

DESCRIPTION

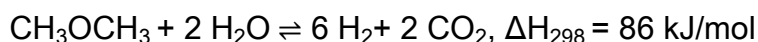
5 **Method for producing hydrogen from DME (dimethyl ether) and plant for carrying out the process**

The present invention relates to a method for producing hydrogen from DME (dimethyl ether) by reforming. Furthermore, the invention relates to a plant for
10 producing hydrogen from DME using a reformer.

The reforming of DME to hydrogen (H₂) and carbon dioxide (CO₂) is being researched, for example, as H₂ fuel for fuel cells, as described in the article "Research of hydrogen production by dimethylether reforming in fuel cells" by
15 Lei Guo, Open Access Library Journal, Vol. 05 No. 01 (2018), article ID: 81839 DOI:.4236/OALIB.1104266.

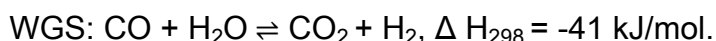
The following equations play a role in the production of DME and its reforming.

20 Steam reforming of DME (net reaction):

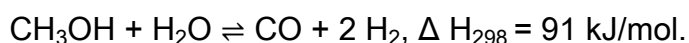


in equilibrium with

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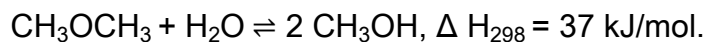


Methanol (MeOH) decomposition:



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DME decomposition:



- 5 The abbreviation WGS stands for the water gas shift reaction, also known as the water gas conversion reaction.

Various publications deal with a catalyst for steam and autothermal reforming under low pressure and temperatures below 500°C. Different catalyst materi-
 10 als are used, whereby a combination of an acid catalyst for converting DME with H₂O to methanol and a methanol catalyst with WGS function is always applied. In this context, reference is made to the articles "Unravelling the role of ceria in improving the stability of Mo₂C-based catalysts for the steam re-
 forming of dimethyl ether" by Jing-Hong Lian et al., Catal. Sci. Technol.,
 15 2021, Issue 11, 5570-5578, and "Hydrogen production by steam reforming of DME in a large scale CFB reactor. Part I: Computational model and predic-
 tions" by Francis A. Elewuwa and Yassir T. Makkawi, International Journal of Hydrogen Energy, 2015, Volume 40, Issue 46, pages 15865-15876, and
 "Steam reforming of dimethyl ether" by Kaoru Takeishi and Hiromitsu Suzuki,
 20 Applied Catalysis A: General, 2004, Volume 260, Issue 1, pages 111-117 and "Thermodynamics of Hydrogen Production from Dimethyl Ether Steam Reforming and Hydrolysis" by Troy A. Semelsberger and Rodney L. Borup, Los Alamos National Laboratory, LA-14166, October 2004, Web.
 doi:10.2172/836682. and "Hydrogen production and temperature control for
 25 DME autothermal reforming process" by Tie-qing Zhang et al., Energy, Volume 239, Part A, 2022, 121980.

It is also known to carry out steam reforming of methane and hydrocarbon gases, up to LPG, using a nickel-based catalyst at elevated pressures of up to
 30 40 bar and temperatures between 750°C and 950°C. This is described, for

example, in the book "Concepts in Syngas manufacture," Catalytic Science Series: Vol. 10 (2011) by Jens Rostrup-Nielsen and Lars J. Kristiansen.

5 The known methods for reforming MeOH and DME are associated with the disadvantage of catalyst deactivation. Furthermore, the DME and MeOH slip of the reactor increases dramatically at higher pressures, resulting in comparatively complex hydrogen gas purification.

10 It is an object of the present invention to provide an alternative method for producing hydrogen from DME that avoids or at least reduces the disadvantages of the prior art and enables efficient and low-maintenance operation. Furthermore, a plant for carrying out the method is to be provided.

15 In a method of the type mentioned at the outset, this object is solved according to the invention in that the reforming is carried out at a pressure in the range from 15 bar to 70 bar, preferably in the range from 20 bar to 40 bar, and at a reformer outlet temperature in the range from 750°C to 1050°C, and a nickel- or cobalt-based catalyst material is used for the reforming process.

20 The second object is solved in a plant of the type mentioned at the outset according to the invention by the reformer being embodied to carry out steam reforming of DME at a pressure in the range from 15 bar to 70 bar, preferably in the range from 20 bar to 40 bar, and at a reformer outlet temperature in the range from 750°C to 1050°C, preferably in the range from 775°C to 1050°C,
25 and the reformer comprises a nickel- or cobalt-based catalyst material, and that a DME evaporation device is provided upstream of the reformer.

The invention is thus based on the idea of producing hydrogen from DME at higher temperatures and pressures than those used in the prior art, specifically
30 in temperature and pressure ranges that were previously only intended for hy-

drogen production from other starting materials. According to the invention, a nickel (Ni) or cobalt (Co) based catalyst material is used, whereby a Ni-based catalyst material has proven to be particularly suitable. These catalyst materials are characterized by higher stability and lower costs compared to the catalyst materials previously used for DME steam reforming to obtain hydrogen at lower pressures and lower temperatures.

