interdependent, at least with respect to scientists' need of funding and policy-makers' need of scientific expertise. Third, we need to study in greater detail the hybrid forums where scientists and policy-makers interact, and where diverse social interests may participate.

Notes

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[i] This is observed from the media database Retriever (www.retriever.no), using the search term 'hydrogen society'.
[ii] http://www.hydrogen.no/h2forum
[iii] Research Scientist Q, interviewed 2007-16-08.
[iv] See *Sem-erklæringen av 08.10.2001*, page 15
[v] Ta naturgassen i bruk! LO og Arbeiderpartiet 05.07.2001 page 10
[vi] In the parliamentary plenary session 07.12.2001 (minutes from plenary sessions can be accessed from www.stortinget.no)
[vii] See Sigvald Oppebøen Hansen in Plenary session in parliament 15.03.2002
[viii] See Ingvild Vaggen Malvik in Plenary session in parliament 15.03.2002
[ix] Parliament plenary debate 12.12.2002, Øyvind Halleraker.
[x]Research Scientist D, interviewed 2008-19-05.
[xi] Leader of NGO, interviewed 2008-04-01.
[xii] Research director R, interviewed 2008-27-05.
[xiii] Professor E, interviewed 2008-05-05.

[xiv] Research director I, interviewed 2008-26-05
[xv] Research scientist C, interviewed 2008-19-05.
[xvi] Research director I, interviewed 2008-26-05.
[xvii] Research Scientist D, interviewed 2008-19-05.

References

Alkemade, F and RAA Suurs. 2012. Patterns of expectations for emerging sustainable technologies. *Technological Forecasting & Social Change*, 79: 448-456.

Beck, U 2006. Reflexive governance: politics in the global risk society. In J-P. Voss, D. Bauknecht and R. Kemp, eds. *Reflexive Governance for Sustainable Development*, Cheltenham, UK: Edward Elgar, pp. 31-56.

Bennett, CJ and M Howitt. 1992. The lessons of learning: Reconciling theories of policy learning and policy change. *Policy Sciences*, 25: 275-294.

Bijker, WE, R Bal R and R Hendriks 2009 *The paradox of scientific authority: the role of scientific advice in democracies.* Cambridge, Mass.: The MIT press.

Bockris, J O'M. 2002. The origin of ideas on a Hydrogen Economy and its solution to the decay of the environment. *International Journal of Hydrogen Energy*, 27: 731-740.

Borup, M, N Brown, K Konrad and H van Lente. 2006. The Sociology of Expectations in Science and Technology. *Technology Analysis & Strategic Management*, 18 (3-4): 285-298.

Budsjett-innst. S. nr. 13 (2004-2005) *Budsjettinnstilling til Stortinget frå samferdselskomiteen*.

Callon, M. 1987. Society in the Making: The Stud7 of Technology as a Tool for Sociological Analysis. In Bijker, WE, TP Hughes, T Pinch *The Social Construction of Technological Systems*. Cambridge, Mass. and London: The MIT Press

Callon, M., J. Law and A. Rip, eds. 1986. *Mapping the dynamics of science and technology*. London: Palgrave Macmillan.

Energi 21 (2011) *Energi21. National Strategy for Research, Development, Demonstration and Commercialisation of New Energy Technology*, Oslo (downloaded from www.energi21.no at 2012-03-06).

Innst. S. nr. 122 (1999-2000) *Innstilling fra energi- og miljøkomiteen om energipolitikken*

Innst. S. nr. 167 (2002-2003) *Instilling fra energi- og miljøkomiteen om innelands bruk av naturgass mv.*

Irwin, A. 2008. STS Perspectives on Scientific Governance. In Hackett, EJ, O Amsterdamska, M Lynch, and J Wajcman *The Handbook of Science and Technology Studies*. Cambridge, Mass. and London: The MIT Press

Jasanoff, S. 1990. *The fifth branch: science advisers as policymakers.* Cambridge, Mass.: Harvard University Press.

Jasanoff, S. 2011. Quality control and peer review in advisory science. In Lentsch, J. and P. Weingart, eds. 2011. *The Politics of Scientific Advice. Institutional Design for Quality Assurance*, pp. 19-35. Cambridge, UK: Cambridge University Press

Johnston, B, M C Mayo and A Khare. 2005. Hydrogen: the energy source for the 21st century. *Technovation*, 25: 569-585

Kvamsdal, H. and Ø. Ulleberg 2000 *Hydrogensamfunnet – en nasjonal mulighetsstudie* [*The hydrogen society – a national opportunity review*]. SINTEF Report TR A5197.

Kårstein, A. 2008 HyNor – den norske hydrogenveien? En studie av en stor tekno-politisk hybrid. *PhD-thesis*. Trondheim: Norwegian University of Science and Technology (NTNU)

Latour, B. 1987. *Science in action: how to follow scientists and engineers through society*. Milton Keynes: Open University Press.

Latour, B. 2004. "Why Has Critique Run out of Steam? From Matters of Fact to Matters of Concern." *Critical Inquiry* no. 30 (2):225-248.

Latour, B. 2007. "Turning Around Politics: A Note on Gerard de Vries' Paper." *Social Studies of Science*, 37 (5):811-820.

Lentsch, J. and P. Weingart, eds. 2011. *The Politics of Scientific Advice. Institutional Design for Quality Assurance*, Cambridge, UK: Cambridge University Press

McDowall, W and M Eames. 2006. Forecasts, scenarios, visions, backcasts and roadmaps to the hydrogen economy: A review of the hydrogen futures literature. *Energy Policy*, 34: 1236-1250

NOU 1998:11 *Energi- og kraftbalansen mot 2020*

NOU 2002:7 *Gassteknologi, miljø og verdiskaping*

NOU 2004:11 *Hydrogen som fremtidens energibærer*

NOU 2006:18 *Et klimavennlig Norge*

Nowotny, H., P. Scott, and M. Gibbons. 2001. *Re-thinking science: knowledge and the public in an age of uncertainty.* Cambridge, UK: Polity Press

Nye, D. 1996. *American Technological Sublime*, Cambridge, MA: The MIT Press

Satsning på hydrogen som energibærer innenfor transport og stasjonær energiforsyning, 2005, Olje- og Energidepartementet og Samferdselsdepartementet [Ministry of Oil and Energy and Ministry of Transportation]

