dena
German Energy Agency

Power to Gas system solution.

Opportunities, challenges and parameters on the way to marketability.

Strategieplattform
Power to Gas

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Introduction.

Energy policy objectives.

The German energy supply system is changing fundamentally. The Federal Government set the course for a sustainable energy supply with its current Energy Concept and the resolutions on an accelerated energy transition. For example, greenhouse gas emissions are to be reduced by at least 80 percent by 2050 compared with 1990.

The Federal Government has also set other ambitious goals, e.g. increasing the proportion of gross final energy consumption supplied via renewable energy to 60 percent by 2050. Innovative technical solutions are required to reach these goals and guarantee a secure and economical energy supply. Power to Gas is a particularly promising system solution.

The innovative system solution.

The idea behind Power to Gas is to convert electricity from renewable energy sources to hydrogen or methane. The renewable gas can be transported in the existing gas infrastructure, stored and then used in a range of applications. It is reconverted when in demand. Likewise, the direct use of hydrogen, for instance in the mobility sector or in refineries, is possible. Power to Gas is a cross-sectoral system solution with which renewable energy sources can be integrated into the energy supply system. Power to Gas can help reduce CO_2 emissions in various sectors of consumption in that the renewable gas produced via Power to Gas replaces fossil fuels in mobility, industry, heat supply and power generation. As an electricity storage method, Power to Gas can also contribute to compensating the increasing fluctuations in electricity generation from wind and solar energy, and facilitate long-term use of electricity that could not be integrated directly into the electricity grid.

Status quo and outlook.

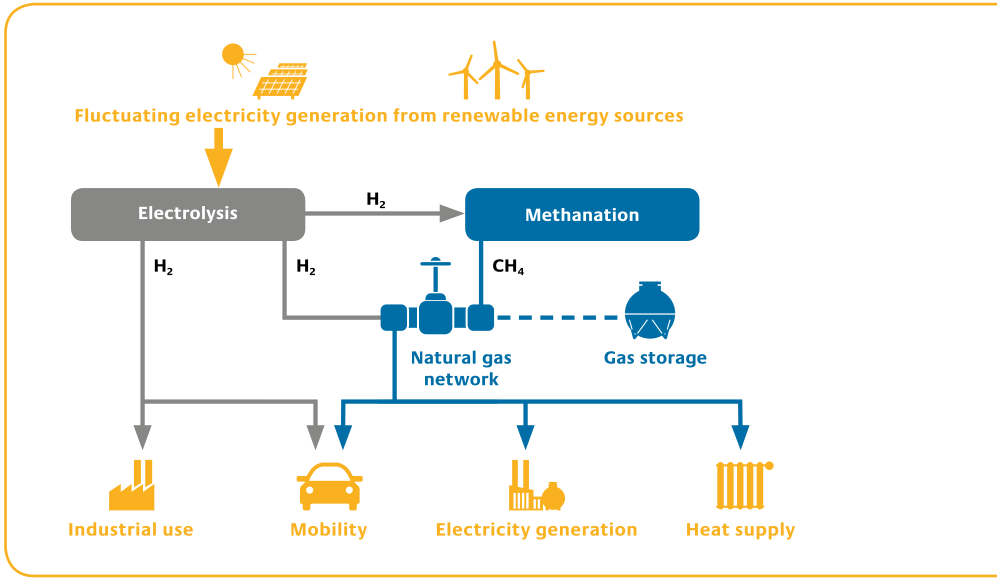
Power to Gas has the potential to be a versatile, cross-sectoral technology supporting the implementation of the energy transition and integrating renewable energy into the different energy consumption areas. The technology is mature and ready for use. However, until it is fully ready for the market, in particular with regard to economic use, some central regulatory parameters need adjusting. This publication presents key data and facts about the Power to Gas system solution and illustrates the progress made in its implementation, as well as the remaining challenges.

The Power to Gas system solution.

Power to Gas offers the option of converting electricity from renewable energy sources into gas and feeding it into the gas infrastructure, or using it directly. This way, electricity can be stored, distributed and made available for various energy usage scenarios. Power to Gas is referred to as a system solution due to its many cross-sectoral applications and the various technologies it employs.

The natural gas infrastructure can accept up to **2%** hydrogen.