Preferably, an optionally supported Ni-based catalyst material with a Ni content of at least 2 wt%, preferably at least 5 wt%, is used.

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Hydrogen production under elevated pressure makes it possible to dispense with a downstream compressor. The hydrogen produced can be fed into further applications without compression, for example be injected into a pipeline and transported to a place of use or used for heating purposes. Since hydrogen compressors in particular are generally associated with a comparatively high failure and outage rate, maintenance costs can be avoided and downtimes significantly reduced.

Conventional components can also be used, at least in part, to implement the method or plant according to the invention, in particular components that have previously been used for hydrogen production by steam reforming of methane or hydrocarbon gases.

The method according to the invention does not have to include a desulfurization process, since DME does not contain sulfur. Accordingly, the plant according to the invention does not require a desulfurization device.

The reformer is, in a manner known per se, a reactor in which the reforming process is carried out or can take place. The reformer can, for example, be tubular, in particular cylindrical.

The reformer may be, for example, a fired reformer, in particular a gas-fired reformer, with a burner. Alternatively or additionally, it is possible for the reformer to be embodied for electrical heating or to be electrically heated.

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The reformer may be embodied in particular as a steam reformer or an autothermal reformer.

If the reformer is embodied as a steam reformer, steam reforming is carried out in particular at a reformer outlet temperature in the range from 750°C to 950°C, preferably in the range from 775°C to 950°C. In an advantageous embodiment, a steam reformer comprises two or more reformer tubes, each of which is equipped with the catalyst material, in particular at least partially filled with it.

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If the reformer is embodied as an autothermal reformer, steam reforming is preferably carried out at a reformer outlet temperature in the range from 950°C to 1050°C. In autothermal reforming, a portion of oxygen (O_2) is added in a manner sufficiently known, which provides the reaction heat through partial combustion of DME. External heating is then not necessary.

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The reformer outlet temperature in particular is the gas temperature at the outlet or exit of the reformer. The gas emerging from the reformer can also be referred to as synthesis gas. As a rule, the gas temperature at the outlet of the reformer is the maximum gas temperature in the reformer. The temperature distribution in the direction of gas flow through the reformer can be such that the gas temperature initially decreases slightly after entering the reformer and then rises continuously from a minimum to a maximum temperature, particularly at the outlet or exit of the reformer. The outlet is preferably considered to be the point at which the catalyst bed ends. If, for example, the reformer is

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designed as a steam reformer with a plurality of reformer tubes, it is appropriate for the reforming to be carried out in at least one, preferably all, of the plurality of reformer tubes at a reformer outlet temperature in the range from 750°C to 1050°C, preferably in the range from 750°C to 950°C. Thermocouples are suitable for measuring the reformer outlet temperature in a manner known per se.

The reforming being carried out at a pressure in the range from 15 bar to 70 bar in particular means that this pressure is present at the H₂ product. To achieve this, a feed gas pressure at the reformer inlet that is 5 bar higher is generally required. Accordingly, it is preferable that DME feed gas with a pressure in the range from 20 bar to 75 bar, preferably in the range from 25 bar to 45 bar, is fed to the reformer. If, for example, the reformer is embodied as a steam reformer with a plurality of reformer tubes, it is appropriate for the reforming to be carried out in at least one, preferably all, of the plurality of reformer tubes at a pressure within the ranges mentioned.

In the case where a fired reformer with a burner is used, it has proven advantageous to partially condense the flue gas. Heat integration of the flue gas may be provided to further increase efficiency, and partial condensation of the flue gas may take place in a final stage of heat integration. The condensation enthalpy can be used in particular to heat the DME feed, the combustion air, and/or to heat water. Accordingly, if the invention comprises a reformer with a burner, the plant may comprise a condensation device for partial condensation of the flue gas, in particular in a final stage of flue gas heat integration. A heat exchanger provided for condensation is advantageously made, at least partially, of stainless steel.

One embodiment of the method according to the invention is characterized in that a catalyst bed with at least two, preferably exactly two, layers is used.

Then at least one, preferably exactly one, layer can comprise or consist of an acidic catalyst material, in particular gamma alumina or a zeolite, and at least one further, preferably exactly one further, layer can comprise or consist of a nickel- or cobalt-based catalyst material. Accordingly, in the plant according to the invention the reformer may comprise a catalyst bed with at least two, preferably exactly two, layers, wherein at least one, preferably exactly one, layer comprises or consists of an acidic catalyst material, in particular gamma alumina or a zeolite, and at least one further layer, preferably exactly one further layer, comprises or consists of a nickel- and/or cobalt-based catalyst material, or wherein two layers comprise or consist of a nickel-based catalyst material.

A combination with an acidic catalyst has proven particularly suitable for steam reformers.

In the case of two layers with or consisting of a nickel-based catalyst material, it is preferable that these two layers differ from each other, e.g., in terms of their nickel content or doping.

