Hydrogen import options for Germany

Analysis with an in-depth look at synthetic natural gas (SNG) with a nearly closed carbon cycle

ANALYSIS

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IMPRESSUM

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Preface

Dear reader,

Russia's attack on Ukraine has prompted Europe to seek alternatives to Russian gas. Germany in particular has set about building LNG terminals at breakneck speed. However, the possible long-term nature of the associated import contracts raises the question of whether they are compatible with Germany's goal of becoming climate neutral by 2045 and planning its infrastructure accordingly. One argument is that the import terminals could in future be used to import renewable hydrogen. Though there is broad consensus that the transition to climate neutrality will require renewable hydrogen and the molecules produced from it to be imported in substantial quantities, the form of, schedule for and feasibility of the imports are still being debated, as is the question of whether the LNG terminals can really be regarded as "H_2-ready".

In this context, a novel concept was proposed for Germany that would combine LNG terminals with renewable hydrogen by using synthetic natural gas (SNG) and additionally feature a nearly closed carbon cycle. Current industry plans envisage roughly 15 terawatt hours of SNG being imported each year by 2030, which corresponds to around five percent of the total capacity of the planned LNG terminal. To date, the SNG route with a nearly closed carbon cycle has not been independently investigated in the literature.

To provide a broader foundation upon which to debate this option, we asked Hamburg University of Technology to shed light on the advantages and disadvantages of this concept and to compare it with other import options that have been discussed at greater length so far.

I hope you will enjoy reading this publication!
Frank Peter
Director, Agora Industry

Conclusions at a glance:

1	**Germany will need sufficient hydrogen imports to achieve its goal of climate neutrality in the power sector by 2035 and to decarbonise the steel and chemical industries.** According to the National Hydrogen Strategy, imports of at least 45 TWh of hydrogen per year will be needed from 2030. In addition to pipeline imports, other hydrogen carriers could also be imported by ship.
2	**At a cost of < € 1/kg H_2, pipelines are the cheapest way of importing pure hydrogen.** Importing hydrogen carriers by ship increases the cost of transport, following reconversion, to roughly €2 to 5/kg H_2. Hydrogen derivatives such as ammonia or hot briquetted iron (HBI) that can be further processed directly constitute a cost-effective alternative in many cases (< €1.5/kg H_2). Technological innovations are a key prerequisite for all import options, with the exception of hydrogen pipelines and ammonia for immediate use.
3	**Using synthetic natural gas (SNG) with a nearly closed carbon cycle as a hydrogen carrier entails three challenges:** (1) the complex interplay of several components with a comparatively low level of technology readiness and an implementation period of ten years; (2) competition with other import options that could prove cheaper than SNG in the medium term; (3) regulatory uncertainty regarding the measurement, reporting and verification of international carbon flows.
4	**Short-term use of existing natural gas grids for transporting SNG could pose a risk to the energy transition if as a result the necessary repurposing of methane pipelines for hydrogen is delayed.** In view of their critical importance, the emphasis in Germany should be on conversion to and construction of hydrogen pipelines. The creation of new CO_2 infrastructure should focus on no-regret CCS applications.

Conclusions from the viewpoint of Agora Industry

Climate targets can only be met with sufficient hydrogen imports

According to its Climate Change Act, Germany is to cut its greenhouse gas emissions by 65 percent by 2030, compared with 1990 levels. A large part of this reduction in emissions can be achieved through national measures, one central role being played by the expansion of renewable energies. Domestic production of renewable hydrogen is not sufficient for those applications that require hydrogen to be climate-neutral, however. In order to supply the relevant *no-regret* applications with hydrogen, Germany will additionally need to import substantial quantities – at least 45 terawatt hours per year from 2030, according to the *National Hydrogen Strategy*.[1]

No-regret applications that require hydrogen for climate neutrality

For as long as renewable hydrogen needs to be publicly funded, it should be limited to those applications in which direct electrification – which is more energy efficient – is not feasible. A whole series of independent studies has shown that such *no-regret* applications encompass the following: non-energy industrial processes such as in the steel and chemical industries, green fuels for long-haul aviation and maritime shipping, and seasonal storage facilities to back up renewable energies in the power system, including residual heat load in district heating. The goal of a climate-neutral power sector will see this demand grow significantly as we head towards 2035.[2]

