Energy Proceedings
Vol 29, 2022
ISSN 2004-2965

Building new H2 pipelines or repurposing natural gas pipelines for H2 admixture? – An economic perspective on effective climate mitigation#

Franziska M. Hoffart[1, 2]

[1] Institute for Macroeconomics, Ruhr-University Bochum, Universitätsstraße 150, Bochum, Germany, franziska.hoffart@rub.de
[2] Energy, Transportation, Environment Department, German Institute for Economic Research, Mohrenstraße 58, 10117 Berlin

ABSTRACT

Emission-free hydrogen is a crucial contributor to the decarbonization of the energy supply. To establish a H2 economy, a H2 infrastructure is needed and requires investment and energy policy decisions today. The aim of the paper is to inform these decisions by comparing and contrasting the construction of new H2 pipelines with the repurposing of natural gas pipelines for future H2 admixture.1) feasibility and (2) 1.5°C alignment are proposed as evaluation criteria for effective climate mitigation. The results show that building new H2 pipelines for renewable H2 is feasible and 1.5°C-aligned. Gas pipeline investments for future retrofitting are not recommended due to energy transition risks such as fossil-lock in and asset stranding.

Keywords: Hydrogen supply chain, energy transition, renewable hydrogen, energy infrastructure, transition risk, climate-related risks

NONMENCLATURE

Abbreviations	
H2	Hydrogen
CCS	Carbon capture and storage
CH4	Methane

1. INTRODUCTION

Hydrogen (H2) is a key component of a decarbonized energy supply and thus climate mitigation [1,2]. Establishing a H2 economy represents a three-fold chicken and egg problem of coordinating what comes first – supply, demand or infrastructure. A pipeline infrastructure for H2 is critical for unlocking the potential of H2 and facilitating the development of an H2 economy. Therefore, investment and political decisions for a H2 pipelines infrastructure are required today. These decisions are relevant for economic actors who operate Germany's energy infrastructure and political decision-makers, who set the political conditions.

However, it is uncertain what the infrastructure should look like and what requirements need to be met [3]. Therefore, the investment and political decisions are not trivial. New infrastructure will shape the energy system and related emissions for decades due to its long technical lifespan [4]. Different supply chains might develop, which depend on the type, amount and production method of H2 (supply side), but also on potential applications and users (demand side). There is also the question of whether new pipes should be built or old gas pipelines should be repurposed [5,6]. This question concerns the usage of carbon capture and storage (CCS) as well as the future of fossil natural gas (infrastructure) [7]. Despite the fact, that only renewable H2 is regarded as sustainable in the long, using non-renewable fossil-based hydrogen is also discussed [8,9] and decisive for the design of H2 pipelines.

For effective climate change mitigation, other considerations are relevant as well. Given the urgency for climate mitigation, an infrastructure that is technically feasible but has a low chance of succeeding is problematic. The same is applicable to new infrastructure that does not comply with the Paris Agreement and may be forced to shut down before its technical lifespan ends.

The aim of the paper is thus to compare and contrast two infrastructure options, namely building new H2 pipelines and repurposing natural gas pipelines for H2 admixture, to inform investment and political decisions. *(1) feasibility* and *(2) 1.5°C-alignment* are proposed as suitable evaluation criteria. The paper offers a new approach that includes insights from different disciplines for a holistic, socio-technical analysis. The following research question is answered: In order to effectively mitigate global warming, should new H2 pipes be constructed, or should natural gas pipelines be repurposed for H2 admixture?

The remainder of the paper is structured as follows. Section 2 describes the approach and the criteria in more detail. In section 3, the results are presented. Section 4 offers recommendations regarding the establishment of a H2 economies. The paper ends with concluding remarks.

2. APPROACH

I propose that investments and political decisions related to H2 infrastructure should be based on two criteria, namely *1) feasibility* and *2) 1.5°C-alignment.*

The criterion of *feasibility* is based on the understanding that energy transitions, which include building new infrastructure, are socio-technical transitions [10,11]. How these systems develop depends on economic, political, social and technical aspects [10–12], which need to be considered. Based on Hoffart et al. [13], Schubert et al. [14], Majone [15], I define feasibility as a high chance of implementation. A H2 infrastructure is feasible if it is technically (necessary precondition), economically, legally and sociologically feasible and finds majorities in political decision-making [12,13]. Additionally, all constraints need to be considered and solved for an option to be feasible [15].

