SRU German Advisory Council on the Environment

The role of hydrogen in climate protection: quality rather than quantity

SUMMARY | November 2021

Contents

Hydrogen can be an important building block for the goal of greenhouse gas neutrality, but only if it is produced in an environmentally friendly and sustainable way and used sparingly. The production of green hydrogen requires large quantities of renewable electricity and thus indirectly uses land, water and raw materials. Hydrogen should therefore only be used where there are no more efficient options for climate protection. A complete decarbonisation of the economy can only succeed if less energy is consumed overall.

In June 2021, the German Advisory Council on the Environment (SRU) published a comprehensive statement on the role of hydrogen in climate protection in Germany. Based on this analysis, in this publication the SRU draws strategic conclusions and makes policy recommendations for the production and use of hydrogen. The full reasoning, further details and extensive references can be found in the German-language long text version.

1 Making environmentally friendly and sustainable hydrogen available

Hydrogen is currently produced almost exclusively from fossil fuels and is greenhouse gas intensive. In Germany, hydrogen is mainly produced from natural gas ("grey hydrogen"). Large amounts of CO_2 are emitted in the process. This form of production therefore cannot contribute to climate protection. **Instead, hydrogen needs to be produced in an environmentally friendly and sustainable way.**

Only so-called green hydrogen can meet this requirement. Green hydrogen can be produced without emitting greenhouse gases by splitting water using renewable energy sources. To ensure that hydrogen is environmentally friendly and sustainable, however, other environmental aspects beyond climate protection must be taken into account. Moreover, social concerns, such as ensuring compliance with social standards throughout the supply chain, must also be taken into account. **Hydrogen produced in accordance with environmental and social criteria yet to be defined more precisely could be referred to as dark green hydrogen, drawing on the existing classification.** For dark green hydrogen, it is important that sustainability criteria and a certification system are established in the near future (see Table 1). The dominant production method for dark green hydrogen will probably be water electrolysis powered by wind or solar energy. Although there will be some emissions associated with the manufacturing of the facilities required, these will gradually decrease in the course of decarbonisation. Hydrogen produced using biomass is sometimes also referred to as green hydrogen; however, its production is usually not environmentally friendly and sustainable. It would therefore not fall under the designation "dark green".

1.1 No state support for blue or turquoise hydrogen

Some actors regard some forms of low-carbon hydrogen as bridging technologies, in particular so-called blue hydrogen. Blue hydrogen is produced from natural gas, whereby the resulting CO_2 is partially captured and stored (CCS). **In the view of the SRU, however, this is**

not a sustainable option. For one thing, blue hydrogen still entails greenhouse gas emissions despite the CCS process: methane losses during the extraction and transport of natural gas as well as CO_2 losses during the capture, transport and storage of CO_2 have to be taken into account. **In addition, the storage of CO_2 involves ecological and health risks.** These include, for example, the salinisation of groundwater, surface waters or soils, as well as health hazards if CO_2 escapes due to accidents.

In Germany, underground storage of CO_2 is currently not legally permitted. For the production of blue hydrogen in Germany, suitable CO_2 storage sites would therefore have to be found in other countries and the CO_2 would have to be transported by pipeline or ship. **However, neither in Europe nor worldwide is there sufficient storage capacity for CO_2 available in the foreseeable future.** In view of the lead times for CCS projects (including the search for storage sites, public consultation processes, financing), a sufficient expansion of CCS capacity in the next few years seems unlikely.

The production of hydrogen via the pyrolysis of methane is being tested as another possible transitional solution ("turquoise hydrogen"). Here, too, methane losses during the extraction and transport of natural gas must be taken into account. Moreover, the process is still in the early stages of development. It may not be ready for industrial production for another 10 to 15 years, and is therefore unsuitable as a bridging technology.

The production of both blue and turquoise hydrogen entails the risk that fossil infrastructure will be held on to for too long. Infrastructure would be built (both production facilities and supply infrastructure) that would exist alongside the infrastructure for green hydrogen. The use of the infrastructure for blue or turquoise hydrogen would have to be limited until the mid- or late 2040s at the very latest due to the goal of greenhouse gas neutrality by 2045 (in Germany) or 2050 (in the EU) (see Fig. 3). If the investment costs have not yet been amortised by then, the desire to avoid stranded assets could jeopardise the phase-out of blue or turquoise hydrogen production. In addition, there is the risk that the production and use of blue hydrogen becomes established during the transition period (due, among other things, to the already existing infrastructure for grey hydrogen and the initially cheaper price of blue hydrogen compared to green hydrogen), delaying or preventing the replacement of blue hydrogen by green hydrogen (lock-in effect). **The SRU therefore recommends that the German government should continue to exclude state financial support for all hydrogen produced from fossil fuels.**

In addition to hydrogen from fossil fuels using CCS or the pyrolysis technology, hydrogen produced using nuclear energy ("pink hydrogen") is also being discussed as a low-carbon hydrogen. However, this is also not sustainable on account of the safety risks and the unresolved question of final disposal. Moreover, the construction of new nuclear power plants is not economically viable.