Owens, S. 2010. Learning across levels of governance: Expert advice and the adoption of carbon dioxide emissions reduction targets in the UK. *Global Environmental Change*, 20:394-401

Owens, S. 2011. Knowledge, advice and influence: the role of the UK Royal Commission on Environmental Pollution, 1970-2009. In Lentsch, J. and P. Weingart, eds. 2011. *The Politics of Scientific Advice. Institutional Design for Quality Assurance*, pp. 73-101. Cambridge, UK: Cambridge University Press

Park, S. 2011. Iceland's hydrogen energy policy development (1998-2007) from a sociotechnical experiment viewpoint. *International Journal of Hydrogen Energy*, 36: 10443-10454

Pielke, R.A. 2007. *The honest broker: making sense of science in policy and politics*. Cambridge: Cambridge University Press

Rifkin, J. 2002. *The Hydrogen Economy*. New York: Putnam

Sanne, D. 2006 *Hydrogen and Fuel Cells in Norway - Who's who. (First edition, May 2006).* Oslo: Birkebeinerlaugets bedriftsuvikling (BBU)

Sovacool, B K and B Brossman. 2010. Symbolic convergence and the hydrogen economy. *Energy Policy,* 38: 1999-2012

St. meld. nr. 58 (1996-97) *Miljøpolitikk for en bærekraftig utvikling*

St. meld nr. 46 (1999-2000) *Nasjonal Transportplan 2002-2011*

St. meld. nr. 29 (1997-98) *Norges oppfølging av Kyotoprotokollen*

St. meld. nr 29 (1998-99) *Om energipolitikken*

St. meld. nr. 15 (2001-2002) *Tilleggsmelding til St.meld. nr. 54 (2000-2001) Norsk klimapolitikk*

St. meld. nr. 9 (2002-2003) *Om innenlands bruk av naturgass mv.*

St. prp. nr. 1 (2002-2003) *Statsbudsjettet for budsjetterminen 2003*

van Lente, H and S Bakker. 2010. Competing expectations: the case of hydrogen storage technologies. *Technology Analysis & Strategic Management,* 22 (6): 693-709

Chapter four: Advising or advocating?

Funding applications as policy advice

Abstract

In this paper I analyze how the relevance of science is argued in a set of funding applications that achieved funding from the Norwegian Clean Energy for the Future program. The applicants combine advocating their project with a promise of usefulness to a wider problem context. Within the fairly strong formatting that an application is exposed to, the scientists not only repeat the goals of the funding agency, they also make the case for giving priority to their technology and describe scientific opportunities inherent in doing so. Thus, I argue that the funding applications are used as a channel for a specific, not too radical, form of policy advice. This implies that studies of funding applications and other ways in which scientists argue relevance may be useful if we want to increase our understanding of the scientists' side of the proposed new dialogue between science and society.

It is commonly stated that science systems are changing towards an increased focus on strategic goals and the production of relevant knowledge (Hessels & van Lente 2008). One of the ways this can be seen is in how broader societal impact criteria are included in the review of science funding applications, in some cases even as part of the peer review process (Holbrook & Frodeman 2011). As (perceived) relevance becomes a condition for funding, scientists applying for funding are asked to not only present the scientific merit but also the societal benefit of their research proposal. This paper studies the way in which scientists advocate their projects as relevant when writing research proposals. Are scientists merely repeating descriptions of broader social impact criteria as defined by funders? Or do they employ research proposals to more actively argue the relevance of science, thus performing a kind of policy advice?

The content of research proposals has not been widely studied. However, both studies of peer review (Hansson 2010) and of evaluative cultures (Lamont 2009) indicate that writing and reviewing applications is more complex than just ticking off boxes. The addition of societal impact criteria may further increase this complexity, as it raises questions about whether scientists have any special qualifications in regards to judging the societal impact of science (be it their own projects as applicants or other projects as reviewers) (Holbrook & Frodeman 2011:239). On the one hand, drawing a clear border between science and politics can be a way for scientists to maintain scientific authority when being part of the policy process (Jasanoff, 1990:95). On the other hand, some argue that 'scientists must overcome their fear of contamination by the social' (Nowotny, Scott & Gibbons 2001:235). Funding applications may be especially interesting in this regard because the scientists are here actively invited to cross the border between the scientific and the political.

The empirical basis for this paper is the hydrogen-related applications which achieved funding from the Research Council of Norway's Clean Energy for the Future (Renergi) program over a 5-year time period. I first examine what kind of social impact criteria the Renergi program uses, and then compare it to the relevance arguments employed by the scientists. Do the scientists simply repeat what the Research Council seems to want to hear, or do they use the application to more actively provide arguments for why hydrogen energy research should be given priority in current science policy? What arguments are used, and what kind of advisory role is enacted? To illuminate this, I have chosen to draw on theoretical perspectives that put the issue of relevance into a broader science studies context, including studies of scientists as policy advisers.

Making relevance? Scientist-policy interaction

Science policy rhetoric has increasingly emphasized the importance of societal relevance of science (e.g. Benner & Sandström 2000; Demeritt 2000; Etzkowitz & Leydesdorff 2000; Irwin 2006). There is reason to be cautious with assuming that focus on relevance is a completely new phenomenon – expected benefits, periodic focus on contexts of application and the need for science to get resources from the government or the wealthy are all trends that can be traced back to the emergence of modern science (Hessels, van Lente & Smits 2009). Nevertheless, the ways in which relevance is handled within science policy may be changing. Nowotny, Scott and Gibbons observe that 'In many countries, Research Councils have increasingly adopted more pro-active (or top-down) research priorities in place of essentially reactive (or bottom-up) policies, whereby the best research proposals, as identified by peer review, are funded. Much greater emphasis is now placed on thematic programmes. Although typically broad in their scope, these programmes are often the product of an awkward – and unstable – compromise between 'political' goals, promising science, and available research capacity' (Nowotny, Scott & Gibbons 2003:182). This description is connected to the development that has been described as the emergence of a 'Mode 2' of knowledge production – where scientists, rather than being privileged gatekeepers of knowledge, are in a continuous dialogue with non-academian actors about both the questions asked and how the answers should be understood (Nowotny, Scott & Gibbons 2003).