The catalyst material may be located on a carrier or carrier material. Ni-based catalyst materials are often arranged on a carrier material such as aluminum oxide.

Another advantageous embodiment of the method according to the invention is characterized in that a catalyst bed is used which comprises a first and a second region, wherein the first region comprises or is formed by a first catalyst material and the second region comprises or is formed by a second catalyst material which differs from the first catalyst material.

The plant according to the invention can be characterized accordingly in that the reformer has a catalyst bed comprising a first and a second region, wherein the first region comprises or is formed by a first catalyst material and the second region comprises or is formed by a second catalyst material different
5 from the first catalyst material.

The two regions may be directly adjacent to each other, in other words, they may not be spaced apart. The catalyst bed may comprise exactly two regions. It may be divided into the two regions.

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The catalyst bed can also be embodied and arranged in a reformer used for the reforming process in such a way that the first and second areas are flowed through successively by the DME and/or by a product formed from the DME during the reforming process. In particular, the arrangement is such that the
15 first region is flowed through before the second region. The two regions are preferably located one behind the other in the direction of flow through the reformer.

It may be further preferred that the first catalyst material is a acidic catalyst material and the second catalyst material is a nickel- or cobalt-based catalyst material.
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Alternatively or additionally, the first region is arranged upstream of the second region.

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The reformer, which may be embodied as a steam reformer, for example, may comprise at least one reformer tube, which is preferably arranged vertically and in which the catalyst bed is arranged. In this case, the first region is conveniently located at the top and the second region is conveniently located at
30 the bottom of the reformer tube.

The catalyst bed may, for example, comprise a catalyst filling or be provided by such a filling, which has proven to be particularly advantageous.

- 5 In a particularly advantageous embodiment of the method according to the invention, it is further provided that a CO₂ separation process is carried out after the reforming process. It should be emphasized that "after" means that the CO₂ separation process does not have to follow immediately, in other words directly, after the reforming process, but that further steps can take place
10 between reforming and CO₂ separation, e.g., cooling and/or a water gas shift reaction in at least one water gas shift reactor.

Preferably, CO₂ capture is carried out in the process gas rather than in the flue gas.

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- CO₂ capture is further preferably carried out by chemical scrubbing, in particular amine scrubbing in one or two stages, and/or by physical scrubbing, in particular based on methanol and/or DME, and/or by a membrane process and/or by an adsorption process. It is also possible that CO₂ capture is carried
20 out by or includes a condensation process, preferably whereby the cooling required for condensation of the CO₂ is provided by means of an open or closed cooling circuit containing DME as a refrigerant. CO₂ capture may also comprise a combination of two or more of the aforementioned processes.

- 25 Alternatively or additionally, it may be provided that the CO₂ separation is carried out with a CO₂ separation rate of at least 55%, in particular at least 75%, preferably with a CO₂ separation rate in the range from 80 % to 99%. The percentages refer in particular to a molar basis of separated CO₂ molecules to C molecules entering through the feed stream. By way of example, for 1 mol

of DME feed stream (corresponding to 2 mol of C feed), 1 mol of CO₂ is captured, which would correspond to a capture rate of 50%.

5 In the invention, a CO₂ separation device can be provided downstream of the reformer, which is designed accordingly. The CO₂ separation device can be connected directly downstream of the reformer, or via one or more additional devices, which are then connected between the reformer and the CO₂ separation device.

10 If a fired reformer, in particular a gas-fired reformer, with a burner is used, it may be provided, in order to increase efficiency, that gas originating from the CO₂ separation process is fed to the burner and used as fuel for the burner. In the plant according to the invention, at least one connecting line connecting the CO₂ separation device and the burner may be provided for this purpose,
15 via which the gas originating from the CO₂ separation device can be fed to the burner.

Alternatively or in addition, it is possible that recycling from the CO₂ separation device to the reformer does not take place as fuel to a burner thereof, but as
20 input gas for reforming. This is for the recovery of CO, methane, and DME. The plant according to the invention may accordingly have at least one connecting line connecting the CO₂ separation device and the reformer, in particular its feed gas inlet.

25 Another advantageous embodiment of the method according to the invention is characterized in that a gas-heated auxiliary reformer is used. It has proven to be expedient to supply the auxiliary reformer with synthesis gas obtained in the reformer for its heating.

The plant according to the invention can be characterized in an analogous manner in that a gas-heated auxiliary reformer is provided, wherein the auxiliary reformer can be heated by means of synthesis gas obtained in the reformer. It can also be said that the hot synthesis gas leaving the reformer serves as heating gas for the auxiliary reformer. This further increases efficiency. Hot synthesis gas taken from the reformer can be the only heat source used by the auxiliary reformer. The auxiliary reformer, in particular, is not fired. It is possible that all of the synthesis gas leaving the reformer is used as a heat source for the auxiliary reformer. After the synthesis gas has passed through the auxiliary reformer and released some of its heat energy there, it can be subjected to further process steps to obtain an H₂ product.