Other hydrogen applications are controversial or a bad idea, as Table 1 shows. Using hydrogen to produce low-temperature heat below 200 degrees Celsius is far less efficient than using heat pumps that produce several units of usable heat from one unit of renewable electricity. For temperatures of between 200 and 500 degrees Celsius, electric boilers can supply the required heat.[3]

Hydrogen applications dictate the preferred transport options

Which type of hydrogen transport should be given preference will be dictated largely by how the hydrogen is to be used. Among the *no-regret* applications, the power sector in particular is reliant on pure hydrogen for long-term storage. This applies in much the same way to refineries. In principle, most other applications could also work with hydrogen derivatives for direct use that are cheaper to transport. In the case of liquid molecules that contain carbon, such as Fischer-Tropsch products or methanol, there is for example broad consensus that they should be imported to Germany for the most part because they are comparatively easy to transport.[4]

Even though transport costs may not be the only aspect to be taken into account in the assessment,[5] they nonetheless play an important role. The competitiveness of different transport options depends in each case on factors such as synergies with local infrastructure, the exact design of the system or the technical requirements of the offtakers; all of these have a direct bearing on the efficiency of the value

1 Federal Government (2023)

2 Prognos (2022); Agora Energiewende, Prognos, Consentec (2022); Agora Energiewende, Agora Industry (2022)

3 Agora Industry, FutureCamp (2022); Öko-Institut and Fraunhofer ISE (2022); Agora Energiewende, Fraunhofer IEG (2023)

4 FFE (2022)

5 cf. Acatech 2022, Prognos et al. 2023

Need for molecules in addition to green electrons — Table 1

Green molecules needed?	Industry	Transport	Power sector	Buildings
No-regret	· Reaction agents (DRI steel) · Feedstock (ammonia, chemicals)	· Long-haul aviation · Maritime shipping	· Renewable energy back-up depending on wind and solar share and seasonal demand structure	· Heating grids (residual heat load *)
Controversial	· High-temperature heat	· Trucks and buses ** · Short-haul aviation and shipping · Trains ***	· Absolute size of need given other flexibility and storage options	
Bad idea	· Low-temperature heat	· Cars · Light-duty vehicles		· Building-level heating

* After using renewable energy, ambient and waste heat as much as possible. Especially relevant for large existing district heating systems with high flow temperatures. Note that according to the UNFCCC Common Reporting Format, district heating is classified as being part of the power sector.

** Series production currently more advanced on electric than on hydrogen for heavy duty vehicles and buses. Hydrogen heavy duty to be deployed at this point in time only in locations with synergies (ports, industry clusters).

*** Depending on distance, frequency and energy supply options

Agora Energiewende, Agora Industy (2022)

chain and thus also influence the overall costs and greenhouse gas emissions.

Pipelines are the cheapest transport option

Hydrogen can be imported by pipeline or ship in different forms. All the figures cited below relate to Table 2. Hydrogen derivatives for direct use differ fundamentally in the sense that they are not converted back into hydrogen.

Imports by pipeline entail only minor energy losses during compression of the gas, which is why this route offers high energy efficiency, low greenhouse gas emission intensity and low transport costs of less than one euro per kilogram of hydrogen for distances of up to 2 000 km. Even though both new and converted pipelines have a high level of technology readiness,[6] implementation can take several years: converting existing natural gas pipelines takes three to five years, while building new pipelines from scratch takes eight to ten years.

This import option is at the heart of the discussions about a future cross-border European Hydrogen Backbone.[7] The supplier countries that can be accessed in this manner are limited, however, with the result that only limited diversification is possible – with all the implications this has in terms of security of supply. The best resources in terms of wind and solar power for the production of renewable hydrogen, combined with the requisite availability of

6 Technology readiness levels range from 1 ("Initial idea") to 9 ("Commercial operation in relevant environment") or 11 ("Proof of stability") (IEA 2020, 2023)