How may Research Councils communicate the goals of a program to potential applicants? If we emphasize the role of the Research Council as definers of societal relevance, and the scientists merely as someone delivering what is asked for, the process may be close to what Latour (2005) calls formatting: the creation of a form the users know of and can follow in a given situation. 'A supermarket, for instance, has preformatted you to be a consumer, but only a generic one. To transform yourself into an active and understanding consumer, you also need to be equipped with an ability to calculate and to choose. […] [The] source of competence might be located at your fingertips: there are plug-ins circulating to which you can subscribe, and that you can download on the spot to become locally and provisionally competent.' (Latour 2005: 209-10).

However, some approaches contend that scientists may be more active than simply following a given format when placing their research in a societal context. One of the ways scientists are found to do this is through creating new visions about the future society that a technology, innovation or policy is supposed to exist in, or through hooking up to existing such visions (Callon 1987; Dierkes, Hoffman & Marz 1996). Callon (1987) describes how engineers involved in the electrical car innovation in France very actively created visions, or scenarios, not only for the technology, but for the whole societal structure in which the electrical cars were supposed to exist: 'EDF's engineers presented a plan for the VEL [electric vehicle] that determined not only the precise characteristics of the vehicle it wished to promote but also the social universe in which the vehicle would function' (Callon 1987: 84). These scenarios are for the most part pre-made, even before the innovation process starts, and works as a guiding vision for the design process, and as a tool for enrolling other actors. Callon emphasizes the central role of the engineers in the visionary process by calling them engineer-sociologists.

Gjøen (2001) presents a slightly different view on who the most central actors in the creation of visions are, and what role visions play in processes of translation and relevance making. Though Gjøen partly builds on Callon's (1987) work, she shows how experts, however important in the production of visions, are not the only ones involved in their creation. Politicians, user representations, NGOs, and industrial actors are just as important in the development of visions as engineers and researchers. Instead of seeing the vision as pre-made, though perhaps malleable, like Callon, Gjøen focuses instead on the visions as a place of dialogue, a 'trading zone' (Galison 1997) and meeting place for different actors, where they connect and come to an agreement over what this technology being developed might mean. This take on visions thus emphasizes how they may become an instrument for defining relevance.

With what kind of rhetorical strategies can scientists employ visions and scenarios to garner support for projects? Latour (1987: 115-7) describes a set of possible strategies for gaining relevance through translation of interests. Translation is a matter of connecting with other actors, and linking their goals to your goals – either by joining in with their goals (Latour's strategy 1), convincing them that they want what you already want (strategy 2), convincing them to do what they already plan to do in a slightly different way (that can possibly solve some other problems on the way) (strategy 3), or by creating new goals, displacing goals, finding new groups of actors with an interest in what you can offer (strategy 4). Clearly, these are rhetorical templates for arguing the relevance of particular research efforts.

Translation theory has mainly been used to study how techno-scientists can go about producing actor networks centred on their research results and/or new technologies. However, scientists may also be engaged in science policy, which has a particular focus on the general development of scientific goals, strategies for supporting science, and ways of distributing resources between scientific areas and scientists. This may be seen as an example of scientists being used more broadly as experts in policy-making, highlighting the issue of 'how policy actors draw upon scientific knowledge to justify collective action' (Jasanoff & Wynne 1998: 6).

While a focus on translation strategies points to science as being as much about relevance, and getting heard or attracting interest, as it is about getting the facts right, ideas about the neutrality of scientists are still important in shaping what kind of roles they can take on. As Jasanoff (1990: 9) puts it, 'Published accounts of science in policy thus deepen the paradox of advice and legitimacy, for by questioning whether technical advisers can ever be dispassionate, decisive, or value-neutral, they cut at the roots of the conventional justification for scientific advice.' Thus we need to examine roles for scientists interacting with policy beyond a more traditional distinction between ‘proper scientists’ and ‘issue advocates,’ where the former present the facts objectively without venturing into interpreting what they might mean politically or ethically, while the latter are tainted by values or interests. According to Pielke (2007), there are more potential roles for scientists interacting with society than these two. His central message is that ‘scientists have choices about if, how and when they decide to become actively engaged in policy and politics’ (Pielke 2007: 135), and that such choices have consequences both for society, the scientific enterprise as a whole, and the individual scientists themselves. Pielke describes four such (idealized) roles: the ‘Pure Scientist,’ the ‘Issue Advocate,’ the ‘Science Arbiter,’ and the ‘Honest Broker.’ The Pure Scientist is characterized by the fact that he/she has no interest in the decision-making process, but simply wants to share fundamental information about facts. The Issue Advocate is characterized by his/her trying to limit choice and convince others about a particular choice. The Science Arbiter is characterized by his/her attempt to be a resource for the decision-maker, standing ready to answer factual questions that the decision-maker thinks are relevant, but not to tell them what to prefer. The Honest Broker tries to expand (or clarify) the scope of choice for decision-making in a way that allows for the decision-maker to make a choice based on his/her own preferences and values (this is, Pielke holds, often best achieved through a collection of experts working together with a range of views, experiences and knowledge, and not necessarily something that one scientist alone can manage).

It may, however, be harder to choose freely between these roles of engagement than Pielke envisions. Traditional criteria for being scientific – objective, neutral, apolitical – still stand strong, even with the turn toward an increased focus on relevance that can be discerned in recent science policy rhetoric (Benner and Sandström 2000; Irwin 2006). Thus, it may be more fruitful to view Pielke's four categories as roles that scientists are coerced into – that they end up having to take on – rather than roles that they choose. Viewed as roles that scientists end up having to take on, Pielke’s initially normative categories can be applied analytically to uncover assumptions about science's role in society, but they may also be seen as potentially shaping the ways in which scientists may attempt to point out scientific opportunities, argue relevance, and provide advice. Thus, Latour and Pielke may be seen to share two important observations about relevance: 1) relevance is a relational concept, which cannot be discussed generally, the questions of ‘relevant for what,’ and ‘relevant for whom’ must be addressed; 2) there is more than one way in which scientists can engage with society, policy, and politics.

