Hydrogen research: technology first, society second?

Hydrogen futures are in the making right in front of our eyes and will determine socio-ecological path dependencies for decades to come. However, expertise on the societal effects of the hydrogen transition is in its infancy. Future energy research needs to include the social sciences, humanities and interdisciplinary studies: energy cultures have to be examined as well as power relations and anticipation processes since the need for (green) hydrogen is likely to require a massive expansion of renewable energy plants.

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Hydrogen has a centuries-long history as a potential secondary energy carrier. Particularly within the last two years, this potential is being put into reality in the European Union. A hydrogen strategy has been released and model regions called *European Hydrogen Valleys*[1] have been set up as blueprints for future hydrogen energy systems. The various hydrogen infrastructures differ, for example, on whether they are built in polycentric or monocentric settlements, rely on so-called green, blue or gray hydrogen, import hydrogen from other parts of the world or produce it on-site, strive toward energy system integration or a single application. In other words: hydrogen brings with it a variety of potential infrastructure combinations each affecting socio-ecological developments differently.

We identify a gap between political action, technological developments and expertise from the social sciences and humanities in the hydrogen transition. We argue that the respective funding and research needs to be scaled up. Building energy infrastructures in a technocratic manner without knowledge about the societal effects of hydrogen as an energy carrier could otherwise result in long-lasting socio-ecological mismatches.

Contested hydrogen futures in the making

"Clean hydrogen is a perfect means towards our goal of climate neutrality," claims the president of the European Commission, Ursula von der Leyen.[2] In 2020, the *EU Strategy for Energy System Integration* was complemented by a *Hydrogen Strategy for a Climate-neutral Europe*, making hydrogen a core element of Europe's energy future. Companies and industry as well as national and public authorities are already participating in the EU's *European Clean Hydrogen Alliance*.[3] Accordingly, many EU member states are promoting both types of clean hydrogen: green – produced with renewables – and blue – produced with fossil fuels with carbon capture and storage. Germany, for example, has launched a nine billion Euro program for hydrogen technology innovation,[4] revised its *Energy Industry Act (Energiewirtschaftsgesetz, EnWG)*[5] to regulate the expansion of a hydrogen network and in its *HyLand* project[6] is supporting twenty-five model regions.

Yet, Europe's hydrogen transition is embedded in an almost incomprehensible number of emerging institutions, projects and initiatives worldwide.[7] Consequently, debates on the possible effects of the hydrogen energy system, composed of all elements that comprise the production, conversion, transportation and usage of hydrogen energy, are increasing (Van Renssen 2020). While some see a vital contribution to achieving the 1.5 to 2 °C target of the *Paris Agreement* on climate change (IRENA 2020a, 2020b), especially in green hydrogen, others are skeptical about hydrogen's impact on socio-ecological transformations, assuming it merely replaces fossil fuels while reproducing existent injustices (Balanyá and van Scharen 2020). Again, while some assume that a hydrogen economy provides sustainable jobs in Europe (Kaiser and Malanowski 2020), others fear that hydrogen imports enforce unregulated working conditions and (post)colonial structures of exploitation in some producing countries (Van de Graaf et al. 2020). Yet, governance approaches that proactively and systematically take these societal effects into account are hard to find.

This also holds true for research, where systematic investigations on societal effects are missing. The same pattern seems to emerge as in climate change research in general: only 0.12 % of research funding is allocated to the social sciences (Overland and

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Sovacool 2020). This ignores experiences of the on-going renewable energy transition, in which it has been shown that understanding the role of societies is as important as the technology itself – the scientific knowledge and how it is used in building an energy system (Davidson and Gross 2018). Respective studies have investigated, for example, citizens' associations for and against wind turbines or transmission lines (Radtke et al. 2020), protests against the uncertain future of coal regions (Leipprand and Flachsland 2018), or democratization of the energy system through decentralization with solar panels on rooftops (Szulecki and Overland 2020).

Hydrogen research in the social sciences and humanities can currently not cope with the pace of political action and technological development. Therefore, we argue for speeding up and scaling up relevant research.

Hydrogen research is fragmentary

Currently, there is rarely any inter- and transdisciplinary sustainability research on hydrogen that reflects on societal development.[8] The only journal specialized in hydrogen research, the *International Journal of Hydrogen Energy*, focuses on the technological aspects of hydrogen. In particular, it seems as if reflexive research on the hydrogen transition has to catch up even more than research for the hydrogen transition since the first major projects for the latter, such as *HyPat*[9], a global hydrogen potential atlas, are already in the making. Hydrogen-society interactions that consider the interplay of the mentalities, institutional and material dimensions of hydrogen infrastructures, have to take center stage (Harvey et al. 2019).