- Electricity from renewable energy sources is used in an electrolyser to split water into hydrogen and oxygen.
- Hydrogen can be directly fed into the existing natural gas infrastructure and stored there up to the permissible concentration of currently two percent by volume.
- To convert and feed in a greater volume of renewable electricity, methane (synthetic natural gas, SNG) can be produced in a second step using this hydrogen with the addition of carbon dioxide.
- The gases produced with renewable electricity can lower greenhouse gas emissions significantly in the consumption sectors in which they are used.
- Combining an electrolyser with a biogas plant is particularly efficient, as it allows the carbon dioxide in the biogas to be used for methanation. That almost doubles the amount of methane produced.



Power to Gas use options.

Power to Gas offers alternative fuels for mobility: Power to Gas offers new opportunities in the transport sector to reduce climate-damaging CO_2 emissions and other pollutants, whereas the renewably produced fuel replaces its fossil cousin. Non-biogenic fuels will have an important role to play in achieving climate protection goals. The amounts in question can only be supplied by hydrogen or methane. Also, electricity-based fuels have a far lower impact on land use than plant-based fuels. Hydrogen and methane from volatile renewable energy sources can be more easily produced than liquid renewable fuels.

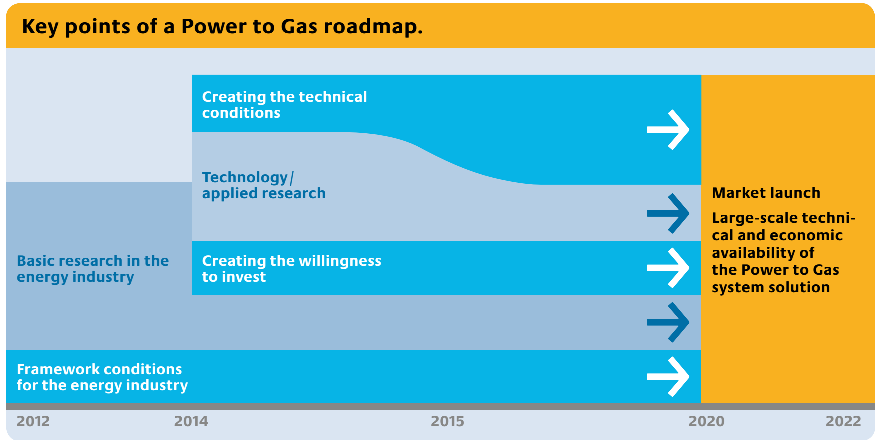
Power to Gas in industrial use: Renewably produced hydrogen allows the substitution of hydrogen from fossil sources and may, for example, be used in fuel refineries, in the chemical industry, and in steel plants (direct reduction). Likewise, renewably produced methane can replace fossil natural gas in the industry.

Power to Gas provides fuel for heat supply: The renewable gas from the Power to Gas process flows through the natural gas infrastructure to domestic and commercial heating systems, where it can replace fossil natural gas. A particularly efficient use of energy in this context is in combined heat and power plants.

Power to Gas as a long-term storage in the electricity sector: Due to the large storage capacity of the natural gas network and the connected gas storage systems, Power to Gas has a high potential for storing large amounts of energy. If necessary, the renewable gas produced using the Power to Gas process can be reconverted in gas power plants or cogeneration plants.

For more information about use options and the roadmap, please visit: **www.powertogas.info/stellschrauben** or: **www.powertogas.info/roadmap**

Key points of a roadmap.



The dena Power to Gas Strategy Platform presented a roadmap for the further development of the Power to Gas system solution. It identifies key areas of action and issues and associated time corridors that must be considered for a successful utilisation of Power to Gas, involving all sectors of consumption (electricity, heat, transport, material use) and the interaction of politics, industry, academia and research. The roadmap outlines a chronologically structured path – from today's point of view – with which the large-scale, economically viable use of Power to Gas can be achieved by 2022.

Objectives and derived problems as well as the necessary stakeholders are defined. The aim of the dena Strategy Platform partners is to build a Power to Gas plant capacity of 1,000 MWel in Germany by 2022.

Technology: Electrolysis.