What expectations can we formulate from the theory in regards to what the relevance arguments in funding applications look like? Translation theory has made us expect to find scientists as inventive makers of visions, thought to be attractive to, e.g. funding agencies. This would imply a creative production of arguments with respect to social relevance of a proposed research project, which may serve as a tool to create interest among and potentially enroll a broad set of actors. A more cynical approach could be to expect that the scientists are mainly mirroring expressed expectations of the funding agency, employing some kind of format made available from the Renergi program. In the following I will look in-depth at the descriptions of relevance that the Renergi program makes available to potential applicants, and at the ways in which the applicants argue the relevance of their projects, to explore to what extent these theoretical expectations fit with the data. To what extent do research proposals actually provide visions about what the research work will lead to? If they do, what kinds of issues are presented? And how do the proposals relate to the call issued by the funding agency?

Method

The empirical basis for this paper is hydrogen related-applications submitted to the Clean Energy for the Future program (Renergi) of the Research Council of Norway (RCN). The Renergi program was chosen after consulting a list of Norwegian hydrogen research projects at the RCN-supported website Hydrogenplattformen, indicating that Renergi is the largest funding source for Norwegian hydrogen research. The list shows a total of 63 hydrogen research projects, of which 42 is funded by the Renergi program. The other funding sources are the Nanotechnology and New Materials program (8), the Program on Power Generation with Carbon Capture and Storage (5) and the EU 6th Framework Program (8) (Hydrogenplattformen 2006).

After a request to view the application documents was approved, a representative from the Research Council of Norway collected the hydrogen-related applications which had gotten funding from the Renergi program from its start-up in 2004 and until 2009. Approval was not given to see rejected applications. In total 55 applications were in the selection from the RCN. The projects were submitted as either Research Projects (FP), Knowledge-building Projects for Industry (KMB), or Innovation Projects for the Industrial Sector (BIP); in the following individual applications are identified by project type and a (randomly assigned) number. The Research Projects category is for proposals from a researcher or group of researchers, the Knowledge-building Projects for Industry category is designated for applications from collaborations between researchers and industry, and the Innovation Projects for the Industrial Sector category is open for applications from companies (alone or together with a research institution).

The analysis was done in two steps. The first step was carried out on the premises of the RCN. The documents made available for research by the RCN representative were read, and analyzed for the applicants' explanations of the relevance of their research projects. The outcome of this step was a document quoting what the applications said about relevance in its entirety.

For the second step of the analysis, the selected text material from the first round of analysis was read closely for different arguments for the relevance of hydrogen research. This 'open coding' (Corbin & Strauss 2008) qualitative content analysis yielded 15 different relevance arguments. These 15 arguments were then combined into larger categories or 'argument families', to borrow a term from Malone (2009). For example, climate, environment, and local (motor vehicle) emissions were grouped together under the umbrella category of ‘environmental arguments’. Five overarching categories were the result of this: political arguments, environmental arguments, economic arguments, international arguments, and safety arguments.

The Renergi Program as Requester of Relevance

The Renergi program is one of the RCN’s large scale programs, running from 2004-2013 and with a yearly funding of close to 33 million Euro (or 255 million NKR in 2009).1 The program is supposed to address both basic and applied research, while at the same time being connected to national research priorities. Its funding decision process is as follows:2 First, RCN staff will sort out any applications that do not fulfill formal requirements, Then, evaluations of the projects are done by either international referees (in the case of Research Projects (FP) and Knowledge-building Projects for Industry (KMB)), or by Norwegian and Nordic experts (in the case of Innovation Projects for the Industrial Sector (BIP)). Finally, the actual funding allocation is done by the program board of Renergi.3 The program board has members from industry, government, universities and research institutes (one Danish, the rest Norwegian), and the representatives from academia are research leaders as well as researchers themselves.

Are there any readily available formats offered which the scientists may use to make their relevance arguments when they apply for funding from the Renergi program? The RCN has a general template that all applications of a specific project type (FP, KMB and BIP) must use, regardless of program. Apart from formal demands such as a project leader and budget information, the templates contain two sets of guidelines that affect relevance. All templates encompass environmental impacts (positive and negative), ethical perspectives (does the project raise specific ethical questions, if so how will they be dealt with?), gender issues, and ask for an assessment of both a national and an international perspective (be it as a consideration of the international technological state-of-the-art (KMB), national/international markets (BIP), or key challenges to knowledge both nationally and internationally (FP)). The template part of the RCN guidelines represents a topical formatting, structuring the application by telling the applicants questions their texts need to address. This is further underlined by several of the questions serving as a kind of checklist for potential problems – judging from the accepted applications studied in this paper, addressing the ethical side of a project is a question in which the RCN is satisfied with a one-sentence answer stating the absence of any ethical problems (as it was done in most of the applications).

However, the templates also state that some kind of relevance needs to be addressed in the applications. The template for FPs indicates that the application should start with 'a brief description of the relevance of the project relative to the call for proposals,' the BiP template for a project starts by asking applicants to 'Describe the underlying idea for value creation that provides the motivation for the R&D project,' and the KMB projects are initially asked to 'Describe the underlying knowledge challenges and needs that provide the justification for initiating the project,' while later also (like the BIP applications) being asked to outline the potential for value added in participating companies. Societal relevance is also addressed directly, in the RP template by having a section on 'Relevance and benefit to society,' while the KMB and BiP templates simply ask that the applications list 'Other socio-economic benefits' [other than to the involved companies]. Pointing out these kinds of benefits, thus identifying scientific opportunities made available if the research goes through, is clearly an opening to providing a kind of policy advice.

The templates are not the only guideline for applications – each call for applications also give specifics on what kind of research is suitable for that call and program. This is where a potential applicant would go to see what kind of challenges they are invited to address. As all the calls for Renergi are based on the Renergi program plan 2004-2013 (Research Council of Norway 2004),4 I have chosen to use this plan to examine which issues the applicants in the data have made their research relevant for.

The main goal of Renergi, as stated, is to ‘develop knowledge and solutions which can serve as foundation for environmentally friendly, economical and rational management of the country’s energy resources, high degree of energy supply security and internationally competitive industry development in connection with the energy sector’(ibid). The plan specifies this by listing a number of sub-goals related to energy efficiency and security: reductions in climate gas emissions, local emissions and area use; development of new products and services; development of knowledge that can facilitate government strategies, business strategies and public debate in the energy area; public policy instruments, energy systems and energy management that take into account the next generation of climate agreements and the long-term energy policy goals of the EU; and energy policies that foster value added in the energy sector and in the associated supplier industries ensuring that this sector continues to play its central role in the Norwegian economy.