The synthesis gas used as heating gas does not come into contact with the catalyst material of the auxiliary reformer. If, for example, the auxiliary reformer comprises several tubes filled with catalyst material, the synthesis gas used as heating gas is conveniently passed over the outside of the tubes, which do not have catalyst material.

The auxiliary reformer can be connected upstream of the reformer or in parallel with the reformer, whereby the upstream or parallel connection refers in particular to the feed gas flow or the DME/synthesis gas flow through the plant.

In the case of upstream connection, the DME feed gas, preferably the entire feed gas flow, is passed through the auxiliary reformer and the downstream reformer. The hot outlet gas from the reformer is returned to the auxiliary reformer to serve as heating gas there.

In the case of parallel connection, the feed gas flow to the reformer is divided. It is distributed between the reformer and the auxiliary reformer, with the reformer usually receiving a larger proportion of the feed gas than the parallel

auxiliary reformer. The hot outlet gas from the reformer is fed to the parallel auxiliary reformer as heating gas and its thermal energy is used in the auxiliary reformer. After the outlet gas from the reformer has passed through the auxiliary reformer as heating gas and released heat there, it is mixed with the outlet
5 gas from the auxiliary reformer, the two synthesis gas streams in other words being combined or mixed.

It has proven particularly suitable when the reformer is embodied as an auto-thermal reformer and the auxiliary reformer as a steam reformer, or when both
10 the reformer and the auxiliary reformer are embodied as steam reformers.

Alternatively or in addition, it is possible to use an adiabatic pre-reformer upstream of the reformer. Upstream refers to the feed gas stream. The plant according to the invention may comprise such a pre-reformer. If an adiabatic pre-
15 reformer is present, it preferably comprises an acidic catalyst material or a Ni-based catalyst material with a higher Ni loading than the catalyst material of the reformer.

It is expedient to cool the synthesis gas obtained by the reforming, in particular
20 steam reforming or autothermal reforming, taking place in the reformer. For this purpose, a cooling device may be provided downstream of the reformer.

In order to increase the hydrogen yield, it may furthermore be provided that the synthesis gas obtained by the reforming in the reformer is subjected to a
25 water gas shift reaction. The water gas shift reaction preferably is carried out after cooling. At least one water gas shift reactor may be provided downstream of the reformer, and preferably downstream of a synthesis gas cooling device, for this purpose. It is also possible to use two or more water gas shift reactors, in particular connected in series. For example, a high-temperature shift in the
30 range from 300°C to 450°C can be carried out in a high-temperature water gas

shift reactor, in particular up to a CO content in the range from 4 vol.% to 2.5 vol.% CO, and a subsequent medium-temperature shift in the range of 220°C to 270°C in a medium-temperature water gas shift reactor, in particular up to a CO content in the range of 2 vol.% to 0.5 vol.% CO. As an alternative to a medium-temperature shift, or additionally to and following such a shift, a low-temperature shift in the range from 180°C to 250°C can be carried out in a low-temperature water gas shift reactor, in particular up to a CO content in the range from 1 vol.% to 0.2 vol.% CO.

- 10 A high-temperature water gas shift reactor can, for example, be embodied as an adiabatic reactor and/or comprise an iron-based catalyst and a chromium-based catalyst. A medium-temperature water gas shift reactor can, for example, be embodied as a cooled isothermal reactor and/or comprise a copper-based catalyst. A low-temperature water gas shift reactor can, for example, be embodied as an adiabatic reactor and/or comprise a copper-based catalyst and a catalyst with zinc on aluminum oxide.

CO₂ separation can then be carried out in particular after the water gas shift reaction in one or more water gas shift reactors. A CO₂ separation device of the invention can preferably be provided downstream of the water gas shift reactor or water gas shift reactors.

It should be noted that further treatment steps can and preferably should be carried out between the water gas shift reaction and the CO₂ separation. For example, cooling and condensation separation may be carried out after the water gas shift reaction. Accordingly, the plant according to the invention may have a cooling device and a condensation separation device, which may be connected between a (last) water gas shift reactor and a CO₂ separation device.

Furthermore, it may be provided that "recycling" takes place from the CO₂ separation device to the or at least one water gas shift reactor. This is for the recovery of CO, methane, and DME. The plant according to the invention may therefore further comprise at least one connecting line connecting the
5 CO₂ separation device and the or at least one water gas shift reactor.

In a further development of the method according to the invention, hydrogen purification is also carried out after CO₂ separation. The hydrogen purification can be carried out in particular by pressure swing adsorption or include this
10 process. The plant according to the invention may comprise a hydrogen purification device downstream of the reformer, which in a preferred further development comprises at least one pressure swing adsorption reactor.