Summarizing the few current publications in this area, three fields of investigation can be identified: perception and acceptance of hydrogen, its social costs and consequences, and ethnographic studies on the making of hydrogen energy cultures.

Research on perception and acceptance of hydrogen

At the beginning of the 2000s, acceptance research classified hydrogen technology and fuel cells as largely unknown by the general public (Altmann et al. 2004). More recently, it was found that hydrogen is supported as a solution to sustainability problems in many countries in the Global North (Scott and Powells 2020b, Achterberg et al. 2010). Concerns, in particular in private households in terms of heating and cooking, are primarily related to the high explosiveness of hydrogen (Scott and Powells 2020a). Studies on acceptance are limited to certain applications of hydrogen and specific geographic regions (Achterberg 2012, Apostolou and Welcher 2021, Glanz and Schönauer 2021, Iribarren et al. 2016).

Research on social costs and consequences

A second field deals with the social costs or consequences of establishing hydrogen regimes. At the level of international relations this includes geopolitical rearrangements: dependence on countries and organizations extracting fossil fuels might decrease, while at the same time new hydrogen exporters, such as Chile or Australia, would gain influence, which will affect society in these countries (Van de Graaf et al. 2020, Pflugmann and Blasio 2020). As calls for energy autarky are increasing, assessments even identify green energy potentials large enough to produce hydrogen within Europe (Kakoulaki et al. 2021). Schlör et al. (2017) use data from exporters of hydrogen to calculate the social footprint for Germany, Austria and Spain. The analysis shows, for example, how social conditions in Chinese production facilities influence the social footprint of hydrogen usage in Germany. Another report expects rising energy costs due to hydrogen use for private households in Germany (Committee on Climate Change 2018).

Research on hydrogen energy cultures

One additional, rather ethnographic, field explores the making of hydrogen cultures and futures. The focus of these studies is so far a project on the Orkney Islands in Scotland as a first-of its-kind wind-to-hydrogen regime that integrates hydrogen production with mobility, heating and electricity generation. Based on ten years of fieldwork, Watts (2018) develops an energy saga of the Orkney Islands that takes into account the 6,000 years of technology development on the islands, the agency of waves and stones, poetry, >

1 *www.h2v.eu*
2 Speech by President von der Leyen to the hydrogen council: *https://ec.europa.eu/commission/presscorner/detail/en/SPEECH_21_158.*
3 *www.ech2a.eu*
4 *www.bmwi.de/Redaktion/DE/Publikationen/Energie/die-nationale-wasserstoffstrategie.pdf?__blob=publicationFile&v=20*
5 *www.bmwi.de/Redaktion/DE/Downloads/Gesetz/gesetzentwurf-enwg-novelle.pdf?__blob=publicationFile&v=4*
6 *www.now-gmbh.de/sektoren-themen/sektorenkopplung*
7 Including the *Hydrogen Global Initiative* of the World Energy Council: *www.worldenergy.org/impact-communities/innovation/hydrogen-charter*, and the *Hydrogen Energy Ministerial Meeting* of the Clean Energy Ministerial forum: *www.cleanenergyministerial.org/initiative-clean-energy-ministerial/hydrogen-initiative*.
8 *GAIA* itself is a prime example with only three articles, in issue 2/2000 (*GAIA* 9/2), that explicitly mention hydrogen. All three were written on the occasion of the *HYFORUM 2000* in Munich and formulate expectations for the future use of hydrogen on the basis of technical considerations.
9 *www.wasserstoff-leitprojekte.de/grundlagenforschung/transport_import*

the voices of investors and local communities. She demonstrates the entangled forces at play in the making of a local low carbon energy future. Studying the same islands, Westrom (2020) focuses in his ethnographic account on the conflictual negotiations in the Scottish community on the distribution of financial gains and shifts in the local governance structure.

Future hydrogen research

Findings on the societal dimensions of hydrogen are fragmentary, also in terms of their geographical focus. This does not do justice to hydrogen futures that are already in the making and, as with previous energy carriers, expected to determine socio-ecological path dependencies for decades to come. Energy research from a social science and humanities perspective can still become part of these developments. It does not have to be limited to acceptance research or conflict studies after technological infrastructures are established, or to retell the history of the hydrogen energy transition some decades from now. Our aim in the following section is to open a new field of study on hydrogen-society interactions, which we understand as a result of the above-mentioned interplay of the mentalities, institutional and material dimensions of hydrogen infrastructures. We assign each of the dimensions to one branch of science and propose six fields of investigation to encourage a debate on which areas need to be addressed.