The criterion of *1.5°C-alignment* is crucial as an economic factor for H2 infrastructure investment and energy policy decisions. It implies a backward-looking perspective from an emission-free future to the present and investigates the impact of H2 infrastructures on the environment and energy transitions.

I apply these criteria to two H2 pipeline infrastructure options for Germany within a European H2/CCS chain. For reasons of simplicity, is assume that Norway is exporting blue H2 to Germany, where it is mixed into the natural gas grid. CO2 from carbon capture technologies is transported to the Netherlands for offshore storage (CCS). In Option 1, blue H2 from Norway is imported to Germany and blended into the Germany natural gas grid. In Option 2, new pipelines for H2 are build.

For the evaluation of these two-infrastructure options – I refer to *(1) pipeline reuse and admixture* and *(2) new H2 pipelines* – a four step approach is applied.

In step one, researchers from the disciplines of economics (the author), sociology, law and engineers are asked in semi-structured interviews to identify three implementation requirements per infrastructure option (3x2) that need to be met for a successful implementation. In a second step, these implementation requirements were grouped in fostering and hindering requirements and were used to identify the most feasible infrastructure option. In step three, I assessed the environmental implications of the two infrastructure options by comparing renewable and green hydrogen. In the last step, I compared implications of the two infrastructure options on energy transition regarding the climate-related energy transition risks of assets stranding and fossil lock-ins.

3. RESULTS

3.1 Analysis of feasibility

An overview of the implementation requirements is presented in Table 1. The researcher from engineering did not see any purely technical, but only techno-economic requirements. This interesting finding is in line with the paper's understanding of feasibility, which defines technical feasibility as a necessary, but insufficient precondition for a successful implementation.

Reuse and admixture		***New H2 pipelines***	
	Discipline of law		
2.1	Cost allocation of blue H2 production	3.1	Legal regime for H2 pipelines
2.2	Clarification of gas definition	3.2	Non-discrimination of blue H2
2.3	Coordination of gas quality	3.3	H2 tariffs regulations
	Discipline of sociology		
2.4	Acceptance of pipeline retrofitting	3.4	Acceptance of H2 pipelines
2.5	Synergies with renew. energy systems	3.5	Synergies with renew. energy systems
2.6	Acceptance for H2	3.6	Acceptance of H2
	Discipline of economics		
2.7	Competitiveness of H2	3.7	Governmental market incentives
2.8	H2 demand for admixture	3.8	High demand for H2
2.9	Supply for H2 admixture	3.9	High supply for H2
	Discipline of engineering		
2.10	Incentive to inject H2	3.10	Competitiveness of H2 technologies
2.11	Constant H2 admixture <30%	3.11	Low-cost H2 pipelines
2.12	Investments in pipeline retrofitting	3.12	Infrastructure synergies via industry hotspots

Table 1: Overview of implementation requirements
Source: Author's own contribution

To distil the critical implementation requirements which either foster or hinder the implementation of the two infrastructure options, each researcher has evaluated the chance of realization and the costs of the key