The Renergi program plan’s evaluation criteria also explicitly state the importance of societal relevance, especially in its second result goal focusing on ‘Relevance and user orientation. All research in RENERGI shall be of use to/benefit Norwegian users (industry/commerce and authorities) – in a shorter or longer term. Cooperation with relevant users will therefore be a way to ensure relevance, but the form of such cooperation will vary’ (ibid pp. 16-7).

Hydrogen is one of seven issues given particular focus in RENERGI’s program plan. The plan notes that there has been a strong international focus on the development of hydrogen as an energy carrier, motivated by both environmental and energy security concerns. The often cited vision of ‘the Hydrogen Society’ is mentioned, as is the possibility of positive effects for both parties if hydrogen research can be linked to the Norwegian natural gas industry. In addition to the more general goals mentioned above, security issues and hydrogen in the transport sector are identified as particular challenges in hydrogen research (ibid p. 11).

No individual application is expected to address the entire Renergi program plan (and none of the studied applications did). Unlike the questions on ethical, gender and environmental issues above, which provided a checklist quite reminiscent of Latour's formatting plug-ins, the plan is a science policy document is giving account of a set of political goals, inviting suggestions on how scientific efforts can bring them closer. The RCN is asking the applicants to describe how what they wish to do aligns with and helps realize what the RCN wishes to do – the scientists are invited to translate extensive policy goals into definite research proposals.

Hydrogen visions – radical or incremental?

What kinds of visions are present in the applications, and how closely do they resemble the program plan? One starting point is the much alluded to vision of the 'Hydrogen Society' as outlined by Rifkin (2002), see also Ogden (1999), and Eames et al (2006). This vision was indeed present in the data, as could be seen when one application answered the question of implications for the environment by stating that 'The project concerns metal hydrides to be used for storage of hydrogen. This is an important part of the vision for the "Hydrogen Economy" and therefore very relevant for the physical environment.'5 However, hydrogen society visions seem to be less common than expected. The hydrogen society and/or –economy is explicitly referred to in 11 of the applications, but it seems to be more shorthand than a visionary painting – it is often referred to without much effort at describing it.

Do other visions play a more prominent role? Bakker & van Lente's (2007) overview of the various hydrogen visions that circulate in the international research community identify two main kinds of hydrogen visions: a) those that are 'pure' hydrogen visions, tied to the notion of a hydrogen society, a hydrogen economy or the like; b) those that are, in a sense, broader – that is, they draw on other visions like the climate issue, or democracy as by-product of distributed energy systems etc. My data supports the observation that broader visions are an important part of the picture. One such appeal to broader visions states that: 'Hydrogen has now widely been accepted as the ultimate medium- to long-term universal fuel to build the bridge for renewable energies to private mobility.'6 By describing hydrogen as a road to a shared goal, the applicant is connecting their work to the goals of Renergi in the manner suggested by Latour's third translation strategy. Hydrogen is a detour to the desired renewable future.

The idea of Norway as an energy nation was also clearly present in several applications, with a focus on Norway's role as a producer of fossil fuels and of Norway's large (potential) production of renewable energy. Emphasis could also simply be put on energy as an important part of the Norwegian economy: 'The energy sector is an area where Norway has vital interests and very good possibilities and basis. With the prospect of the liquefaction of hydrogen being an important technology in the future energy industry of Norway, it is very important to have independent knowledge within this area.'7 This is one of several examples of a vision with hydrogen as a cornerstone of the Norwegian energy sector – that sees hydrogen as connected to both natural gas use and renewables. Thus, hydrogen is inscribed on the vision of Norway as an energy nation. The unquestioning support of the continuance of the energy sector as the centerpiece of Norwegian economy resembles Latour's first translation strategy, with the researchers joining with the goals of the Norwegian state.

Elements of Latour's second translation strategy are also present in the applications. It is hard to draw the exact line between suggesting a detour (strategy three) and trying to convince the reader of the application that what she wants is actually what the applicant wants. Nevertheless, when hydrogen becomes a hardly-mentioned backdrop that is still a prerequisite for almost any other energy use, strategy two might be put in play:

The project will be an important step to realise high efficiency power plants. The technologies may be used to utilise a variety of hydrocarbon fuels, such as natural gas, biogas, gasified solid fuel and liquid fuels and will contribute to enable environmental friendly power conversion based on fossil and renewable fuels. Highly efficient and decentralised power productions will clear the way for other environmental technology improvements such as electrifying of transport or utilization of biomass, and also reduce the need of long distance power transport through large wires.8

Another vision is also invoked together with an attempt to use the second translation strategy – an idea that development of new technologies will lead to progress. This vision is obviously not unique for hydrogen technology, but nevertheless offers an opportunity to argue that since I want technology (and progress), you want what I want, too: 'Overall, this project covers broader aspects than research confined to either surface or bulk kinetics. This approach is novel and, moreover, essential to succeed in reaching an improved understanding of the overall process. Such fundamental insight will serve as the bases for development of new and better materials for existing industrial processes, as well as for the design of new technologies.'9

The visions found in the applications are variations on three themes: a future renewable/hydrogen society, a Norwegian future where energy (fossil and renewable) still plays a central role, and a vision of progress through developing new technologies. Referring to the hydrogen society places hydrogen in the center, but the implications are similar to those of promoting the renewable future as the goal, with hydrogen as the energy carrier enabling renewable energy sources to take on increased responsibilities. While fossil and renewable futures at first glance might seem like opposites, the themes are not always mutually exclusive. The argument that a combination of these are needed, with natural gas being the environmentally friendly option that is closest to realization, has been made repeatedly in Norwegian policy documents (see Swensen, 2010:30-31). The combination of the hydrogen society and connections to renewable energy as well as natural gas closely resembles what the Renergi program plan describes in its section on hydrogen. While the scientists accept the invite to translation that the plan issues, they do so by proposing incremental rather than radical visions: translation strategies are applied to show how the existing visions of the RCN can be deepened, broadened or strengthened by the technologies the applicants represent, but no alternative overarching vision is presented. Does this mean that the scientists are merely mirroring the program plan?

Relevance in the mirror?

If the scientists are merely mirroring the program plan, it would be reasonable to expect a fairly small variety in the ways which relevance is argued. In the following, I will use two approaches to explore how much variety there is to be found within the relevance arguments: a closer analysis of the five argument families that I found will be used to look at how the scientists argue in their applications, and simultaneously I will use the roles proposed by Pielke (2007) to look at the ways in which the scientists argue.