In an advantageous further development of the method according to the invention, a gas originating from the hydrogen purification, which preferably comprises H₂ and CH₄ and CO, is compressed and fed to the inlet side of a reformer used for the reforming process, in particular together with the DME. If the hydrogen purification is carried out by pressure swing adsorption, it is expedient that a tail gas from the pressure swing adsorption is compressed and
15 fed to the reformer on the inlet side together with the DME.
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The plant according to the invention can be characterized accordingly by the provision of a connecting line between the hydrogen purification device and the reformer, via which a gas originating from the hydrogen purification device, preferably comprising H₂, CH₄, and CO, in particular a tail gas from the pressure swing adsorption, can be fed to the reformer on the inlet side, preferably together with the DME. There also is a compressor for compressing the gas originating from the hydrogen purification device, in particular PSA partial gas, so that the gas can be returned to the reformer in a compressed state.
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In other words, in these embodiments, there is a return, or "recycling," from the hydrogen purification (device) to the reformer. This is possible in light of the use of DME as feed gas. Since DME contains few inert gases, such as N_2 or Ar, no outlet is required for these substances. They can enter the H_2 . Since the
5 concentration of inert gases such as N_2 and Ar in the DME is low, the concentration of these components in the H_2 is also low.

The tail gas from pressure swing adsorption refers in particular to a gas that contains or is composed of (gas) components that were adsorbed during the
10 higher pressure phase and subsequently desorbed again for regeneration. The tail gas, which has a comparatively low pressure, is compressed, returned to the reformer, and reformed with the DME, in particular converted to syngas.

If the reformer is embodied as a fired reformer with a burner, at least one connecting line connecting the hydrogen purification device and the burner may
15 be provided, via which a gas originating from the hydrogen purification device can be fed to the burner and used as fuel. If the hydrogen purification involves pressure swing adsorption or if the hydrogen purification device of the plant comprises at least one pressure swing adsorption reactor, PSA tail gas in particular
20 can be fed to the burner.

The hydrogen purification device may also be integrated into the CO_2 separation device. The CO_2 separation device may, for example, comprise a module for CO_2 separation by chemical and/or physical scrubbing and/or by membrane
25 and/or adsorption processes and a pressure swing adsorption reactor connected downstream of this module.

Since dimethyl ether is usually transported in liquid form, it is expedient to supply the DME in liquid form and vaporize it before it enters the reformer, in par-

ticular steam reformer or autothermic reformer. In the plant according to the invention, a DME vaporization device is provided upstream of the reformer.

5 In a further preferred embodiment, a thermal energy storage device is used to provide the energy required for DME vaporization during a start-up phase. The plant according to the invention may comprise a thermal energy storage device via which the DME vaporization device can be supplied with thermal energy.

10 A cooling device for cooling the synthesis gas obtained by reforming may be provided downstream of the reformer. The synthesis gas or its cooling process may also be used to obtain water vapor. The cooling device may comprise or be formed by a heat exchanger, and the heat exchanger may have at least one line for synthesis gas and at least one line for water. The line for water
15 may be part of a water vapor generation device upstream of the reformer in the plant according to the invention.

It has also proven advantageous to superheat the vaporized DME before it enters the reformer. A superheating device can be provided upstream of the
20 reformer. Such is conveniently located downstream of the DME vaporization device. The superheating device is or will preferably be electrically powered. An example is an electric process gas heater. Superheating can also take place in the flue gas. Steam is usually added beforehand.

25 A steam generating device may also be provided upstream of the reformer. If such a device is present, it can be fed via a thermal energy storage device, in other words supplied with thermal energy, particularly during a start-up phase. A thermal energy storage device can be used which is also accessed by the DME vaporization device during a start-up phase.

If a superheating device and a water vapor generation device are present, it is advantageous for the superheating device to be connected on its inlet side to an outlet of the DME evaporation device and to an outlet of the water vapor generation device in order to be able to superheat a mixture of evaporated DME and water vapor.

In the method according to the invention, it may be provided that vaporized DME is mixed with water vapor and the mixture of DME and water vapor is superheated.

The steam/DME ratio is preferably in the range of 3 to 10, preferably 4 to 8, on a molar basis. A ratio within these ranges can be set within the framework of the method. Another advantageous embodiment of the method is further characterized in that no combustion of a purge stream, in particular a gas purge stream, takes place. The plant according to the invention furthermore does not require any components for such a purge stream.

Especially if an electrically heated reformer, an autothermal reformer, or a combination of an electrically heated reformer and an autothermal reformer is provided instead of a fired reformer, an outlet for inert components (purge stream) is usually required, since there is no burner for the reformer in the plant. However, due to the high purity of the DME feed, it is possible to implement a method and a plant without gas purge that must be burned. Gas phase impurities such as CH_4 and N_2 are released with H_2 and liquid phase impurities with CO_2 . It is possible that a liquid purge and possibly degassing are provided in the condensate or vapor system to prevent accumulation.

Even though the method and plant according to the invention can function without combustion of a purge stream, it is not excluded that such combustion may occur, in particular if a reformer with a burner is present.