7 Agora Energiewende and AFRY Management Consulting (2021); European Hydrogen Backbone (2022)

Comparison of hydrogen import options — Table 2

Type of transport	H_2-Pipeline	Shipping		
Goods to be transported	**Pure H_2**	**H_2 carrier**		**H_2 derivatives for direct use**
Variants	Re-purposed, newly built	Ammonia (NH_3), liquid H_2 (LH_2), LOHC, methanol (MeOH)	synthetic natural gas (SNG) with nearly closed CO_2 cycle	Ammonia (NH_3), methanol (MeOH), Fischer-Tropsch (FT) product, hot briquetted iron (HBI)
Target molecule	H_2	H_2	H_2	= transport molecule
Overall energy efficiency*	66 %	36 – 52 %	38 – 44 %	n. a.
CO_2 intensity* [kg $CO_{2\text{-eq}}$/kg H_2]	0.08	0.5 – 1.7	0.7 – 0.9	n. a.
Total costs in 2030 [€/kg H_2]*	4.8	5.9 – 9.2	6.9 – 8.1	n. a.
Transport costs in 2030 [€/kg H_2]**	< 1	~ 2 – 5	~ 3.5 – 4.5	NH_3: 1.3 MeOH: 2.0 FT: 2.2 HBI: < 0.3
Technology readiness of key components [1 low – 11 high]* **	**8** Re-purposed **10** Newly built	**4** NH_3 cracker (large) **7** LH_2 tanker **3** LH_2 bunkering **6 – 7** LOHC molecule **11** LOHC tanker	**7** catalytic methanation **5** autothermal reforming **4 – 7** CO_2 shipping **n.S.** dual-gas ship SNG/CO_2 **6 – 7** direct air capture (DAC) **5 – 6** oxyfuel gas power plant	**11** NH_3 tanker **6 – 7** direct air capture (DAC) **6** HBI: H_2-based direct reduction of iron ore (DRI)
Implementation horizon in years******	**3 – 5** (Re-purposed) **8 – 10** (Newly built)	**6 – 10**	**10**	**2** (NH_3) – 10
Implications for the infrastructure in Germany	• Increases demand for H_2 transport pipelines	• Increases demand for H_2 transport pipelines	• Increases demand for H_2 transport pipelines • extended use of natural gas pipelines • Increased demand for CO_2 pipelines to transport larger volumes	• Reduces demand for H_2 transport pipelines
diversification of sources to improve security of supply	limited	high	high	high

*TUHH (2023); With transport distances of 10 500 km (ship) and 660 km (pipeline), and hydrogen supply at 100 bar. CO_2 intensity without embodied emissions from renewables; total costs including hydrogen production costs

**Hydrogen transport costs including conversion costs, and excluding hydrogen production costs; own calculations based on TUHH (2023), Acatech (2022), Agora Industry and Wuppertal Institut (2023); transport distance of 2 000 km (newly built onshore pipeline with 1016 mm) and ~10 000 km (ship); HBI without CAPEX of DRI plant and shipping, which in an alternative scenario would occur in any case.

***Based on IEA (2023); autothermal reforming with CO_2 capture; important TRL 4-6: prototype; 7-8: demonstration; 9: commercial operation in relevant environment; for practical orientation about HBI see Agora Industry and Wuppertal Institut (2023).

****Based on Acatech (2022), Prognos et al. (2023)

Note: for further aspects such as environmental impacts, see Prognos et al. 2023 and Acatech 2022

Agora Industry (2023)

land, are to be found at sites beyond Europe and above all in the Global South, meaning that the import of hydrogen to Europe by ship constitutes an important alternative.

Transport by ship will be more expensive

The expansion of LNG infrastructure that has taken place since Russia's attack on Ukraine has also given new impetus to the discussion of whether to import other hydrogen carriers and derivatives for direct use by ship. Following a basic introduction, we look at how SNG compares as a new hydrogen carrier.

Widely discussed hydrogen carriers are ammonia, liquid hydrogen (LH_2) and liquid organic hydrogen carriers (LOHC). To a considerably lesser extent, this also applies to methanol, which additionally requires a green carbon source.[8] A hydrogen *carrier* means that reconversion into gaseous hydrogen takes place at the end of the transport chain.[9]

As a result of considerable losses during energy conversion, the overall energy efficiency of the carriers, from hydrogen production to delivery of the hydrogen, is 36 to 52 percent. This increases greenhouse gas emissions, while transport costs, at two to five euros per kilogram, are also significantly higher than with pipeline transport. The expected implementation horizon ranges from six years (in the case of ammonia) to as many as ten years; this is due to the relatively low level of technology readiness, especially with respect to the storage of liquid hydrogen, though also when it comes to ammonia cracking and LOHC molecules. In the long term, shipping allows a large number of different supplier countries to be accessed, thereby increasing security of supply.