When looking closer at the arguments scientists present, I am looking for traces of three of Pielke's four roles in their argumentative repertoire: the Issue Advocate (trying to limit choice and convince others about a particular choice), the Science Arbiter (attempting to be a resource for the decision-maker, standing ready to answer factual questions without stating what should be preferred) and the Honest Broker (trying to expand or clarify) the scope of choice for decision-making in a way that allows for the decision-maker to make a choice based on his or her own preferences and values, thus tying science to policy alternatives). The role of a Pure Scientist, just sharing fundamental information about facts, clearly does not fit with the formatting that I in the former sections have established is happening.

The relevance arguments presented in the 55 analyzed applications were grouped into five different argument families (the numbers show number of applications with a specific argument):

- Politics (53)

- Environment (50)
- Economy (47)
- International (25)
- Safety (15)

The variations between the categories reinforce the impression that the goals outlined by the RCN must be adapted to specific projects by the applicants – the applications do not all argue relevance in the same way. However, the three first categories are present in a very large part of the applications (respectively 96, 91 and 85 per cent). How were these arguments presented and in what manner?

Arguments in the Politics category are characterized by references to explicit or implied political goals. Applicants might refer to political documents, citing the goals that these documents describe;

The Norwegian Hydrogen Committee describes in "Norwegian Public Review 2004:11 (NOU 2004:11) Hydrogen as the future energy carrier" that hydrogen storage systems/technologies is a key area for Norway. […] The program RENERGI within the Norwegian Research Council, for which this application is sent, also points out hydrogen storage as an important topic for research within the program.10

The NOU 2004:11 is often chosen as a point of reference. Some choose to point to international political goals, like the targets set by the US Department of Energy for hydrogen storage tanks. More direct regulations that need to be complied with are also mentioned, for example a soon-to be implemented Norwegian regulation on waste treatment.

While some of the references to political goals cite specific documents as a source, some choose instead to simply refer to the idea of a hydrogen society or hydrogen economy, or focus on the potential for hydrogen as a replacement for existing energy carriers, primarily within transportation: 'The efforts in developing durable and low-cost fuel cells for the transport sector are very large worldwide today. This is due to the potential environmental benefits and the compatibility with the introduction of a future hydrogen economy.'11 Arguing the benefits of a future hydrogen economy, especially without any disclaimers about this being only one of several possible futures, is clearly closest to the role of an Issue Advocate, a role not unexpected from an applicant. By making a case for seeing this future as a good scientific opportunity, this kind of issue advocacy combines identifying relevance with providing advice for science policy.

However, the arguments in the Politics category also lean on other roles scientists may take on when interacting with politics. The more direct references to the Renergi program plan and its goals are reminiscent of science arbitrage. By observing that the plan lists a challenge and offering research results to help solve it, what is achieved is a promise of science arbitrage. On the other hand, when the scientists make connections between the Renergi program and other policies – as they are expressed in national policy documents and in international (science) policy documents – what they are doing is somewhere between a promise of relevant expertise in an arbitraging manner and the Honest Broker's extension of the scope of choice by pointing out a wider context as relevant. That regulations not directly connected to hydrogen (like the aforementioned waste treatment regulation) are mentioned further reinforces that the scientists also apply an Honest Broker repertoire. A way of arguing somewhere between science arbitrage and honest brokering is also found when some of the applicants points out that their results are relevant as input to making policy, or that they through the research process will facilitate a dialogue that helps make clear what the policy is about, like when one applicant lists 'Establishing a common arena for exchange of knowledge and experience with the aim of reaching consensus between Norwegian stakeholders'12 as one of their goals.

The Environment category consists of both general statements about the environment and references to two specific environmental issues, climate (either explicitly or through reference to CO_2 emissions and carbon capture and storage, CCS), and local pollution. Different kinds of environmental relevance arguments could be employed in the same application:

Hydrogen is by many forecasted to be the energy carrier for the future, mainly because it is a renewable energy source and virtually non-polluting compared to other energy carriers like gasoline and diesel. There exist two main factors towards a change in the world's energy consumption, one global and more related to the manmade increase of the greenhouse effect due to a significantly enlarged use of fossil fuels, and secondly, the local pollution in the largest cities primarily due to exhaust gases from the transport industry. The environmentally consequences of this is tangible for most citizens and thus will be a political issue of growing importance within the most urban areas. This is the main reason why extensive efforts are made recently by the largest motor manufacturers on developing electrical vehicles. The motors can then be driven either by rechargeable batteries or fuel cells.13

Again both issue advocacy and (a promise of) science arbitrage are applied – this quote starts out from an advocacy standpoint by asserting that hydrogen is the (forecasted by many) solution for the future, and moves on to describe a set of problems to which a solution is offered. The orientation of the set of problems described is so broad that in a sense, (a promise of) honest brokering is also applied.

Making a clear distinction between these two categories requires a strict border between pre-described problems to which the applicants can offer a solution and a broader scope of choices that the applicants can argue the relevance of. However, the applicants were not always making clear distinctions between problems explicitly listed by the RCN and a wider contextualizing of these problems. This could again be seen in the Economy category, which includes arguments about relevance to the national economy and national interests, as well as more company-oriented arguments (referring to e.g. advantages 'regarding efficiency (reduced energy and raw material use), space requirements, and capital demand relative to conventional methods.'14). While references to the national economy invoke a sense of a broader context or of science arbitrage, again this was combined with a more advocacy-like presentation of hydrogen as a fitting solution to a number of problems:

Norway has vital interests in the energy sector and it is an area where an extensive knowledge basis exists. We are among the leading nations within the oil and gas industry and the income from this sector accounts for a very significant part of Norway's export revenues. Very likely, fossil fuels may be a basis for hydrogen production until cost efficient production from renewable energy sources like wind and wave power may take over. Even with such a scenario, Norway may have great economic opportunities.15

The three argument categories I have described so far (politics, environment and economy) were present in almost 90 per cent of the applications. However, the ways in which they were presented varied. In some cases the applicants seemed outright critical of official policy, with statements like 'Hydrogen technology is defined as a priority in Norway. We have a need to implement it in our country to reduce our CO2 emissions, and to contribute the same technology to rest of the world. This is our moral responsibility in return for our immense contribution to world CO2 outlets via our production and prosperity of oil and gas.'16 What the prevalence of these three argument categories indicates is thus not that the scientists argue in a way that directly mirrors the Renergi program plan. Instead, what becomes clear is an understanding of a relevant Renergi application as an application touching on these three themes – themes well founded in the program plan, but with considerable leeway when it comes to how the arguments within these three themes are presented.