As the forms of low-carbon hydrogen listed above are not environmentally friendly or sustainable, they should not play a significant role at EU level either. The SRU therefore recommends that the German government should also promote the necessary phase-out of fossil fuels and support the use of green hydrogen in the European Union (EU). It would make sense, for example, for the future EU funding framework (Project of Common Interest (PCI) and Important Project of Common European Interest (IPCEI)) to provide financial support predominantly for green hydrogen projects.

1.2 Creating favourable conditions for green hydrogen

Producing green hydrogen is currently still more expensive than producing blue hydrogen. However, the potential for cost degression is higher for green hydrogen than for blue hydrogen. **Under favourable conditions, green hydrogen may become cheaper than blue hydrogen from 2030 onwards.** Such conditions include falling electricity prices, a rapid decline in cost for electrolysers, the availability of an international infrastructure that allows the cheap transport of green hydrogen, and a stringent certification system. However, appropriate CO_2 pricing is also important. For instance, a carbon border tax can help to avoid perverse incentives for the import of fossil hydrogen which would be counterproductive in terms of climate policy. Electricity supply costs are central to the production costs of green hydrogen. The system of relevant taxes, levies and charges should be fundamentally reformed so that environment- and climate-friendly alternatives can prevail over conventional fossil technologies. **Overall, the framework conditions must be made favourable for green hydrogen in Germany and at EU level.**

How long it will take for production and sales of electrolysers and green hydrogen to be fully ramped

up depends primarily on the availability of renewable energy. With a significant additional expansion of wind energy and solar plants, Germany can cover parts of its hydrogen demand from domestic sources. **For green hydrogen, therefore, additional capacity for renewable energy generation is needed beyond the current expansion plans of the German government.** The ramp-up time for green hydrogen is also linked to industrial policy opportunities. The creation of a domestic market for green hydrogen is a prerequisite for future industrial export opportunities on the world market.

Green hydrogen can also be produced with surplus electricity. However, it is not expected that the amount of surplus electricity in Germany will be sufficient to meet the forecast demand for hydrogen. Moreover, surplus electricity can also be put to other good uses. The amount that can theoretically be used depends on regional conditions. **The electrolysers should therefore be operated in a way that serves the system, and their locations should be chosen accordingly.** Spatial proximity shortens the transport route for hydrogen from production to use. There is also the advantage of being able to integrate the waste heat from the electrolysers into their industrial operation. For industrial applications, additional capacity should be built near the site for this purpose (see Fig. 3).

The land potentially available in Germany for the expansion of additional renewable energy is limited due to problems of public acceptability, conflicts with nature conservation, and other competing land uses. **Germany will therefore continue to be dependent on energy imports, which could take the form of hydrogen in a decarbonised energy world.** Green hydrogen will probably be imported mainly from other European countries and neighbouring regions by pipeline. This should be taken into account in infrastructure planning. Downstream products of green hydrogen, such as ammonia or synthetic fuels, can probably also be increasingly imported from the 2030s onwards from more distant locations with good potential for renewable energy. Today's oil and ammonia infrastructure can also be used for this purpose. **But the global supply of green hydrogen will depend on the pace at which the worldwide phase-out of fossil energy production and the expansion of renewable energy in the exporting countries proceed.** The need for imports can be minimised if it is possible to reduce overall energy demand and to successfully pursue ambitious efficiency policies. **Overall, it is to be expected that environmentally friendly and sustainably produced hydrogen will remain a scarce and valuable commodity for the foreseeable future.**

1.3 Introducing consistent certification

In order to ensure that the use of green hydrogen results in benefits for the climate, clear production standards are necessary. **If attention is not paid early on to ambitious sustainability criteria within a transparent and verifiable certification system, there is a risk of externalising the ecological footprint through land use, water and raw material consumption (see Table 1).** Water consumption in particular could have more serious social impacts in the exporting countries than in Germany, for example if the exporting countries are located in arid regions. Furthermore, without appropriate regulations, the additional electricity demand for electrolysis could be partly covered by fossil energy and thus cause additional emissions. Which carbon source is used for the production of synthetic fuels is also relevant. If a fossil source is used, the process is not greenhouse gas neutral.