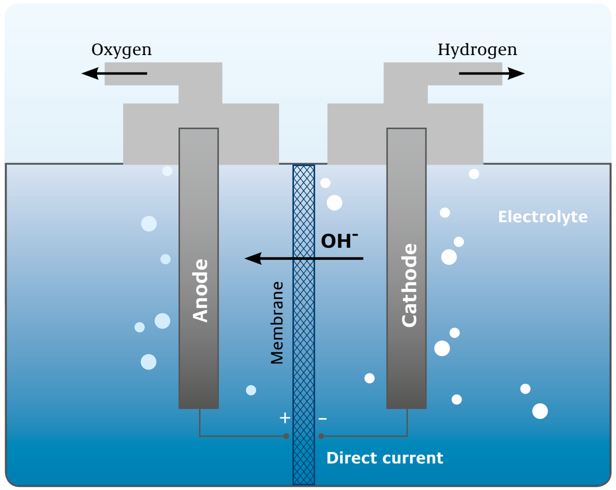
Different technologies must interact seamlessly for the Power to Gas concept to work. The most important processes include electrolysis and methanation. Water electrolysis to generate hydrogen is the core process of the Power to Gas concept. In an electrolyser, water is split into hydrogen and oxygen using electricity.

The three electrolysis processes relevant to Power to Gas are:

- Alkaline water electrolysis with an alkaline liquid electrolyte
- Acidic or polymer electrolyte membrane (PEM) electrolysis with a polymeric solid electrolyte
- High-temperature steam electrolysis using solid oxide electrolytes

Process.
For water electrolysis, there are several technological processes that need to be further optimised with respect to the future integration in the Power to Gas system solution. The processes are being developed continuously to this end.

A distinction must be made between atmospheric pressure and pressure electrolysis when looking at alkaline electrolysis and PEM electrolysis. Advantages of pressure electrolysis lie in the more compact construction and the possibility of direct coupling to many industrial pressure-controlled applications as well as the natural gas infrastructure.



Alkaline electrolysis for hydrogen production.

Key figures.

Properties	Alkaline electrolysis	PEM electrolysis
Investment costs	800 to 1,500 € / kW	2,000 to 6,000 € / kW
Efficiency relative to upper calorific value	67 – 82 %	44 – 86 %
Specific energy consumption	4.0 to 5.0 kWh / Nm^3 H_2	4.0 to 8.0 kWh / Nm^3 H_2

Challenges.
Technical challenges for the use of water electrolysis in the Power to Gas concept include a stabilisation of the specific energy consumption, the necessary power plant dynamics and the consistent extension of maintenance intervals, all required due to fluctuations in electricity generation. The electrochemical processes in the electrolyser can almost instantaneously respond to load changes. Crucial for operation and efficiency of the process, however, are the peripheral components of an electrolysis system such as lye pumps, pressure regulators and product gas separators. Frequent load changes and full shutdowns stress these mechanical components by unsettling the heat balance, thereby shortening the system's service life.

Implementation status.
PEM electrolysers have technical advantages for use in Power to Gas plants, because they follow fluctuating power input better than alkaline electrolysers. They respond more quickly to load changes, even in the lower partial load range, and quickly reach operating temperature in their startup phase. However, further advancements of alkaline electrolysers were also made in terms of the mentioned aspects. Investment costs for PEM electrolysers are still higher than for alkaline electrolysers. Generally speaking, there is a need for further research and development to make PEM electrolysers industrially available, particularly with regard to the use of suitable materials and process engineering.

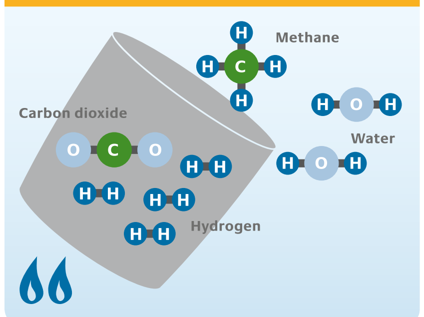
The aim is to reduce the investment costs of electrolysis to 500 €/kW by 2022. Cost reduction potential arises primarily from the continuous increase in annual production quantities and the transition to series production.

Technology: Methanation.

Regeneratively generated hydrogen from the electrolysis process can be converted to methane using carbon dioxide in a downstream methanation process. This process can be technical-catalytic and biological.

Advantages of Methanation.
Via methanation, a synthetic natural gas is produced with combustion properties nearly identical to those of fossil natural gas. It can therefore be integrated in the gas infrastructure without any further restrictions. Producing a particularly pure synthetic natural gas is also crucial considering that individual natural gas applications place very high demands on the quality of natural gas, for example in the glass, ceramics and automotive industries.