While the first three argument categories represent a kind of minimum requirement, a strict formatting theme-wise, the presence of the two last argument categories in some of the applications further underline that the formatting gives room for different approaches as long as the aforementioned requirement is satisfied. The

Safety category straightforwardly states the need for the use of hydrogen as an energy carrier to be safe, that it must not involve a higher risk of accidents or more serious potential accidents than the energy carrier(s) being replaced today (gasoline/diesel). A branch of Norwegian hydrogen research has safety as their main focus, while others refer to it as one of the many issues that might be affected by their research. For the former, the hydrogen safety challenge presented in the program plan becomes a chance to offer science arbitrage by addressing hydrogen safety, and simultaneously advocating the importance of explosion modeling research: 'We know that detonations may occur, but we are not able to predict them. This insecurity has a retarding influence on the development of hydrogen infrastructure.'17

The International argument category contains two tendencies. Some point to the uniqueness of what is being done, or how it is world-leading: 'The primary objective of this project is to promote the implementation of technologies for hydrogen production from natural gas by providing a knowledge base unique for Norway.'18 The other kind of internationally oriented arguments emphasize the importance of hydrogen research through pointing to how many others are working on the same issues: '"The road-map to the hydrogen society" is not yet clear. Several barriers of a technological, economical and political nature have to be addressed. However, there seem to be a consensus that the aim is to finally get there. This is illustrated by the large efforts by governments, research institutions and industry worldwide.'19 The latter kind of international arguments resemble what Kårstein (2008: 86-7) describes as urging the reader to 'jump on the bandwagon', and is another case of applicants using an issue advocacy approach.

As stated above, exploring the way the scientists argue relevance in the funding applications makes it clear that rather than mirroring the Renergi program plan, the scientists operate with an understanding of which themes a relevant Renergi application has to address (with the themes in question being well founded in the program plan), but with a variety of ways in which arguments touching on these themes may be put. This latitude seems to be reflected in that the scientists take on more than one policy advisor role when presenting their case – both issue advocacy and promises of possible science arbitrage or honest brokering are part of their repertoire. This lack of one top-down format for arguments and advisor roles indicates that the scientists play an active role in defining what relevance should mean in the context of the Renergi program. Does this mean that we can see the scientist's relevance arguments as a kind of policy advice?

Funding applications as policy advice

One influential ideal for scientist's interactions with policy describes the task as 'speaking truth to power. Scientists, in this view, should independently establish the facts of the matter as well as they can be established; politicians can then decide how to act upon those facts, taking other social values into consideration' (Jasanoff 2011: 19). However, this linearity-autonomy model, emphasizing the separateness of scientific facts and political values, is difficult to employ to understand scientists seeking funding when the funding agency requires that the scientists argue the social as well as the scientific merit of their proposal. As I have shown, in the case of Renergi, an application is – through a fairly strict formatting – required to argue its own case not only as scientifically interesting but also as socially relevant.

This in-depth study of a set of funding applications has shown that while the Research Council through its guidelines provides a format within which the applicants must fit their relevance arguments, there is still a variety of ways in which applicants can reason within this format. I found a considerable diversity within the different argument categories, and also in how many different argument categories were employed. The scientists did not rely on presenting radically different visions from policy documents – suggestions were more incremental improvement of existing visions. This may be a reflection of a kind of 'business as usual'-stage for the involved technology – hydrogen technologies have a foothold in public policy documents, and thus refining existing visions is a more logical bridging between a specific proposal and policy goals than an introduction of a radically different vision. An important part of the scientists' incremental refinement of existing visions was their attempts at portraying hydrogen as essential for Norway's future as an energy nation – be that future founded on renewables, natural gas or a combination of the two. This employment of Latour's (1987) first translation strategy, with the researchers joining with the goals of the Norwegian state, is clearly an attempt at providing arguments for why hydrogen energy research should be given priority in current policy for science. Without arguing against any other possible technologies that may apply for funding from the Renergi program, hydrogen is presented in a way that fulfills its goal of 'environmentally friendly, economical and rational management of the country's energy resources' (Research Council of Norway 2004) without having to decide between founding such a resource management on renewables or on natural gas resources. Thus we see that funding applications are used as a channel for a specific, not too radical, form of policy advice.

What may we gain from understanding funding applications as a form of policy advice? With their proposition of a new 'Mode 2' kind of knowledge production and the idea of socially robust knowledge, Nowotny, Scott and Gibbons (2003:166) have suggested that scientists may be moving from the role of privileged gatekeepers of knowledge, and towards a continuous dialogue with non-academian actors about both the questions asked in their research and how the answers should be understood. However, a changing relationship between science and society entails two interwoven changes – while the public becomes more central in the assessment of scientific knowledge (as suggested by the concept of 'socially robust knowledge' by Nowotny, Scott and Gibbons 2003:210), simultaneously a space opens where scientists may take part in defining the societal relevance of research. Thus, this paper suggests that funding applications are an important site for study if we want to gain a closer understanding of how the proposed new science-society dialogue happens. While previous research on scientists giving advice to policymakers have focused on particular institutions established for this purpose (see e.g. Lentsch and Weingart 2011), this line of study should be supplemented with more in-depths studies of the ways in which scientists attempt to argue relevance, and thus 'overcome their fear of contamination by the social' (Nowotny, Scott & Gibbons 2001:235), showing through their combined advising and advocating why their matters of fact should be considered matters of (wider) concern (Latour 2004).

Notes

1. Numbers are from http://www.forskningsradet.no/prognett-renergi/Om_programmet/1226993846893 , accessed April 1, 2012. 2009 is the most recent number given for yearly funding.

2. http://www.regjeringen.no/upload/OED/pdf%20filer/Nettpublisering-nyeprosjekter2012.pdf , accessed April 1, 2012, has a description of the Renergi funding decision process.

3. http://www.forskningsradet.no/prognett-renergi/Programstyre/1226993846871 , accessed April 1, 2012, lists the members of the Renergi Program Board.