Hydrogen derivatives for direct use also include some of the aforementioned hydrogen carriers. Energy and costs will be saved if reconversion into hydrogen is not required. This is particularly relevant when it comes to the direct use of ammonia for the production of fertilisers, for example, where the costs of transport amount to 1.3 euros per kilogram of hydrogen, to power-to-liquid products such as methanol (2 euros per kilogram of hydrogen) or to Fischer-Tropsch fuels such as synthetic kerosene (2.2 euros per kilogram of hydrogen). Having said that, with the exception of ammonia these liquid products need a green carbon source, and the level of technology readiness of the direct air capture process that this requires is not yet high. In addition, there is one prominent solid hydrogen derivative: hot briquetted iron (HBI) for the manufacture of steel.[10] HBI's advantage is its low transport costs (less than 0.3 euros per kilogram of hydrogen); this is due to its very high density and the fact that it can use the existing infrastructure for the transport of iron ore. Generally speaking, the import of hydrogen derivatives for direct use has the potential to reduce the need for new hydrogen infrastructure in Germany.

Synthetic natural gas (SNG) with a nearly closed carbon cycle has been proposed by industry as a novel hydrogen carrier concept. This would require SNG produced from renewable hydrogen and CO_2, which would be methanised together in the export country. The resulting SNG behaves like natural gas and can therefore be imported using conventional LNG tankers and terminals.[11] Following carbon capture in Germany, the CO_2 would be transported to the export country by ship and then reused as a hydrogen carrier in a nearly closed cycle. According to the concept, any SNG and CO_2 leaks and losses would be offset by means of direct air capture (DAC) of carbon dioxide in the export country.

8 IEA (2019), IRENA (2022), Acatech (2022)

9 Hydrogen is typically bonded to another carrier molecule. The exception is liquid hydrogen.

10 Agora Industry and Wuppertal Institute (2023)

11 This distinguishes SNG from other hydrogen carriers like ammonia and liquid hydrogen (Prognos et al. 2023).

Carbon capture in Germany could be done either centrally or decentrally, according to the concept. Centralised carbon capture involves splitting SNG into its component parts, hydrogen and CO_2, at the import terminal. The pure hydrogen is then available for further use in Germany. As with most other hydrogen carriers, the energy conversion losses result in an overall efficiency rate of below 50 percent. The greenhouse gas emissions intensity is similar to the emissions generated by the alternative options. The costs of transporting SNG as a hydrogen carrier – i.e. including conversion and reconversion – are quite high by comparison with other carriers (3.5 to 4.5 euros per kilogram of hydrogen).

Decentralised carbon capture involves transporting SNG from the import terminal via natural gas pipelines to various industrial sites and power plants, where the CO_2 would be captured using technologies that would have to be installed in each individual setting.[12] Various modes of transport are available to return the CO_2 to the port: inland vessels, trains, trucks and pipelines, the latter being the cheapest option when the volumes of CO_2 are sufficiently large. The other alternatives are supposed to be sufficient during an initial ramp-up phase of the SNG concept, but would not be enough in total to defossilise an entire LNG terminal with a capacity of 250 terawatt hours of SNG per year – as indicated in the original version of the SNG concept.[13] This would require CO_2 pipelines that do not currently exist.

Technology readiness levels delay implementation

A comparison of the three import options – pure hydrogen, hydrogen carriers and derivatives for direct use – clearly shows that almost all require further technological innovations before they can be implemented. The exceptions are hydrogen pipelines and ammonia for direct use in existing applications. Experience shows that key new energy technologies typically take at least 20 years to develop, from prototype (TRL 4–6) to commercialisation (TRL 9). LEDs for use in lights were an exception, as they were ready for implementation in just ten years. In that case, the political framework conditions helped to speed up the innovation process considerably.[14]

Implementing many of the hydrogen transport options is therefore likely to take eight to ten years. Only ammonia crackers, which are needed to be able to use ammonia as a hydrogen carrier, are expected to be ready for large-scale commercial implementation somewhat more quickly, at six to seven years.[15]

The SNG concept faces three challenges

Technological risk: By comparison with the other import options, the SNG concept with a nearly closed carbon cycle has the largest number of components that have not yet been commercially realised, i.e. that have a technology readiness level of < 8. In particular, the idea of transporting the CO_2 back by ship, possibly with the aid of a yet to be developed multi-gas carrier that can transport both SNG and CO_2, is unlikely to play any role before 2030. Rapid expansion of methanation, which to date exists only in the megawatt range and would need to be upscaled by a factor of 1000 to the gigawatt range, likewise appears challenging. In other words, various technological obstacles will first need to be overcome before the SNG concept can be fully commercially implemented. Accordingly, it can be assumed that fully

12 For the purposes of the present analysis, this variant was not quantified more precisely with respect to efficiency, emissions and overall costs, as the other variant is more relevant to the envisioned hydrogen backbone that is targeted.