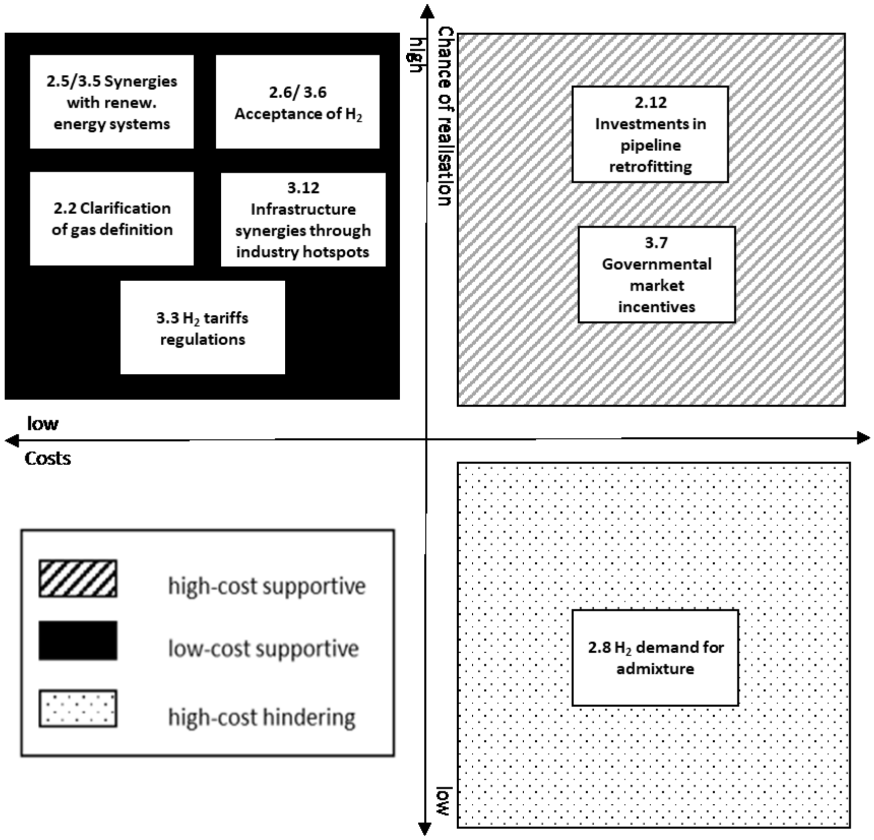

Figure 1.: Critical implementation requirements
Source: Authors' elaboration

requirements they have identified (on a scale from low-medium-high). The results are displayed in Figure 1.

While fostering requirements imply a high chance of realization, hindering means to have a low chance. The costs display the effort that needs to be taken to fulfill the requirements (financial, as well as non-financial). Three types of implementation requirements were revealed to be crucial: (1) low-cost supportive requirements, (2) high-cost supportive requirements, and (3) high-cost impediments. The former can be referred to as low-hanging fruits and represent the majority of requirements. The majority of supportive low-cost requirements are sociological in nature. There were no low-cost hindering requirements. While no techno-economic implementation requirements were categorized as hindering, the hindering requirement is economic in nature. As the most supportive and least hindering implementation requirements refer to option 2 – new H2 pipelines – it is regarded as most feasible.

3.2 Analysis of 1.5°C-alignment

The infrastructure's environmental implementations are primarily determined by the energy carriers[2]. More precisely, the difference between renewable and fossil-based H2 are revealed to be crucial. Renewable H2 produced through electrolysis with renewable energy has close to zero GHG emission along the lifecycle [16,17]. Therefore, only renewable H2 is sustainable in the long run [17,18].

Although blue H2 is considered a low-carbon energy carrier, due to the use of CCS technologies, it is not without emissions and environmental consequences. While the CO2 emissions from production of H2 from natural gas and CCS (30-120 $gCO2_{eq/}$ KWhH2) are lower compared to alternative fossil sources such as coal (570 $gCO2_{eq/}$ KWhH2) or natural gas without CCS (300 $gCO2_{eq/}$ KWhH2), renewable H2 has close to zero CO2 emissions [17]. Blue H2 has high GHG emissions along the entire lifecycle, which also includes methane (CH4) emissions of natural gas [8]. Due to the high global warming potential of CH4 compared to CO2, it is important to take CH4 into account. Direct CH4 emissions are caused by natural gas extraction, transport and storage through leakages or intended flaring and venting.

Additionally, CCS has undesired consequences for the environment and for humans, such as salination of

[2] The GHG emissions related to the construction of pipelines exceed the scope of the paper.

ground water [8]. The process of CCS requires additional energy [19]. Under current law, carbon storage is not allowed in Germany [20], which means storage abroad is required. It is also unclear if there will be sufficient and safe international storage capacities [21]. From an ethical perspective, the monitoring of CCS places a huge burden on future generations [22].

To avoid negative consequences of electrolysis associated with the high demand for water, regulations for an efficient use of water and the withdrawal of surface and ground water is advisable to, e.g., guarantee supply of drinking water for local people [23]. From an environmental perspective, renewable H2 is thus preferable. Thus, I conclude that H2 infrastructure should be adjusted to renewable H2.

Although green H2 is expected to become cheaper than blue H2 in the future [9], it will remain scarce. As the demand cannot be satisfied with green H2 from Germany, imports are needed, so that green H2 is too valuable for admixture into the natural gas grid. It should only be used in hard-to-abate sectors, such as the steel and cement industry. As the industry mainly needs pure H2, pipeline retrofitting for less than 100% H2 is not advisable [23].

Still, the question remains if these grids should consist of new H2 pipelines or repurposed gas pipelines. Kemfert et al. [24] argue that the expansion of natural gas infrastructure implies serious risks for energy transitions. Following this line of argumentation, investments in gas pipelines for future retrofitting for H2 admixture entail multiple risks.

Firstly, investments in fossil supply chains might imply the creation of carbon lock-ins [25,26]. Fossil fuel dependencies and related emissions can become locked-in, as infrastructure is used for a long time [27]. Fossil natural gas lock-ins are becoming particularly relevant [24] and are enforced by investments in fossil energy infrastructure [28]. Investments in natural gas infrastructure thus create technological lock-ins by establishing technological systems comprising the whole value chain of energy [29].