With regard to the embodiments of the invention, reference is also made to the subclaims and to the following description with reference to the accompanying drawing. The drawing shows:

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Figure 1 a diagram schematically illustrating a first embodiment of the method according to the invention for producing hydrogen from DME;

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Figure 2 a diagram showing the recycling of the PSA tail gas from a hydrogen purification device 8;

Figure 3 a diagram schematically illustrating a second embodiment of the method according to the invention for producing hydrogen from DME;

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Figure 4 a diagram schematically illustrating a third embodiment of the method according to the invention for producing hydrogen from DME;

Figure 5 a diagram schematically illustrating a fourth embodiment of the method according to the invention for producing hydrogen from DME

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Figure 6 a diagram schematically illustrating a fifth embodiment of the method according to the invention for producing hydrogen from DME;

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Figure 7 a diagram schematically illustrating a sixth embodiment of the method according to the invention for producing hydrogen from DME; and

Figure 8 a diagram schematically illustrating a seventh embodiment of the method according to the invention for producing hydrogen from DME; and

Figure 9 a highly simplified, purely schematic cross-sectional view of a reformer tube containing a catalyst bed with a first and a second region, which are flowed through in succession.

- 5 In the figures, identical or corresponding elements are assigned the same reference signs.

Figure 1 shows a purely schematic representation of a first embodiment of the method according to the invention for producing hydrogen from DME by re-
 10 forming. The method is carried out in a plant, some components of which are indicated purely schematically in Figure 1 by rectangular block elements. This plant represents a first embodiment of a plant according to the invention. Arrows A-J indicate a material or gas flow through the plant during operation or associated fluid connection lines.

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The plant comprises a DME evaporation device 1 and a water vapor generation device 2, both being connected upstream of a superheating device 3 of the plant. The superheating device 3, in turn, is connected upstream of a reformer 4. In the embodiment shown in Figure 1, the reformer 4 is a steam
 20 reformer, which is embodied as a cylindrical tube reactor in which the steam reforming of DME can take place. The steam reformer 4 comprises a nickel-based catalyst material, which is not shown separately in Figure 1.

Downstream of the reformer 4 is a cooling device 5 for cooling synthesis gas,
 25 which is obtained during operation by the reforming, in this case steam reforming, taking place in the reformer 4 and which exits the reformer 4 on the outlet side. Downstream of the cooling device 5, and thus also of the reformer 4, is a water gas shift reactor 6.

Downstream of the water gas shift reactor 6, there is also a CO₂ separation device 7 for separating CO₂ from the synthesis gas obtained by reforming. The CO₂ separation process is also referred to as "carbon capture" or CC for short.

5 During operation, liquid DME is fed to the DME vaporization device 1, as indicated by arrow A in Figure 1, and the DME is vaporized in the DME vaporization device 1, in other words, converted into a gaseous state. During a start-up phase, a thermal energy storage device of the plant, not separately being shown in Figure 1, can be used to provide the thermal energy required for the
10 vaporization of the liquid DME.

At the same time, water is fed to the steam generator 2, as indicated by arrow C in Figure 1, and vaporized in the steam generator 2. For this purpose, a thermal energy storage device can be used as well, at least during a start-up
15 phase of the plant, whereby the same thermal energy storage device may be used as for the DME evaporation device 1.

As indicated by arrow B, gaseous DME is fed from the DME evaporation device 1 into the superheating device 3. Water vapor produced in the water vapor generation device 2 is also fed into the superheating device 3. This is shown
20 by arrow D.

The two arrowheads without lines on the water vapor generator 2 are intended to indicate an energy flow.

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In the superheating device 3, a mixture of gaseous DME and water vapor is obtained and superheated. The superheating can be achieved electrically, for example using an electric process gas heater (also known as a "flow heater"). The superheated gas mixture is fed to the steam reformer 4, as shown by ar-
30 row E.

Reforming takes place in the reformer 4 at a pressure in the range from 15 to 70 bar, preferably in the range from 20 to 40 bar, and at a steam reformer outlet temperature in the range from 750 °C to 1050 °C. Reformer 4 is embodied to operate at these temperatures and pressures. The nickel-based catalyst material arranged in steam reformer 4 is used for the reforming process. It should be noted that it is also possible to use a catalyst bed with at least two catalyst layers. It can also be said that a catalyst bed comprising two regions or layers is used. Accordingly, such a bed can also be arranged in the reformer 4. A corresponding embodiment is discussed in more detail below in connection with Figure 9. If the reformer 4 is designed as a steam reformer, one layer or region is preferably an acidic catalyst, or comprises such a catalyst, such as gamma alumina, and a second layer or region comprises a nickel- or cobalt-based catalyst. Two layers/plies/regions made of or containing a Ni-based catalyst material have also proven particularly effective for an autothermal reformer.

The reformer 4 can be an electrically heated reformer 4 or a fired, in particular gas-fired, reformer 4. Electrically heated steam reformers are sometimes referred to as e-SMR for short. It is also possible to use a combination of electric and fired heating for the reformer 4. The reformer 4 accordingly can be embodied to be heated both electrically and by firing. If the reformer 4 is (also) designed as a fired reformer 4, it conveniently has at least one burner (not shown separately in Figure 1).