Humanities and the mentalities dimension of hydrogen infrastructures

1. Hydrogen as an energy carrier corresponds to influential sets of mentalities, histories and envisioned materialities. This statement calls for research on hydrogen energy cultures (Stephenson et al. 2010, Pfister and Schweighofer 2018). The hydrogen roots detected might be highly surprising: during World War II hydrogen was used by the Nazis to make synthetic fuels out of coal (Strangers 2000). More recently, Stephenson et al. (2021) described different national decarburization pathways in India, Denmark, China, and Russia that derived from different energy cultures and historical developments over the past 30 years. What kind of hydrogen energy cultures, also in comparison to other energy carriers such as oil or uranium, are emerging and to which pathways are they pointing?

2. Hydrogen brings with it genuine aesthetics that will engender distrust, approval and rejection in societies. This requires an understanding of how aesthetics can be steered. Literature provides an emotional and philosophical interpretation of energy, going beyond the often objective accounts of the sciences (Scott 2020). In a similar vein, the arts can help to reflect, criticize and inspire the ongoing hydrogen transition and raise awareness of its potentials and dangers. This includes, for example, Peter Fend's experimental proposal *Submarine for Conversion of Plastics and Biomass,*[10] a concept for producing methane and hydrogen by repurposing

Russian nuclear submarines to harvest plastic waste and brown algae from the sea for energy production. Which sources allow for a reflection of the aesthetics of hydrogen and how can they be incorporated in the hydrogen transition?

Social sciences and the institutional dimension of hydrogen infrastructures

3. Hydrogen technologies require governance arrangements that guide their development. This requires identifying what the governance arrangements should look like. We know that technological development is not neutral, but emerges under specific societal, economic and political circumstances (Johnsen and Jameson 2021). Together, hydrogen technologies will form larger infrastructures that produce winners and losers, create and dissolve borders and build path dependencies for future generations as part of the larger technosphere (Harvey et al. 2019, Thacker et al. 2019, Zalasiewicz et al. 2017). What characterizes good hydrogen governance and how can it foster the potentials of hydrogen?

4. The hydrogen transition interferes with existing manifestations of intersectionality and inequality. This statement calls for the examination of implicit power structures. As energy-society interactions have shown, this includes forms of oppression between and within countries, novel (post)colonial structures, and shifts from petro- to hydrogen-masculinity already observable when looking at the management boards of hydrogen projects (Daggett 2018, Bell et al. 2020, Newell 2021). In addition, questions of distributive justice and usage conflicts are imminent as the demand for (green) hydrogen might not only be higher than production capacities, but may also require a massive expansion of renewable energy plants. To what extent are marginalized voices part of the making of hydrogen futures and how can they be strengthened?

Interdisciplinary sciences and the material dimension of hydrogen infrastructures

5. As an element, hydrogen is not only relevant for the energy transition but in manifold entanglements is also part of our socio-ecological systems. This requires a contextualization of hydrogen in the energy transition in contrast to its other occurrences. From a planetary perspective (Hanusch et al. 2021), this includes understanding hydrogen as a "hyperobject" (Morton 2013) and thus not only as an energy carrier, but also as the first atom that formed after the Big Bang and the most common atom in the universe. It can be harnessed in hydrogen bombs to destroy the planet and as a means of energy storage to save it, or it occurs as an intermediate product in the chemical industry. Which interrelations with hydrogen have societies built, which ones should be terminated and which novel connections should be fostered?

6. The hydrogen transition will create path dependencies for decades to come. This requires inclusive anticipation processes. Social impact assessments are an established approach to understanding the societal effects of infrastructure projects, particularly relevant when developing costly technologies such as hydrogen energy systems (Zhao and Ravn Nielsen 2018). Here, one can tie in with examples on how emerging knowledge-based technologies such as hydrogen can be steered (Nordmann 2014). On this basis, anticipation workshops involving citizens need to build "hydrogen literacy," not only to cope with but also to co-create hydrogen futures and formulate transferable learning from the renewable energy transition of the past decades (Boyd et al. 2015). How should a truly democratic anticipation exercise be designed?

10 *zkm.de/de/node/26595/a-f#submarine-for-conversion-of-plastics-biomass*

Conclusion

Hydrogen energy is becoming an additional layer of energy infrastructure, bringing with it various forms of innovation, exnovation, renovation and imitation of energy-society interrelations. While we demonstrated that research in the social sciences and humanities can currently not cope with the pace of political action and technological development, we also argued for speeding up and scaling up relevant research to make the hydrogen transition not solely a technocratic one. Ultimately, every energy transition is also a cultural transition. Understanding that can help us use the hydrogen transition as a catalyst not only for a more democratic European energy union, but also for reducing our impact on the earth system.

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