Second, investments in natural gas infrastructure may result in transition risk associated with changing policies and preference that come along with transitions to zero-emissions systems (also known as transition risks)[30]. Especially the stranding of fossil (energy) assets represents a main challenge for energy transitions [31]. Climate policies impose limits to usage of fossil natural gas and related infrastructure [32]. Investments in natural gas infrastructure might strand even before retrofitting might occur. Tong et al. [4] calculate, for example, that emissions from existing and planned energy infrastructure already exceed the entire 1.5°C-emission budget.

In sum, these considerations reveal, that building new pipelines instead of investing in gas pipelines for future retrofitting is preferable from an economic and transition view.

4. DISCUSSION

The analysis showed that new pipelines for renewable H2 are feasible as well as 1.5°C-aligned and can thus support effective climate mitigation. Putting H2 pipelines into practice is linked to the three-fold chicken and egg problem of coordinating H2 infrastructure, H2 demand and H2 supply.

To enable trade and transport of H2 from the supplier to the demand side, a H2 supply chain is required. Future H2 suppliers might not offer H2 when there is insufficient demand or transport options. To make binding purchasing agreements, an attractive offer (sufficient amount, decent price and transportation) is needed.

While the energy infrastructure is mainly constructed and operated by economic actors, policy-makers set the framework conditions and can indirectly influence the market ramp up. In the following, I offer recommendations based on SRU [21] for both for economic investment and political policy decisions that refer to the different aspect of infrastructure, demand and supply based on (see Table 2).

Infrastructure
• New demand-oriented pipelines for renewable H2
• Step-by-step construction near industry clusters
• Combine H2 pipelines development with gas and energy development plans and emission budget
Supply
• Significant expansion of renewable energies
• Political decision for a natural gas exit
• Subsidies only for renewable hydrogen
Demand
• H2 certification to ensure sustainability criteria
• Contracts and quotas between H2 buyers and sellers

Table 2: Recommendations

5. CONCLUSION

This study represents an evaluation of two H2 pipeline infrastructure options for Germany in terms of *(1) feasibility* and *(2) 1.5°C-alignment* to inform investment and energy policy decisions. Pipeline infrastructures, that are feasible but not in line with climate goals, lead to economic risks and delay energy transitions. The same applies for infrastructures that are 1.5°C-aligned but not feasible, as they can hardly be implemented.

The analysis of the implementation requirements showed that the chances for a successful H2 infrastructure implementation are generally high in Germany, as there are more supportive than hindering implementation requirements (criterion 1).

Assessing the environmental and energy transition impacts (criterion 2) revealed that only renewable H2 is sustainable. Due to the scarcity of H2, admixing renewable H2 into the natural gas grid is not recommended for efficiency and economic reasons. Also, blue H2 is not without emissions and has negative environmental implications. Investments in the gas grid for future retrofitting has revealed to present serious risks for the energy transition through lock-ins and asset stranding. In sum, new H2 pipelines (option 2) for green H2 is the most feasible and 1.5°C-aligned option.

ACKNOWLEDGEMENT

This research is partly based on the ACT ELEGANCY, Project No 271498, which has received funding from DETEC (CH), BMWi (DE), RVO (NL), Gassnova (NO), BEIS (UK), Gassco, Equinor and Total, and is cofunded by the European Commission under the Horizon 2020 programme, ACT Grant Agreement No 691712.