Technology: Methanation



Methanation to produce SNG.

Challenges.
Methanation is an additional conversion step in the Power to Gas process, and as such it incurs additional efficiency losses. However, methanation can also be coupled with a biogas plant, which opens up synergies, and efficiency of the overall process can be increased.

Implementation status.
With the so-called in-situ process, methanation takes place in the fermenter of a biogas plant. Carbon dioxide present in the biogas is used directly for methanation without any prior separation process taking place. With this method, a high-quality gas with a methane content of 96 to 99 percent is produced. Technical-catalytic methanation also achieves a high gas quality through its use of membrane technology.

The carbon dioxide required for methanation can be obtained from biogenic carbon sources – for example from biogas, sewage gas, biomass gasification, breweries or the bioethanol industry. A combination with carbon dioxide from conventional power plants or industrial processes, such as cement or steel production, may be a way to reduce CO_2 emissions in the energy supply system.

Technology and applied research.

Technical components	Research subjects
Electrolyser	– Testing and advancing different electrolysis processes for use in Power to Gas systems – Flexibility of the electrolyser in terms of fluctuating power supply and rapid load changes – raising efficiency
Feeding hydrogen into the natural gas network	– Feed-in into the different gas network levels – Feed-in via a regional hydrogen network – Distributing hydrogen in the gas network – Effects of different H_2 concentrations on natural gas applications – Increasing the H_2 concentration in the gas network
Hydrogen storage	– Suitability of hydrogen storage systems for use in Power to Gas systems, such as stationary pressure storage: medium-pressure storage, high-pressure storage, solid state hydrogen storage, cavern storage – Connection to a hydrogen pipeline
Hydrogen as a fuel (directly or mixed)	– Potential and development costs of hydrogen as a fuel – Hydrogen production at petrol stations – Refuelling technologies – Supply concepts for petrol stations – Distributing hydrogen in the fuel production process
Material use of hydrogen	– Connecting Power to Gas systems to industrial plants – Manufacturing chemical precursors using hydrogen as a substitute for petroleum as a raw material – Reduction of metals
Methanation	– Suitability of different carbon sources, for example, ambient air, biogas plants or fossil fuel power plants – Direct methanation in the biogas reactor (in situ) – Suitability of various catalysts for methanation
Methane as a fuel	– Feeding into the natural gas network – Dispensing via balancing system in natural gas filling stations – Use of LNG as a fuel for lorries and shipping traffic
Waste heat as a by-product of electrolysis	– Feeding into the district or local heating network – Use as process energy (e.g. in biogas plants) – Use for heating buildings
Oxygen as a by-product of electrolysis	– Material use in the industry – Developing usage concepts

Economic efficiency.

Business models.
Power to Gas offers numerous options for commercial use due to its technical flexibility and the wide range of applications of hydrogen and methane. Therefore, there are many different economically feasible business models for Power to Gas plants, such as:

- Sales of renewable gas to end customers, e. g. households or manufacturing companies
- Distribution of hydrogen and/or methane for heat generation, for example with combined heat and power plants
- Distribution of hydrogen and/or methane for the transport sector, for example with hydrogen filling stations
- Distribution of hydrogen and/or methane for the industry, for example to refineries, chemical plants or steel works
- Provision of ancillary services, such as participation in the balancing energy market

Economic efficiency.

- A major factor of the economic efficiency of Power to Gas plants are the investment costs for electrolysis and methanation. Depending on plant size, costs can amount to 2,500 – 3,500 €/kW of electric power (€/kWel) or 1,500 €/kWel for alkaline electrolysis.
- In addition to investment costs for Power to Gas, the operating costs, in particular electricity purchase conditions, are a significant factor. Depending on the use option and the plant operator, electricity purchase from renewable energy sources can differ in nature.
- For the methanation process, costs and availability of carbon dioxide must be considered. The aim is to optimally leverage synergistic effects with other processes. For a pure hydrogen use option, the costs of a nationwide hydrogen infrastructure have to be considered.
- A cost reduction of Power to Gas can be achieved in particular by lowering investment costs, increasing the efficiency of the overall system as well as a proper classification as non-final consumers.