The synthesis gas obtained by reforming, which exits the reformer 4, is fed to the cooling device 5 and cooled therein. The gas flow between the reformer 4 and the cooling device 5 or a corresponding connecting line is illustrated in Figure 1 by the arrow F. By way of example, the reforming process is controlled, at least temporarily, in such a way that the steam reformer outlet tem-

perature is around 900 °C. The synthesis gas leaving the reformer 4 at this temperature, for example, can be cooled in the cooling device 5 to 300 to 400 °C, for example.

- 5 In order to increase efficiency, the synthesis gas cooling process can also be used to generate water vapor from liquid water, especially after a start-up phase of the plant. For this purpose, the cooling device 5 may, for example, comprise at least one heat exchanger or be given by at least one heat exchanger, which has at least one line for synthesis gas and at least one line for
- 10 water. The at least one line for water may be part of the water vapor generation device 2. It should be noted that in schematic, greatly simplified Figure 1, the internal structure of the water vapor generation device 2 and the cooling device 5 is not shown and the corresponding lines are not visible.
- 15 The synthesis gas cooled in the cooling device 5 then enters the water gas shift reactor 6, as indicated by arrow G. In this reactor, it undergoes a water gas shift reaction in order to increase the hydrogen yield. It should be noted that the plant may also have more than one water gas shift reactors 6, which are then conveniently connected in series and passed through one after the
- 20 other. For example, two or more water gas shift reactors 6 can cover different temperature ranges. A high-temperature shift in the range of 300 to 450°C and a subsequent medium-temperature shift in the range of 220 to 270°C or a low-temperature shift in the range of 180°C to 250°C may be provided, for example.
- 25 The gas exiting the water gas shift reactor 6 on the outlet side is fed to the CO₂ separation device 7 (arrow H). It should be noted that the gas exiting the water gas shift reactor 6 can be used to vaporize DME. For this purpose, a heat exchanger may be connected between the (or, in the case of several, in particular the last) water gas shift reactor 6 and the CO₂ separation device 7, which
- 30 may comprise at least one line for gas leaving the water gas shift reactor 6 and

at least one line for liquid DME. The at least one line for liquid DME can be part of the DME vaporization device 1. It should also be noted that in schematic, greatly simplified Figure 1, the heat exchanger downstream of the water gas shift reactor 6 and the internal structure of the DME vaporization device 1 are not shown and the corresponding lines are therefore not visible.

In the CO₂ separation device 7, a CO₂ separation process takes place with a separation rate of 55% or more, preferably 75% or more, in particular a separation rate in the range of 80% to 99%.

The CO₂ separation in the process gas can be carried out in particular by one of the following processes, or combinations of two or more of these processes:

- chemical scrubbing, in particular amine scrubbing in one or two stages,
- physical scrubbing, in particular based on methanol and/or DME,
- membrane process,
- adsorption processes,
- condensation process.

The plant may also comprise a hydrogen purification device, which is provided, for example, by a pressure swing absorption reactor or comprises such a reactor. The hydrogen purification device may be integrated into the CO₂ separation device 7, which is the case in the embodiment shown in Figure 1. For example, the CO₂ separation device may comprise a CO₂ separation module and, in particular, a downstream pressure swing absorption reactor for hydrogen purification.

Alternatively, it is also possible that a hydrogen purification device 8 being separate from the CO₂ separation device 7 and suitably connected downstream of the CO₂ separation device 7, is provided, which preferably comprises a pres-

sure swing absorption reactor or is given by such a reactor. While a separate hydrogen purification device 8 is not shown in Figure 1, it can be seen in Figure 2, which shows some components of the plant shown in Figure 1. In Figure 2, which is also greatly simplified, components 1, 2, 3 for the pretreatment of the DME feed are shown combined in a single block element. The gas fed from the CO₂ separation device 7 into the hydrogen purification device 8, or a corresponding connecting line, is indicated in Figure 2 by arrow H1. Separate CO₂ separation devices 7 and hydrogen purification devices 8 can also be seen in Figures 6, 7, and 8, which show further examples of the method and systems according to the invention in highly simplified, purely schematic representation.

From the CO₂ separation device 7 or the hydrogen purification device 8, a "recycling" can take place to the water gas shift reactor 6 and/or to the reformer 4, not to its burner as fuel gas, but as input gas for reforming in order to recover CO, methane, and DME. This further increases efficiency. In Figure 2, arrow K indicates PSA tail gas discharged from the hydrogen purification device 8 and an associated pipe, which is fed to a compressor 9 and then to the feed gas inlet of the reformer 4, as shown by arrow L. The PSA tail gas originating from hydrogen purification comprises H₂, CH₄ and CO. The corresponding recirculation of PSA tail gas from hydrogen purification can also be seen in Figure 8. The dashed arrow M in Figure 2 illustrates an optional "recycling" to the water gas shift reactor 6, and another dashed arrow N illustrates an optional minimum purge flow.

Figure 1 also indicates with arrow I that gas originating from the CO₂ separation device 7 is returned to the reformer 4, specifically to the burner of the reformer 4, to serve as fuel there. This further increases the efficiency of the plant. In particular, unconverted CO and/or tail gas from pressure swing adsorption, also known as PSA tail gas (for pressure swing adsorption), can be fed to the burner and serve as fuel. For this "recycling," the plant includes a

connecting line that connects the CO₂ separation device 7 to the reformer 4, specifically its burner. It should be noted that in Figures 1 and 2 as well as Figures 3 and 5, the burner of the reformer 4 is not shown separately. This is only the case in Figures 6 and 7, which will be discussed in more detail below.