The federal German government should therefore work at European level and in international organisations such as the International Civil Aviation Organization (ICAO) and the International Maritime Organization (IMO) to support the development and establishment of ambitious and verifiable guarantees of origin and sustainability standards for hydrogen and downstream products. The certification system, which should be internationally standardised as far as possible, should from the outset cover the entire production and transport chain as well as environmentally relevant aspects and should be based on strong ecological sustainability. **The growth of the market for biogenic fuels in Europe has shown that ecologically perverse incentives can arise. If certification does not anticipate this and take it into account, it will be difficult to correct such undesirable developments.** However, this does not mean that all the certification criteria included must necessarily be considered from the outset in support schemes or renewable energy quotas, for example in the context of the Renewable Energy Directive (Directive (EU) 2018/2001, RED II). Bilateral agreements offer the possibility to test sustainability criteria with regard to their practicability. It is important to ensure that the requirements are consistently applicable to different energy carriers such as hydrogen and its downstream products and equally applicable to European production and international imports. Otherwise, there is a risk that policy will create perverse incentives to circumvent requirements. **Wherever public policy supports or requires the use of hydrogen and downstream products, guarantees of origin and sustainability standards should be included as a precondition.** For example, eligibility as a renewable fuel under RED II should be consistently aligned with the above criteria.

One important climate-relevant aspect is a strict additionality criterion for renewable electricity generation. This means that additional electricity demand must not lead to more greenhouse gas emissions. To this end, new, additional renewable energy capacity must be installed to meet the electricity demand for electrolysis. Especially for countries that are currently dependent on petrochemical exports, the export of green hydrogen and downstream products represents an economic model for the future. This should be used as a geostrategic opportunity to develop a transformation strategy in cooperation with these countries. Bilateral agreements offer the possibility to make the import of green hydrogen conditional on rapid decarbonisation of the exporting economy. **The EU and the German government should thus only consider imports from countries which have committed to greenhouse gas neutrality in their nationally determined contributions to the Paris Agreement and which can demonstrate ambitious expansion targets for renewable energy.**

Table 1

Key sustainability and environmental criteria for hydrogen and downstream products

Dimension	Environmental and social requirements
Electricity consumption of electrolysis	• New, additional renewable energy plants • System-friendly operation of electrolysers through geographic proximity to renewable energy production and avoidance of additional bottlenecks in the grid
Other emissions related to production and transport	• Greenhouse gas accounting of hydrogen and products derived from it (Power-to-X (PtX)) for all process steps • For low-carbon hydrogen (via steam reforming): Accounting for both upstream emissions and emissions in CCS process
Additional environmental impacts	Reduction of environmental impacts along the full value chain, for example by • Excluding particular terrestrial and aquatic areas as potential sites for electricity generation, hydrogen or PtX infrastructure, and avoiding damage to these areas (e.g. protected areas, biodiversity-rich ecosystems, or areas hosting rare, endangered, or threatened species or ecosystems) • Assessing and avoiding environmental risks, for example through environmental assessments • Requiring efficient and environmentally friendly use of land and water resources • Setting environmental conditions for resource extraction and for construction, operation and disposal of facilities (e.g. for electricity or heat generation, desalination of sea water, electrolysis, carbon capture) • Setting conditions for the extraction of surface or ground water, taking account of local water availability
Social impacts	Establishing social standards along the full value chain, for example, avoiding negative impacts on the local population in countries producing hydrogen with respect to • Drinking water supply • Food security • Health, human rights, employment standards, access to natural resources including informal and formal land and water rights

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Up to this point, certification has been discussed primarily with regard to green hydrogen, as only this type of hydrogen can be environmentally friendly and sustainable. **Should the EU decide, despite the problems mentioned above, to promote the use of low-carbon hydrogen as well, then equally stringent climate and sustainability requirements should be applied.** In the production of blue and turquoise hydrogen, water consumption required for the extraction of fossil resources must be taken into account. In addition, upstream emissions must be accounted for separately and the permanent storage of the captured carbon must be ensured. **If the captured carbon is used for oil recovery, the hydrogen produced should not be accredited as low-carbon hydrogen.** The purpose of this form of Carbon Capture and Utilisation (CCU) is the continued extraction of fossil oil, and this runs counter to the actual goal of reducing overall emissions.