For central positions of the Strategy Platform regarding efficiency, see: **www.powertogas.info/stellschrauben**

Aspects of efficiency.
In the electrolysis process, about 80 percent of the input energy is converted into hydrogen; heat loss in particular lowers efficiency here. The subsequent methanation process also has an efficiency of approximately 80 percent, provided that waste heat is used as well. The efficiency of electricity-gas-electricity depends on the operating method and the performance variables and is about 40 percent, which roughly corresponds to that of conventional power plants. Increasing efficiency is therefore a key objective of Power to Gas research and development.

An exclusive consideration of Power to Gas's efficiency, however, does not do this system solution any justice. An interdisciplinary approach to the integration of renewable energy sources in the use options of mobility, heat generation and industry is key for Power to Gas. Power to Gas can provide the universal fuel hydrogen with an efficiency level of over 80 percent. For the long-term required option of reconversion, i. e. the use of Power to Gas for energy storage using the natural gas infrastructure, system efficiency needs to be increased significantly. It is therefore important to initiate the necessary development and research activities today.

Location selection.

The choice of location has a decisive impact on the costs of a Power to Gas plant. The choice of location depends on the business model of the planned plant, and must be based on the conditions of both the electricity and the gas network. For example, a plant in which methanation is to take place will benefit from proximity to a source of carbon dioxide.

There are numerous criteria that are relevant to a successful location selection.

Connection to the grid
- Proximity to renewable energy sources
- Grid expansion plans and selection of a voltage level
- Present and future load balancing (demand characteristics)

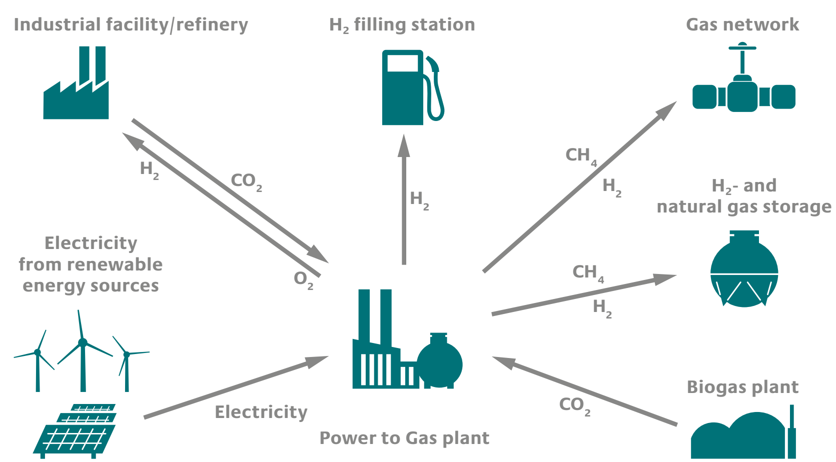
Connection to the gas network
- Physical proximity to the gas network and gas storage tanks
- Compliance with the technical rules for gas properties and the use of gases from renewable sources
- Technical parameters such as load flows and gas composition
- Hydrogen intake capacity (year-round high gas flow rates of advantage)