References

[1] IEA. Global Energy Review: CO2 Emissions in 2021; 2022.
[2] IRENA. Hydrogen: A renewable energy perspective; 2019.
[3] Wietschel M, Hasenauer U, Groot A de. Development of European hydrogen infrastructure scenarios—CO2 reduction potential and infrastructure investment. Energy Policy 2006;34(11):1284–98.
[4] Tong D, Zhang Q, Zheng Y, Caldeira K, Shearer C, Hong C et al. Committed emissions from existing energy infrastructure jeopardize 1.5 °C climate target. Nature 2019;572(7769):373–7.
[5] van de Graaf T, Overland I, Scholten D, Westphal K. The new oil? The geopolitics and international governance of hydrogen. Energy Research & Social Science 2020;70:101667.
[6] Cerniauskas S, Jose Chavez Junco A, Grube T, Robinius M, Stolten D. Options of natural gas pipeline reassignment for hydrogen: Cost assessment for a Germany case study. International Journal of Hydrogen Energy 2020;45(21):12095–107.
[7] Hickey C, Deane P, McInerney C, Ó Gallachóir B. Is there a future for the gas network in a low carbon energy system? Energy Policy 2019;126:480–93.
[8] Howarth RW, Jacobson MZ. How green is blue hydrogen? Energy Sci Eng 2021;9(10):1676–87.
[9] Noussan M, Raimondi PP, Scita R, Hafner M. The Role of Green and Blue Hydrogen in the Energy Transition—A Technological and Geopolitical Perspective. Sustainability 2021;13(1):298.
[10] Miller CA, Richter J, O'Leary J. Socio-energy systems design: A policy framework for energy transitions. Energy Research & Social Science 2015;6:29–40.
[11] Cherp A, Vinichenko V, Jewell J, Brutschin E, Sovacool B. Integrating techno-economic, socio-technical and political perspectives on national energy transitions: A meta-theoretical framework. Energy Research & Social Science 2018;37:175–90.
[12] Hoffart FM, Glanz S, Schönauer A-L, Span R. Transition towards a Low-Carbon Economy through Gas Infrastructure Modification: Economic and Sociological Interdisciplinary Insights. Energy Proceedings 2020;2(1):1–5.
[13] Hoffart FM, Schmitt EJ, Roos M. Rethinking Economic Energy Policy Research –: Developing Qualitative Scenarios to Identify Feasible Energy Policies. Sustainable Development of Energy, Water and Environment Systems 2021;9(2).
[14] Schubert DKJ, Thuß S, Möst D. Does political and social feasibility matter in energy scenarios? Energy Research & Social Science 2015;7:43–54.
[15] Majone G. On the nation of political feasibility. Eur J Political Res 1975;3(3):259–74.
[16] IEA. World Energy Outlook 2019; 2019.
[17] SRU. Wasserstoff im Klimaschutz: Klasse statt Masse. Berlin: Sachverständigenrat für Umweltfragen (SRU); 2021.
[18] BMWi. The National Hydrogen Strategy; 2020.
[19] Zhou Y, Swidler D, Searle S, Baldino C. Life-cycle greenhouse gas emissions of biomethane and hydrogen pathways in the European Union. Washington DC; 2021.
[20] Deutscher Bundestag. Unterrichtung durch die Bundesregierung. Evaluierungsbericht der Bundesregierung über die Anwendung des Kohlendioxid-Speicherungsgesetzes sowie die Erfahrungen zur CCS-Technologie. 19th ed. Berlin; 2018.
[21] SRU. Towards an ambitious environmental policy in Germany and Europe: Summary; 2020.
[22] Steigleder K. The Tasks of Climate Related Energy Ethics – The Example of Carbon Capture and Storage. Jahrbuch für Wissenschaft und Ethik 2017;21(1).
[23] SRU. The role of hydrogen in climate protection: quality rather than quantity: Summary; 2021.
[24] Kemfert C, Praeger F, Braunger I, Hoffart FM, Brauers H, Präger F. The expansion of natural gas infrastructure puts energy transitions at risk. Nature Energy 2022;7(7):582–7.
[25] Seto KC, Davis SJ, Mitchell RB, Stokes EC, Unruh G, Ürge-Vorsatz D. Carbon Lock-In: Types, Causes, and Policy Implications. Annu. Rev. Environ. Resour. 2016;41(1):425–52.
[26] Unruh GC. Escaping carbon lock-in. Energy Policy 2002;30(4):317–25.

[27] Erickson P, Lazarus M, Tempest K. Carbon lock-in from fossil fuel supply infrastructure; 2015.
[28] Fisch-Romito V, Guivarch C, Creutzig F, Minx JC, Callaghan MW. Systematic map of the literature on carbon lock-in induced by long-lived capital. Environmental Research Letters 2021;16:53004.
[29] Powers M. Natural Gas Lock-In. Kansas Law Review 2021;69(5):889–948.
[30] Batten S, Sowerbutts R, Tanaka M. Let's Talk About the Weather: The Impact of Climate Change on Central Banks. Bank of England Working Paper No. 603 2016.
[31] Löffler K, Burandt T, Hainsch K, Oei P-Y. Modeling the low-carbon transition of the European energy system - A quantitative assessment of the stranded assets problem. Energy Strategy Reviews 2019;26:100422.
[32] McGlade C, Ekins P. The geographical distribution of fossil fuels unused when limiting global warming to 2 °C. Nature 2015;517(7533):187–90.