1.4 Building infrastructure step by step and aligning it with climate targets

Two options are under discussion for the transport and distribution of hydrogen. Hydrogen could either be fed into the natural gas grid as an admixture or transported using dedicated pipelines for pure hydrogen. **In the opinion of the SRU, the admixture of hydrogen to the natural gas grid is not a good option.** The SRU also rejects admixture even just as a so-called transitional solution or for small quantities. The most important reason for this is that hydrogen, as a scarce commodity, should be used selectively in those areas and sectors where there are no more efficient decarbonisation options. Furthermore, the technical feasibility and costs of retrofitting natural gas infrastructures for admixture are uncertain and contested. Moreover, in significant application areas such as industry, pure hydrogen is needed. **There is a risk of path dependencies and lock-in effects following from investments in new natural gas infrastructure, especially as the planning of natural gas infrastructure in Germany has so far not taken climate protection targets into account.** These targets need to be firmly embedded as soon as possible. There is also a risk of bad investment decisions and lock-in effects at the level of the end consumer: admixture can impede the adoption of alternative and more efficient technologies, such as heat pumps in the building sector or electromobility in transport.

The need for pipelines for pure hydrogen must be assessed and hydrogen clusters must be established that are aligned with demand in local markets. Planning for the infrastructure should start with local microgrids, not least because factors such as the location of electrolysis plants, import routes and areas of application for hydrogen are still uncertain.

Converting existing natural gas pipelines for the transmission of pure hydrogen involves technical challenges. The technical difficulties posed by different conversion procedures as well as the cost projections remain unclear, and there is much need for further research. **In the view of the SRU, it is not possible at this point to draw the overall conclusion that the conversion of natural gas pipelines would be cheaper than the construction of new hydrogen pipelines.** The cost analysis depends on factors such as the quantity of hydrogen involved and the geographical distribution of renewable electricity sources and electrolysers. In addition, transport distance plays a role, and this is even more important when comparing the cost-effectiveness of different transport options (pipeline, ship, truck). All in all, the economic viability of pipelines requires a high level of demand for hydrogen. **In the view of the SRU, no infrastructure should therefore be built or expensively converted before it is clear how much infrastructure is needed and where.** The regulation of hydrogen grids should also be built up step by step. To this end, it seems sensible for the German government to first clarify, transparently and in line with climate, environmental and sustainability goals, where, in which sectors and on what scale green hydrogen could and should be used (chap. 3). The financing of the development of an infrastructure for hydrogen should continue to be borne by the companies involved rather than being passed on to the end consumers of natural gas.

2 Using a scarce energy carrier efficiently

Hydrogen is needed in a decarbonised economy as an energy carrier and as a raw material. But the use of hydrogen and downstream products does not make economic and ecological sense in all instances where it is being discussed today. A lot of energy is lost in the production of hydrogen and synthetic fuels (see Fig. 1), and further conversion losses are incurred during use. In many instances, there are more efficient alternatives—often the direct use of renewable energy. Because of the conversion losses, the use of hydrogen usually leads to significantly higher primary energy demand. Thus, more renewable energy is required. Since this is not free of environmental impacts either, the result is not only higher costs but also greater environmental damage. **The use of renewable energy and the observance of environmental and social standards in hydrogen production are thus not sufficient to ensure environmentally friendly and sustainable hydrogen use. Another necessary condition is that sufficiency and efficiency measures limit the overall requirement for hydrogen.**

As a commodity that is both scarce and (for the time being) expensive, green hydrogen should only be used in the foreseeable future where there are no more efficient alternatives. Political signalling is crucial here: demand in different sectors should not be unnecessarily increased, for example through infrastructure investments involving path dependencies for applications where the direct use of electricity would be technically feasible and make more economic sense.

The time horizon needs to be kept in mind in relation to hydrogen use, as hardly any green hydrogen is available as yet. **Additional hydrogen use today thus usually leads to higher greenhouse gas emissions compared to fossil alternatives.** Green hydrogen should therefore initially be used primarily where grey hydrogen has been used up to now. **In addition, hydrogen applications should be prioritized where long-term testing and scaling is required and where there is otherwise a risk of a lock-in effect due to upcoming reinvestment in fossil infrastructure.** These include, for example, the steel industry and the chemicals industry.

If the goal of greenhouse gas neutrality is to be achieved by 2045, that means that fossil fuels must no longer be used by that point at the latest. If an earlier date for greenhouse gas neutrality is targeted, the phase-out of fossil energy sources must be carried out even sooner. **Sectoral roadmaps for the phase-out from all fossil energy sources should therefore be developed and approved politically at an early stage (see Fig. 3). If, on the other hand, the technological transformation is not designed proactively and with foresight, and fossil technologies such as combustion engines remain in use until greenhouse gas neutrality, there is a risk of social hardship and structural disruptions.** Combustion engines would have to run exclusively on synthetic fuels, which would place a heavy burden on low-income households in particular due to the likely high prices. Gas or hydrogen heating systems still in operation at that point would also have high operating

Figure 1

Conversion losses in the production of hydrogen and downstream products

	Direct use of electricity	Hydrogen	Power-to-Liquid	Power-to-Gas	Ammonia
Renewable electricity	100 %	100 %	100 %	100 %	100 %
Electrolysis		~67 %	~67 %	~67 %	~67 %
PtX process[1]			~70 %	~80 %	~80 %
Overall efficiency	100 %	~67 %	~47 %	~54 %	~54 %

[1] Power-to-Liquid and Power-to-Gas: including Direct Air Capture (DAC)

SRU 2021; for references, see Figure 6 in the German-language long text version costs due to fuel prices, which would have to be borne by the end consumer. Alternatively, vehicles and heating systems would have to be replaced at that point before the end of their technical service life, which would also lead to additional costs.