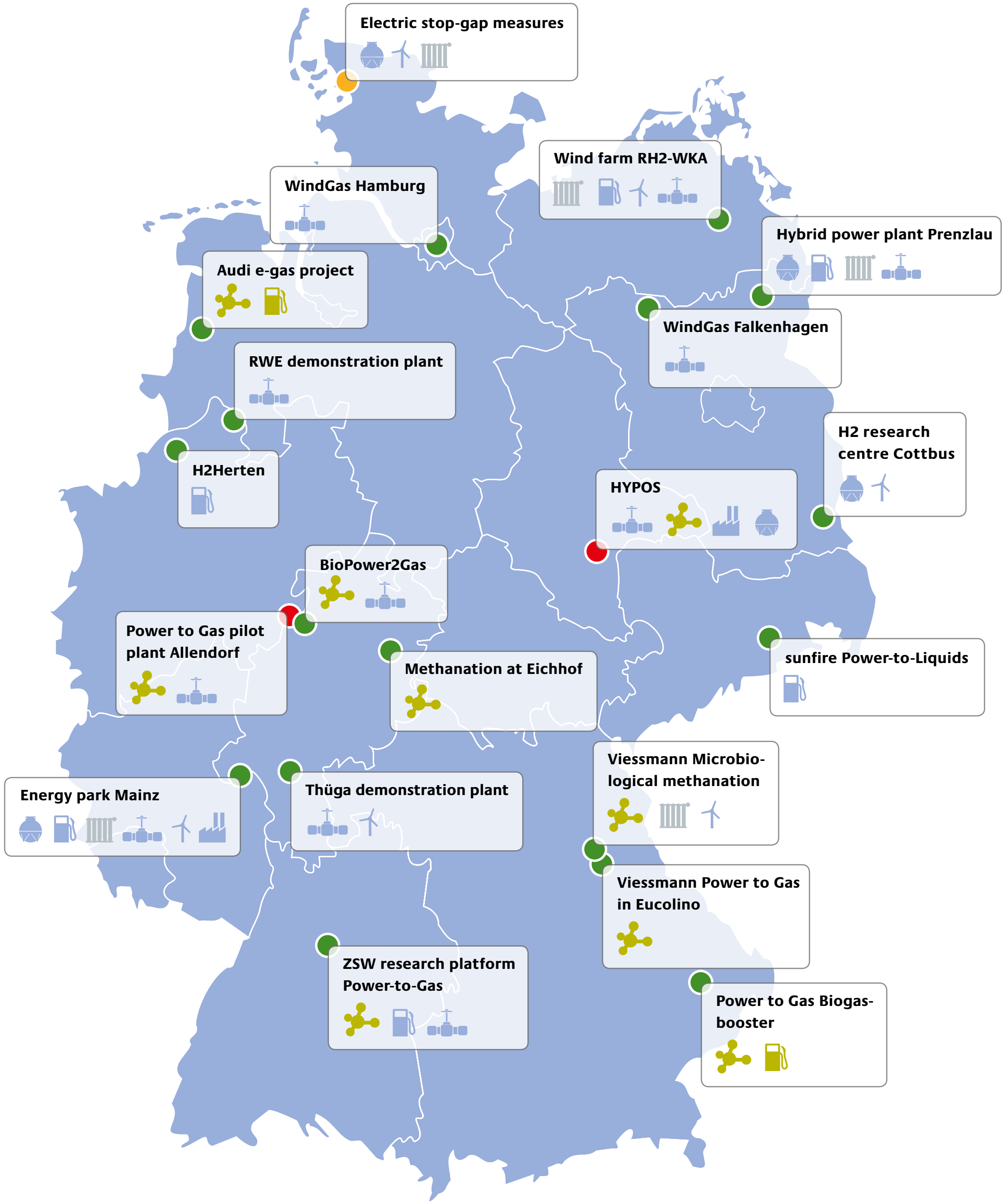
Outlets for hydrogen and methane
- Physical proximity to potential buyers, such as hydrogen filling stations, refineries and chemical industry
- Availability of a source of carbon dioxide in downstream methanation process

Outlets for heat and oxygen (by-products)
- Physical proximity to potential buyers, such as the industry and pre-existing heating networks
- Current and future heating demand of current and potential customers

Approval-related legal aspects
- Temporal and formal requirements, such as preparation of land use plans, public participation