4. An update to the plan for the period 2010-2013 also exists, however it has not been used in this analysis as it was adopted on April 7th 2010, and thus was not accessible for the applicants when they wrote the funding applications analyzed.

5. FP1(see the method section for further explanation of the abbreviations used in this and the following notes)

6. FP10

7. FP3

8. BIP24

9. FP13

10. FP3

11. FP2

12. KMB3

13. FP7

14. BIP22

15. FP3

16. FP16

17. BIP18

18. KMB5

19. FP3

References

Bakker, S., & van Lente, H. (2007) 'Fuelling Chained Expectations in Hydrogen Communities', *International Summer Academy on Technology Studies – Transforming the Energy System*. Deutschlandsberg, Austria.

Benner, M., & Sandström, U. (2000) 'Inertia and change in Scandinavian public-sector research systems: the case of biotechnology', *Science and Public Policy*, 27/6: 443-54.

Callon, M. (1987) 'Society in the Making: The study of Technology as a Tool for Sociological Analysis'. In: Bijker, W. E., Hughes, T. P. & Pinch, T. J. (eds.), *The Social Construction of Technological Systems. New Directions in the Sociology and History of Technology*, pp. 83-103. MIT Press: Cambridge, MA.

Corbin, J. M., & Strauss, A. L. (2008) *Basics of qualitative research: techniques and procedures for developing grounded theory.* Sage Publications: Thousand Oaks, CA.

Demeritt, D. (2000) 'The New Social Contract for Science: Accountability, Relevance,and Value in US and UK Science and Research Policy', *Antipode*, 32/3: 308-29.

Dierkes, M., Hoffman, U., & Marz, L. (1996) *Visions of Technology*. Campus Verlag/St. Martins Press: Frankfurt/New York.

Eames, M., Mcdowall, W., Hodson, M., & Marvin, S. (2006) 'Negotiating contested visions and place-specific expectations of the hydrogen economy', *Technology Analysis & Strategic Management*, 18/3-4: 361-74.

Etzkowitz, H., & Leydesdorff, L. (2000) 'The dynamics of innovation: from National Systems and "Mode 2" to a Triple Helix of university-industry-government relations', *Research Policy*, 29: 109-23

Galison, P. (1997) *Image and logic: a material culture of microphysics*. University of Chicago Press: Chicago.

Gjøen, H. (2001) *Gasstanker: en sosiologisk studie av visjoner og virkelighetskonstruksjoner knyttet til bruk av naturgass i Norge.* PhD dissertation (Norwegian University of Science and Technology).

Hansson, F. (2010) 'Dialogue in or with the peer review? Evaluating research organizations in order to promote organizational learning', *Science and Public Policy*, 37/4: 239-251.

Hessels, L. K., & van Lente, H. (2008). 'Re-thinking new knowledge production: A literature review and a research agenda.' *Research Policy*, 37(4), 740-760.

Hessels, L. K., van Lente, H., & Smits, R. (2009) 'In search of relevance: the changing contract between science and society', *Science and Public Policy*, 36/5: 387-401.

Holbrook, J. B., & Frodeman, R. (2011). 'Peer review and the ex ante assessment of societal impacts.' *Research Evaluation*, 20(3), 239-246.

Hydrogenplattformen. (2006) *Nasjonale prosjekter* <http://www.forskningsradet.no/servlet/Satellite?c=Page&cid=1234130625668&pagename=hydrogen/Hovedsidemal> accessed 2 Nov 2010,

Irwin, A. (2006) 'The Politics of Talk: Coming to Terms with the "New" Scientific Governance', *Social Studies of Science*, 36/2: 299-320.

Jasanoff, S. (1990) *The Fifth Branch - Science Advisers as Policymakers*. Harvard University Press: Cambridge, MA.

Jasanoff, S. (2011) 'Quality control and peer review in advisory science'. In: Lentsch, J. & Weingart, P. (eds.) *The Politics of Scientific Advice - Institutional Design for Quality Assurance*, pp. 19-35. Cambridge University Press: Cambridge.

Jasanoff, S., & Wynne, B. (1998) 'Science and decisionmaking'. In: Rayner, S. & Malone, E. L. (eds.) *Human Choice & Climate Change. Volume 1. The societal framework*, pp. 1-87. Batelle Press; Columbus, OH.

Kårstein, A. (2008) *'HyNor – den norske hydrogenveien? En studie av en stor tekno-politisk hybrid'*, PhD dissertation (Norwegian University of Science and Technology).

Lamont, M. (2009) *How Professors Think. Inside the Curious World of Academic Judgement*. Harvard University Press: Cambridge.

Latour, B. (1987) *Science in action: how to follow scientists and engineers through society*. Open University Press: Milton Keynes.

Latour, Bruno. 2004. 'Why Has Critique Run out of Steam? From Matters of Fact to Matters of Concern.' *Critical Inquiry* 30 (2): 225-248.

Latour, B. (2005) *Reassembling the Social: an Introduction to Actor-Network-Theory.* Oxford University Press: Oxford.

Lentsch, Justus, and Peter Weingart (eds.). 2011. *The Politics of Scientific Advice - Institutional Design for Quality Assurance*. Cambridge: Cambridge University Press.

Malone, E. (2009) *Debating Climate Change. Pathways through Argument to Agreement.* Science in Society Series. Earthscan: London.

Nowotny, H., Scott, P., & Gibbons, M. (2001). *Re-Thinking Science.* Cambridge: Polity Press.

Nowotny, H., Scott, P., & Gibbons, M. (2003). 'Mode 2 Revisited: The New Production of Knowledge.' *Minerva*, 41(3), 179-194.

Ogden, J. M. (1999) 'Developing an infrastructure for hydrogen vehicles: a Southern California case study', *International Journal of Hydrogen Energy*, 24/8: 709-30.

Pielke Jr., R. A. (2007) *The honest broker: making sense of science in policy and politics*. Cambridge University Press: Cambridge.

Research Council of Norway (2004) *Programplan 2004-2013. RENERGI: Clean Energy For The Future.* Research Council of Norway: Oslo.

Rifkin, J. (2002) *The Hydrogen Economy*. Penguin Putnam Inc.: New York.

Swensen, E. F. (2010) *'Gass i fornybarsatsingen - Eller en fornybar satsing på gass ? En studie av den norske energisatingen på 2000-tallet'*, Master's thesis (Norwegian University of Science and Technology).