2.1 Industry: steering reinvestment towards green technologies

In order to decarbonise energy-intensive industries, a fundamental transformation of products, technologies and energy sources will need to be pursued in most industrial sectors (see Fig. 3). This requires a political framework that enables upcoming investment decisions to be taken in favour of environmentally friendly technologies and guarantees investment security for industry. These investment decisions are decisive for achieving greenhouse gas neutrality, as energy-intensive industrial technologies have long investment cycles. In the next few years, reinvestments in industrial sectors such as the steel industry and the chemical industry are on the agenda.

In these industrial sectors, hydrogen is necessary for decarbonisation according to the current state of knowledge. For example, hydrogen is a suitable reducing agent for steel production and is therefore needed for the production of primary steel in the future. **For this purpose, the blast furnace process for primary steel production should be replaced by the direct reduction process using hydrogen in the future.** The direct reduction process has the advantage that it can already be run on natural gas today and the proportion of green hydrogen can be gradually increased. **Due to its low energy consumption and in order to conserve resources, the proportion of secondary steel production should be increased.** Another advantage of the secondary steel route is the fact that the electric arc furnace can be run on renewable electricity in a greenhouse gas-neutral way. In general, the sustainable transformation of industry requires that we no longer think along linear lines. So, for the transformation of industry, the role of the circular economy should be strengthened, energy consumption should be reduced, and products and processes should be replaced or made more efficient.

Green hydrogen is also crucial for the decarbonisation of the chemical industry. Already today, grey hydrogen is used as a material, for example for the synthesis of chemical products and in refineries. The emissions associated with grey hydrogen can be avoided by replacing it with green hydrogen. In the future, other uses for hydrogen in industry will become relevant, for example in order to produce plastics with low greenhouse gas emissions. **In the long term, fossil fuels used as materials should be replaced by green hydrogen.** This can be used as a raw material for the production of ammonia and methanol, among other things. In the chemicals industry, in addition to the use of green hydrogen, it is crucial to use greenhouse gas-neutral carbon sources and to close material cycles.

Not only process-related emissions but also energy-related emissions from industry must be avoided. The low- and high-temperature heat required by industry is currently generated using fossil fuels. This could be provided by hydrogen, but more efficient are power-to-heat (PtH) systems or high-temperature heat pumps that use waste heat.

In order to avoid the premature shutdown (stranded assets) of greenhouse gas-intensive technologies, a clear strategy for the decarbonisation of industry should be implemented now already. This is the only way to avoid lock-in effects. There are several different instruments available for industrial investments in greenhouse gas neutral technologies, such as Carbon Contracts for Difference (CCfD) or quotas for steel, aluminium or plastics produced with low greenhouse gas emissions or recycled. This requires a clear classification of resource- and climate-friendly products compared to conventional alternatives. Sustainable public procurement could contribute to guaranteed sales for these products. It is important to ensure now already the targeted promotion of pilot and demonstration projects in industry in order to provide experience in the use of the new key technologies, to attract investors and to enable them to reach technological maturity.

2.2 Transport: speeding up the electrification of cars and focusing synthetic fuels on international transport

In the transport sector, hydrogen and more especially synthetic fuels will be important in the long term for the decarbonisation of transport modes that cannot practicably be powered directly by electricity. As things stand, this applies in particular to international air and sea transport and perhaps also to some heavy road freight transport. The short-term use of blue hydrogen or hydrogen from less than 80 to 90 % renewable electricity for synthetic fuels, on the other hand, worsens the net greenhouse gas balance when compared with the fossil alternatives.