Power to Gas location factors





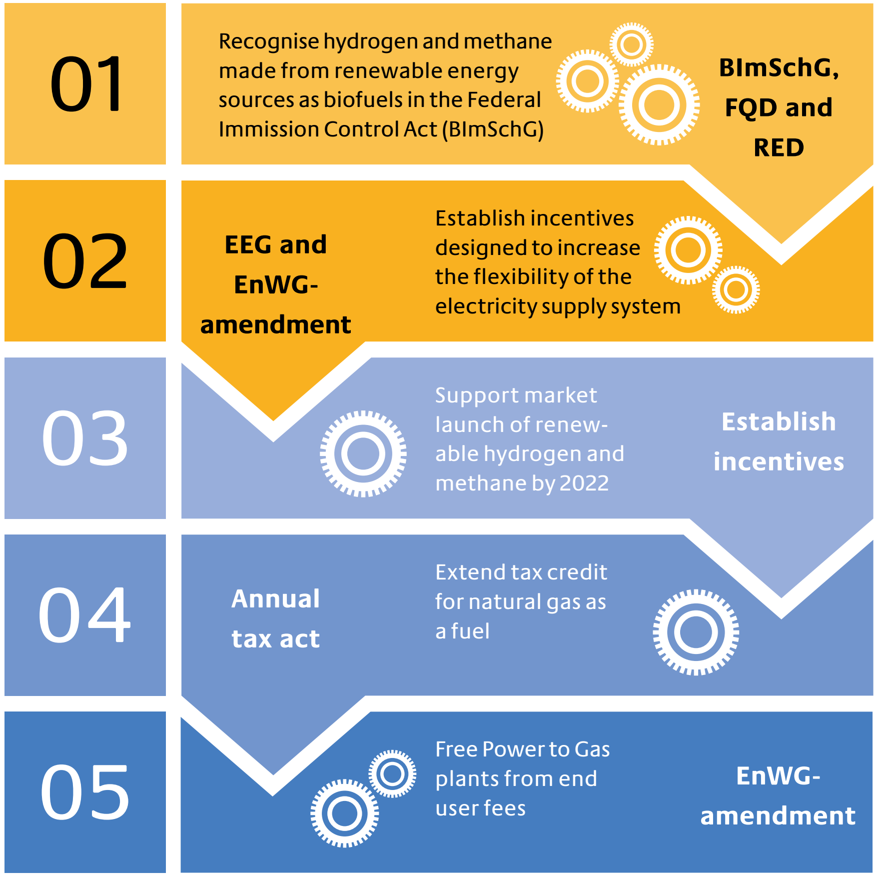
Research and pilot projects.

Germany has over 20 research and pilot facilities that are using and developing Power to Gas technology. These projects have different priorities and objectives. However, they all aim to demonstrate the technical feasibility of achieving standardisation and normalisation, and to lower costs and test business models.

The adjacent project map provides an overview of the current state of Power to Gas projects in Germany. As of August 2015, 20 plants are in operation, 10 Power to Gas projects are in their planning phase, or under construction. The performance range of the installed or planned plants ranges from below 100 kWel to 6 MWel. The projects have been built primarily for research and demonstration purposes and pursue the goal of making Power to Gas an industrially available and commercially viable technology. Learning effects and economies of scale, and the transition to mass production technology will be made possible by a market launch of Power to Gas.

Other pilot and demonstration projects are presented in detail at: **www.powertogas.info/pilotprojekte**

Project status	Legend	Gas
In operation	Methanation	Hydrogen
Under construction	Feed-in into the gas network	Methane
Planning phase	Reconversion	
	Heat generation	
	Gas storage	
	Fuel	
	Material use	



Five Power to Gas parameters.

Power to Gas has the potential to be a versatile, cross-sectoral technology supporting the implementation of the energy transition and integrating renewable energy into the different energy consumption areas. However, the current energy industry framework makes it impossible to use Power to Gas plants profitably. Five regulatory parameters need fine-tuning before Power to Gas is fully ready for market.

Hydrogen and methane made from renewable energy must be recognised as biofuels.
The amended EU directives relating to the quality of petrol and diesel fuels and to the promotion of the use of energy from renewable energy sources must be transposed into German law without delay. This can be done via the Federal Emission Control Act (Bundesimmissionsschutzgesetz, BlmSchG). In this context, the inclusion in the list of biofuels of renewable fuels made from renewable power as opposed to biomass is an essential step.

Incentives designed to increase the flexibility of the electricity system.
The remuneration system under the German Renewable Energy Sources Act (EEG) includes no incentives promoting the storage of electricity. The hardship regulation under the EEG hampers the development and use of storage solutions due to the fact that renewable electricity qualifies for remuneration whether or not it is actually used and fed into the grid. This regulation must be amended and an incentive for storage must be created.

Market launch of renewable hydrogen and methane by 2022 requires political support.
The comprehensive launch of Power to Gas on a profitable basis must be accompanied by political measures. This includes the swift transposition into national law of the multiple inclusion of renewable gases in the fuel market.

Extension of tax reduction on natural gas as a fuel.
The energy tax reduction on natural gas and automotive gas fuels, which is set to expire in 2018, must be extended. This objective should be included in the 2016 annual tax act.

Exemption of energy storage facilities from end user taxes.
Power to Gas facilities are not end users and should not be categorised as such. Exemption will free them from inappropriate taxes and contributions associated with electricity purchases.

Power to Gas Strategy Platform.