13 LNGPrime (2022), Offshore Energy (2022)

14 IEA (2020); in addition, technologies frequently do not manage to exceed a readiness level of 4 to 6 – the "Valley of Death" – due to insufficient incentive for private investment during this phase (PWC 2018).

15 Prognos et al. (2023), Acatech (2022)

implementing the SNG concept with a nearly closed carbon cycle would take ten years.[16]

The industry appears to be aware of this challenge. While early announcements talked of targeting an initial level of 25 terawatt hours of SNG and stepping this up to 75 terawatt hours by 2030 and 250 terawatt hours by 2045[17], currently the talk is only of 15 terawatt hours of SNG imports by 2030.[18]

Commercial risk: For potential SNG users, this technological risk becomes a commercial risk. These could be companies from the industrial and transformation sectors that are subject to the European Emissions Trading System (ETS) and its EU-wide emissions cap. As the emissions cap in the ETS will reach zero in 2039, meaning that no more new allowances will be issued in the foreseeable future,[19] these companies will need sufficient planning security with respect to their greenhouse gas emissions and decarbonisation options in order to be able to correctly assess the future cost burdens.

The competitiveness of SNG is also a factor. For example, it is likely that other import options, such as pure hydrogen by pipeline or hydrogen derivatives for direct use, will be priced more competitively than SNG in the medium term.

Furthermore, there is **regulatory uncertainty** regarding the measurement, reporting and verification of international carbon flows. Any such reporting system would have to take full account of leakages and avoid double counting, for example during carbon capture. In addition, it would need to record the residual emissions offset via DAC in the export country, as provided for in the industry's SNG concept, with a view to ensuring a climate-neutral supply chain. At present, this offsetting is only possible with the aid of international voluntary carbon offset markets whose effectiveness is doubted.[20] The European Commission is working on a Certification Framework for Carbon Removals (CRCF) so that privately certified removals can be recognised. However, it is unclear to what extent this framework will also apply to carbon removals outside the EU.[21]

SNG as transformation risk

Apart from the aforementioned technical challenges, SNG does in principle present an opportunity to use the existing natural gas infrastructure in the short term. This in turn raises the question of how compatible SNG is with the goal of climate neutrality. There is consensus in the relevant energy scenarios and in the documents of the German Federal Government that this will require the hydrogen economy to be ramped up (Figure 1). This will entail a fundamental restructuring of the gas infrastructure. To minimise the costs of this transformation, the emphasis should be placed on converting as many long-distance methane pipelines as possible to a one hundred percent hydrogen infrastructure[22] – based on the hydrogen capacities and quantities needed for climate neutrality. This is the goal outlined by the German Federal Government in its updated *National Hydrogen Strategy*.[23]

SNG entails a transformation risk to the extent that companies might invest in decentralised carbon capture in the short term with a view to using SNG in existing natural gas applications, and could then have an incentive in the medium term to delay the repurposing of natural gas grids into hydrogen grids. There is also a risk elsewhere that financial and regulatory

16 cf. Prognos et al. (2023)

17 LNGPrime (2022), Offshore Energy (2022)

18 TES-H2 (2023)

19 Pahle et al. (2023)

20 Romm (2023)

21 EPRS (2022)

22 FNB Gas (2020, 2023), European Hydrogen Backbone (2022)

23 Federal Government (2023)

measures might not be targeted sufficiently towards the more essential aspects of the hydrogen economy.