For passenger cars and light road freight transport, battery electric vehicles have established a techno-economic advantage in recent years. This is due in particular to the sharp drop in the cost of batteries. Vehicles with fuel cells are not expected to play a significant role in this market segment. **Political efforts should therefore focus on battery-electric passenger cars and create long-term planning security for them.** The development of a charging infrastructure for passenger cars should focus on electric vehicles. **If, by mid-century, as few passenger cars as possible with internal combustion engines are to be powered by the synthetic fuels that will then be absolutely necessary, it makes sense to stop registrations of new vehicles with internal combustion engines from 2030 at the latest.** The CO_2 fleet limits in the “Fit for 55” legislative package should therefore be revised and given greater ambition, and greenhouse gas neutral fuels should not be counted towards the CO_2 limits. Counting them in this way does not create an incentive to increase the efficiency of vehicles with internal combustion engines. Instead, CO_2 fleet limits should be developed further in the direction of efficiency standards. The energy efficiency of vehicles is central to limiting the need for renewable energy. This applies to direct and battery-electric drives, but even more so if hydrogen and synthetic fuels are used.

There are potential applications for hydrogen in some areas of heavy road freight transport and non-electrified rail transport. In the field of heavy road freight transport in particular, there is still a great deal of uncertainty about the most economically sensible path towards decarbonisation. The next few years should therefore be used for large-scale pilot projects to further test an overhead line infrastructure as well as battery-electric and fuel cell drives in parallel. From an ecological point of view, the installation of an overhead line network on busy transit routes seems preferable. **As freight transport operates across borders, there is a need for uniform technical and regulatory standards at European level with respect to all three technology paths.** Towards the mid-2020s, an assessment should be undertaken as to whether a decision in favour of a single technology path and corresponding infrastructure investments can be made in order to avoid the unnecessary costs of building up several infrastructures in parallel.

Synthetic fuels are likely to be needed primarily in international shipping and aviation, where more efficient technical drive alternatives are not available at present. **The market ramp-up of synthetic fuels should therefore be focussed on aviation from the outset via the greenhouse gas reduction quota.**

In addition to alternative drives, more measures are required that focus on traffic avoidance and the modal shift from road transport with efficiency measures. Such a mobility transition requires a great deal of political commitment. Especially in cities, public transport and active mobility can replace motorised private transport in the short term. To provide political support for this, public transport, walking and cycling should be strengthened, multimodality promoted and public space distributed more fairly.

2.3 Buildings: carrying out a comprehensive heating transition

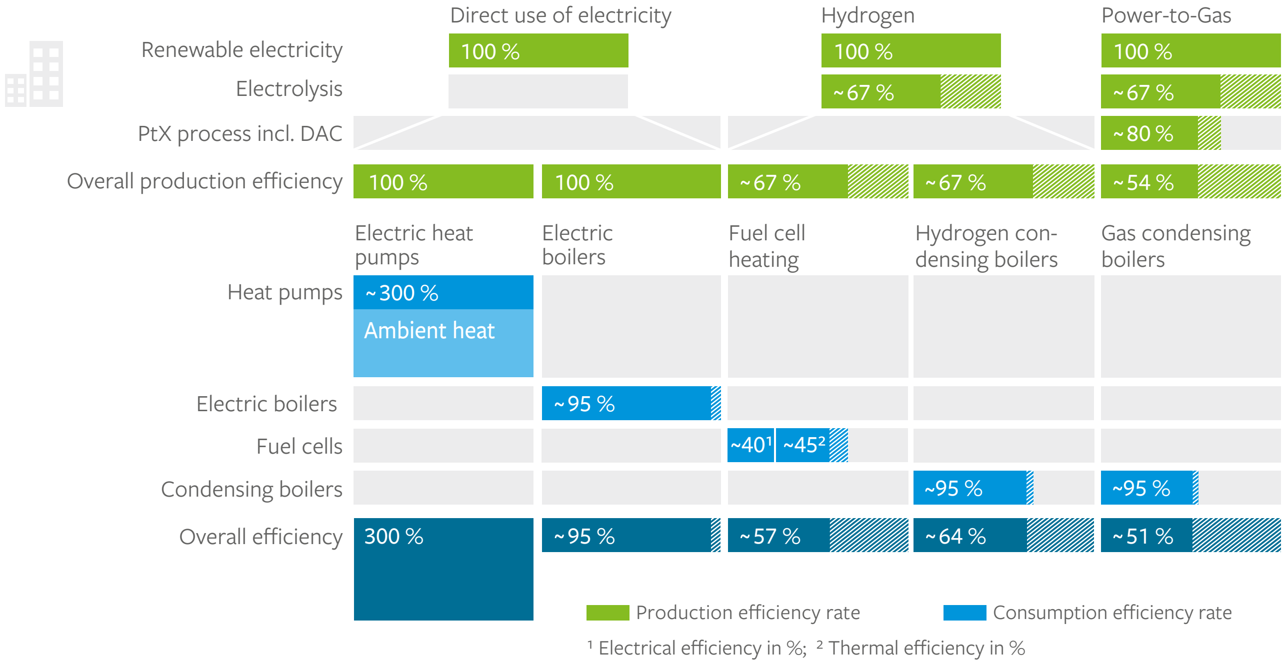
In order to provide heating for buildings in a greenhouse gas-neutral energy system, in addition to hydrogen or synthetic gas, heat pumps and decarbonised heating grids can be used. The decarbonisation of heating through the use of hydrogen or synthetic gas would lead to a significantly higher primary energy demand in the form of renewable energy (see Fig. 2). This option would thus presumably also lead to significantly higher costs for consumers. **Hydrogen and synthetic gas should therefore not be used to provide heat for individual buildings.**