The Deutsche Energie-Agentur (dena) – the German Energy Agency – initiated the Power to Gas Strategy Platform to support the use and development of the Power to Gas system solution.

Together with partners from business, associations and science, it analyses the importance of Power to Gas for the use of renewable electricity and defines the conditions for utilisation of the system solution for economical and large-scale technical deployment. In addition to this, the platform enters into a dialogue with politicians and informs the public on the innovative Power to Gas system solution.

In the Strategy Platform, partners pool their diverse expertise and experience. Regular workshops are held to discuss the most important issues on the development and market launch of the Power to Gas system solution. This includes technological aspects (e.g. of the electrolysis process), the definition of suitable framework conditions, and the establishment of sustainable business models. The equal development of all Power to Gas usage options is a priority for the partners of the Power to Gas Strategy Platform.

Discuss Power to Gas on the group's Xing platform (in german):
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www.youtube.com/user/Power2Gas

www.powertogas.info

Strategy Platform positions.

Power to Gas as a system solution contributes to achieving the energy policy objectives for the consumption sectors of mobility, industry, heat supply and power generation.

From a technological perspective, Power to Gas technology is already operational, providing the opportunity to move from the electricity transition towards an energy transition. Businesses and academia are continuously spurring on the further development and optimisation of processes, components and plant concepts. The government must create the right conditions for a successful launch.

- Hydrogen and methane made from renewable energy must be recognised as biofuels.
- Incentives designed to increase the flexibility of the electricity system.
- Market launch of renewable hydrogen and methane by 2022 requires political support.
- Extension of tax reduction on natural gas as a fuel.
- Exemption of energy storage facilities from end user taxes.

According to the partner institutions of the dena Strategy Platform Power to Gas, increased expansion of Power to Gas plants in the coming ten years and the linking of this expansion with concrete targets is expedient and necessary in order to demonstrate that the Power to Gas system solution is both achievable on an industrial scale and financially feasible. The aim is to install and operate a total Power to Gas capacity of 1,000 MW in Germany by 2022.

Position papers of the Power to Gas Strategy Platform and its partners can be found here:
www.powertogas.info/stellschrauben

Glossary: Legal context.

Currently, there are several regulatory instruments that help to promote the development and application of Power to Gas. The most important ones are listed below:

Renewable Energy Sources Act (EEG)
Exemption from the shared contributions (§ 37 EEG)

- → For the direct purchase of electricity from renewable energy sources for electrolysis
- → For intermediate storage, as long as the storage gas is then used to generate electricity. The shared contributions under the EEG can be lowered by 2 ct/kWh (§ 39 EEG) when using storage gas for other purposes.

Remuneration for reconversion depends on the EEG remuneration of the original source of electricity.

Electricity Tax Law (StromStG)
Exemption from electricity tax

- → For electricity from a renewable energy plant with a rated capacity of up to 2 MW used in the vicinity of the plant (Section 9 of the Electricity Tax Law [StromStG])

Manufacturing companies can request exemptions (Section 9a of the Electricity Tax Law [StromStG]) for electricity taken from the grid for electrolysis.

Federal Emission Control Act (BImSchG)
Renewable hydrogen and SNG currently cannot be offset against the greenhouse gas reduction rate for fuels. However, a statutory ordinance in Section 37 d allows the list of biofuels to be supplemented per the current European legislation.

German Combined Heat and Power Act (KWKG)
Exemption from the CHP surcharge for sourcing electricity from renewable energy sources for electrolysis (§ 9 KWKG).

Energy Industry Act (EnWG)
Exemption from remuneration (§ 118 EnWG)

- → When feeding gas into the natural gas network
- → For plants when storing electrical energy.

Hydrogen and synthetic natural gas (SNG) are legally treated as biogas if the electricity and CO_2 used are from primarily renewable sources (Section 3 of the Energy Industry Act [EnWG]).

Energy Tax Law (EnergieStG)
Currently, hydrogen and SNG from renewable energy sources are not counted towards the biofuel quota. SNG is taxed as conventional natural gas, and until 31 December 2018, it will be subject to tax reduction (§ 1a EnergieStG).

Ordinance on Gas Network Access (GasNZV)
Priority in gas network access given to feed-in of hydrogen and SNG, limitation of grid connection costs for the connected party (§ 33 GasNZV).

Legal information.

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Partner institutions of the Power to Gas Strategy Platform:

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