Infrastructure priority within Germany: long-distance hydrogen pipelines

Hydrogen needs to be transported to the places where it will be used within Germany. In the medium term[24] it will be particularly important to have dispatchable hydrogen power plants up and running in order to guarantee security of supply in the power sector, as this will require pure hydrogen to be available at different locations. These will need to be supplied to meet their specific demand, and will therefore also have to be connected to sufficiently large storage facilities. Against this backdrop, the focus should be on converting pipelines such that they can be used with hydrogen and on building hydrogen pipelines within Germany.[25]

Concentrating new CO_2 infrastructure on *no-regret* CCS applications

Any cost-effective implementation of the SNG concept with a nearly closed carbon cycle and decentralised use will also require, if larger quantities have to be imported,[26] CO_2 pipelines in Germany to transport the carbon captured at the industrial point sources and power plants back to the import terminal, from where the CO_2 would be shipped back to the export terminal at sea.

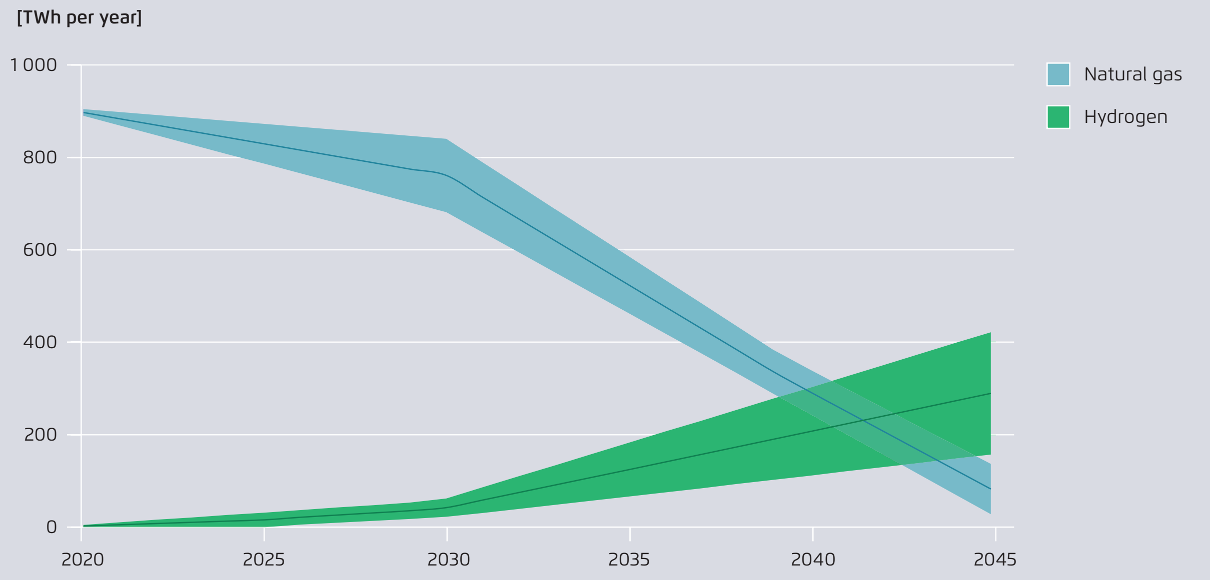
24 The goal of a climate-neutral power sector by 2035 will require 135 TWh of hydrogen per year; in view of the challenges outlined above, this is unlikely to be made available in the form of SNG in sufficient quantities and in time (Agora Energiewende, Prognos, Consentec 2022).

25 Federal Government (2023a, b)

26 As originally planned by the industry, cf. footnote 17.

Energy demand for natural gas (incl. biogas) and hydrogen in different climate neutrality scenarios for Germany in TWh per year

Figure 1



Agora Energiewende (2023) with scenarios from Agora Energiewende (2021), Ariadne (2021), BDI (2021), BMWK (2022), dena (2021)

To date, however, carbon capture and pipelines have been discussed in Germany primarily for unavoidable process emissions from cement and lime production, and for emissions from waste incineration. Those emissions are then to be permanently stored geologically on the basis of carbon capture and storage or – where the carbon in question is biogenic or atmospheric – could be used as carbon feedstock for the chemical industry (carbon capture and utilisation/CCU).[27] CO_2 pipelines should be prioritised for these *no-regret* applications for which carbon capture is indispensable from a technical perspective if they are to become climate-neutral.

This requires strategic planning that combines the System Development Strategy [28] with its goal of a climate-neutral energy system by 2045 with other relevant strategies: the *National Circular Economy Strategy* (NKWS), the *National Biomass Strategy* (NABIS), the *Long-term Strategy for Negative Emissions* and – for residual emissions – the *Carbon Management* Strategy.

27 Agora Industry (2023); Prognos (2022)

28 BMWK (2022)

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