Heating systems in buildings are generally only replaced every thirty years on average. Oil and gas heating systems installed in buildings over the next few years will thus make it more difficult to achieve greenhouse gas neutrality by the middle of the century. In the view of the SRU, clear political signals are therefore needed to prevent inappropriate investments and lock-in effects. The installation of new oil heating systems will already be curtailed in Germany from 2026. **In addition, the SRU recommends that the Federal Government should decide as soon as possible on a ban on the installation of gas heating systems in new buildings (see Fig. 3).** In the medium term, a ban on the installation of such systems in the existing building stock should also be considered. The same should apply to hydrogen heating systems. Exceptions should only be made where more efficient options are not practicable.

Instead of a fuel switch from natural gas to hydrogen or synthetic methane, a comprehensive heating transition is needed. Central to this is the reduction

Figure 2

Overall energy efficiency of different options for heating of individual buildings



SRU 2021; for references, see Figure 11 in the German-language long text version

of demand for heating, which is why the retrofitting rate should be significantly increased. Heating supply should be based on renewable energy sources. Decarbonised heating grids and electrification, using heat pumps, should play a key role in this. The achievement of such a heating transition is also a challenge in terms of planning. Municipal heat supply planning could therefore play an important role. The basis for such a planning exercise should be a coherent overall climate protection concept at the federal level, in order to prevent scarce resources such as hydrogen and biomass from being planned for in larger quantities than are likely to be available on a sustainable basis.

2.4 Electricity supply: accelerating the expansion of renewable energy

The electricity system of the future in Germany and large parts of Europe will be based mainly on wind and solar energy. Hydrogen can take on the role of seasonal storage. However, the demand for hydrogen should be kept as low as possible, if only for cost reasons. Other storage options, the expansion of electricity grids and intelligent load management can all play a role here. Even with complete decarbonisation, the electricity system will need some capacity for the reconversion of hydrogen into electricity in the long term. However, compared to today's conventional power plants, these power plants will only rarely be in operation. **Since seasonal storage is only necessary from the point when the share of renewables in the energy supply is very high, and since little green hydrogen will be available initially, the use of hydrogen in the electricity sector in the coming years is neither expedient nor necessary.** However, the limited number of power plants that may still be planned and built in the coming years should already be hydrogen-ready, so that only minor adjustments will have to be made later on.

There is an immediate need for action with regard to the expansion of renewable energy, which should be rapidly accelerated (see Fig. 3). In Germany, the expansion of wind energy is currently stagnating. An accelerated expansion of renewable energy is also necessary to supply the electrolysers.

3 Avoiding conflicting sectoral planning

Given different demand forecasts and the competition for uses of hydrogen in different sectors, as well as the foreseeable scarcity of absolute quantities of green hydrogen, the question arises as to how it can best be allocated between the consumption sectors (see Fig. 3). **The SRU recommends that the German government should draw up an overall plan to identify in advance, in the broader context of European decarbonisation, the conditions under which hydrogen should be produced and the areas in which the use of hydrogen represents an ecologically and economically sensible decarbonisation path.** Such a plan, aligned with climate, environmental and sustainability goals, should also clarify fundamental requirements for the use of hydrogen. This could help to avoid conflicting sectoral planning. Because there is also always a need to consider more efficient alternatives, the SRU recommends that this review should not be carried out for hydrogen in isolation. There is a need for a comprehensive strategy that integrates and coordinates plausible transformation paths in the consumption sectors with a rapid expansion of renewable energy.

Infrastructure planning should also be taken into account, due to the interactions between the development of the hydrogen, natural gas and electricity grids. **The planning for the three grids should be more closely interlinked and aligned with climate targets.** It should also be borne in mind that further research and development is necessary with respect to some applications, as it is not yet clear which technology path will deliver the lowest economic costs.

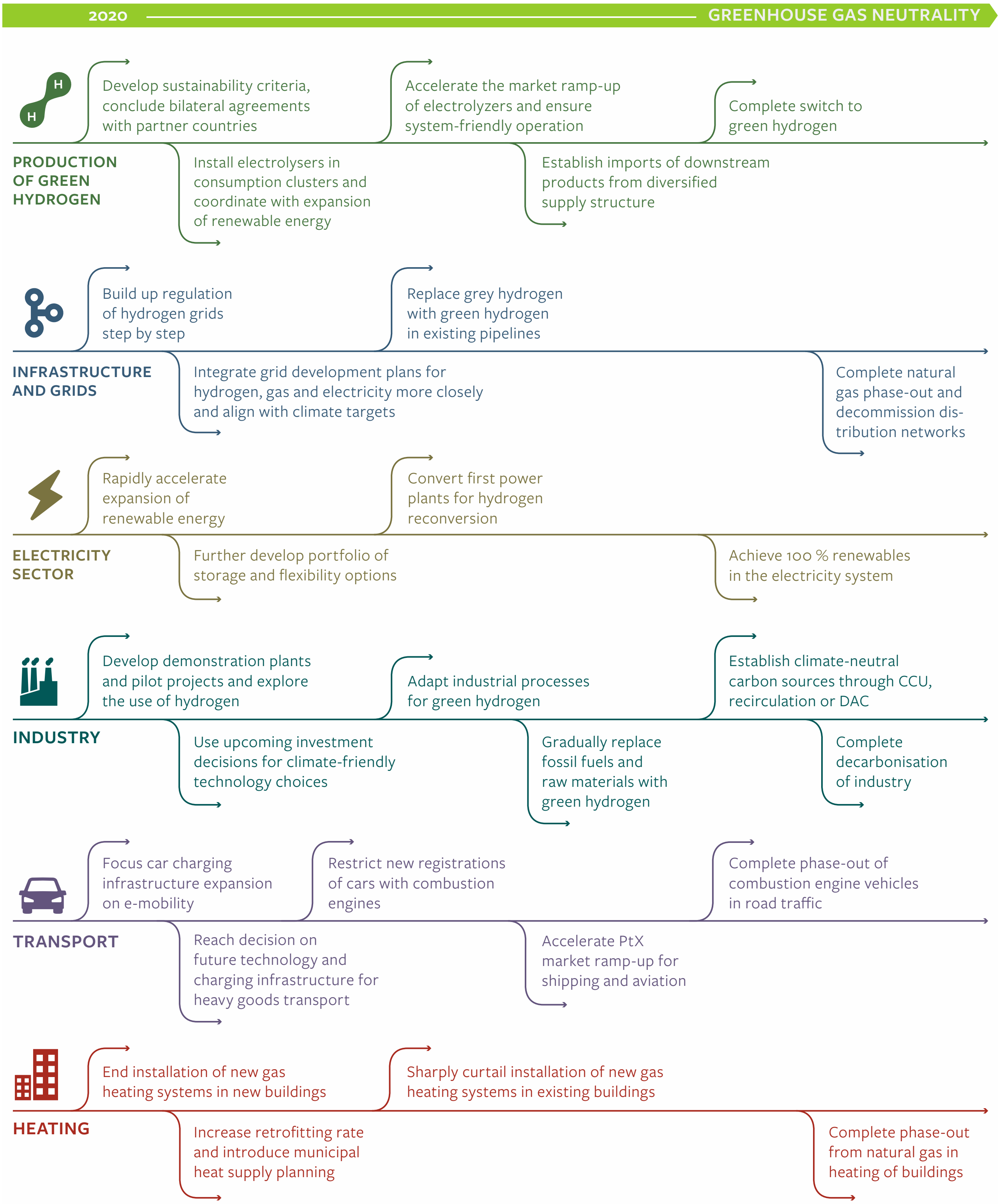
The planning should be coordinated at European level. **A first step could be the improved embedding of national hydrogen scenarios and strategies in the National Energy and Climate Plans (NECP).** This would make it possible to work out, among other things, the import and export scenarios of different countries in order to come up with a plausible forecast for total import demand from outside Europe.

In order for hydrogen and downstream products to be used efficiently, it is important to adjust taxes and levies. Currently, taxes and levies on the different energy sources are not consistently aligned with their energy or CO_2 content, so particularly high levies are imposed on the direct use of electricity. This also makes the operation of electrolysers more expensive. A fundamental reform could counteract this and help create favourable conditions for the production and use of green hydrogen.

Hydrogen is an important building block for the achievement of long-term climate and environmental goals. However, it cannot play an overarching role, but rather a complementary one. To this end, hydrogen should be produced in a way that takes account of environmental criteria and social standards—it could be called ‘dark green hydrogen’—and should be used efficiently in order to contribute to decarbonisation.

Figure 3

Strategic decisions for the sustainable use of hydrogen in the context of decarbonisation



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