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The finished H₂ product exits the CO₂ separation device 7 on the outlet side, as indicated by arrow J in Figures 1 and 2. Since DME reforming in the reformer 4 is carried out at higher pressures than in the prior art, the H₂ product is already available at sufficient pressure. The plant therefore does not require a hydrogen compressor. The hydrogen can, for example, be fed directly into a pipeline to reach a desired point of use. The plant according to the invention also does not require desulfurization, since DME does not contain sulfur.

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It should be noted that, as an alternative to being provided by a steam reformer, the reformer 4 can also be embodied as an autothermal reformer. In this case, O₂ is supplied in a manner known per se (not shown in Figure 1, but indicated in Figure 2 by the dotted arrow O).

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Since the reforming process according to the invention can take place at higher temperatures, it is also possible to counteract slip, in particular CH₄ and/or MeOH and/or DME slip from the reformer 4, by increasing the temperature, preferably by suitably adjusting the reformer outlet temperature. In an advantageous embodiment of the method according to the invention, the slip, in particular the CH₄ and/or MeOH and/or DME slip of the reforming process, is therefore monitored and the reformer outlet temperature is increased if the slip exceeds a predetermined value. If, for example, the reforming initially takes place at an outlet temperature of 900°C as indicated above and an (excessive) slip is detected, the temperature can be increased to 950°C, for example, as a counteract measure. In addition, the DC ratio can be increased over the operating time to further reduce the slip, e.g., from 5 to 7 over the operating time.

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It is also possible to use part of the H₂ product to fire the reformer 4, which can be designed accordingly. A connecting line to the burner of the reformer 4 can be provided (not shown).

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It has proven to be particularly advantageous, especially in terms of efficiency, to use an electrically heated and/or H₂ product-fired reformer 4 in combination with a low-temperature shift, in particular down to 180°C, and "recycling" from the CO₂ separation device 7 or the hydrogen purification device 8 to the or, in
10 the case of several, at least one water gas shift reactor 6 and/or to the reformer 4 – in each case as input gas – for the recovery of CO, methane, and DME, as schematically shown in Figure 2.

Figures 3 to 5 schematically illustrate three further embodiments of inventive
15 methods carried out in corresponding inventive plants. Here, too, some components of the plants are shown only as block elements. As can be seen, the three further embodiments of inventive plants largely correspond to the example in Figure 1. The following section will only discuss the differences; for the remaining aspects, reference is made to the above explanations for Figure
20 1.

The three further embodiments differ from the first example only in that a gas-fired auxiliary reformer 4a (Figures 3 and 4) or an adiabatic pre-reformer 4b (Figure 5) is used.

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Figure 3 shows the case of an additional reformer 4a connected in parallel to the reformer 4, and Figure 4 shows the case of an additional reformer connected in series upstream of the reformer 4.

In case of parallel connection according to Figure 3, the feed gas flow is divided. It is distributed between the reformer 4 and the additional reformer 4a (indicated in Figure 3 by the forked arrow E with two arrowheads), whereby the reformer 4 is usually supplied with a larger proportion of the feed gas than the parallel additional reformer 4a. The hot outlet gas from the reformer 4 is fed to the parallel auxiliary reformer 4a as heating gas (see arrow F_1 in Figure 3) and its thermal energy is used in the auxiliary reformer. After the outlet gas from the reformer 4 has passed through the auxiliary reformer as heating gas and released heat there, it is mixed with the outlet gas from the auxiliary reformer 4a; in other words, the two synthesis gas streams are combined or mixed. This is indicated in Figure 3 by the merging arrow F_2 , which connects the synthesis gas outlet and the heating gas outlet of the auxiliary reformer 4a to the cooling device 5.

In case of serial connection, the entire feed gas stream is first fed to the upstream auxiliary reformer 4a and then to the downstream reformer 4, as indicated in Figure 4 by arrows E and F_1 . The hot outlet gas from the reformer 4 is returned to the auxiliary reformer 4a, specifically to a heating gas inlet thereof, as indicated by arrow F_2 , to serve as heating gas for the auxiliary reformer 4a. The heating gas outlet of the auxiliary reformer 4a is connected to the cooling device 5 (arrow F_3).

It is possible, for example, to use an autothermal reformer 4 in combination with an auxiliary reformer 4a embodied as a steam reformer. It is also possible that both the reformer 4 and the auxiliary reformer 4a are embodied as steam reformers.

As can be seen in Figure 5, the adiabatic pre-reformer 4b of the fourth embodiment is connected upstream of the reformer 4. Gas emerging from the pre-reformer 4b is fed to the reformer 4, as indicated by arrow F_1 , and gas emer-

ging from the reformer 4 is fed to the cooling device 5 (see arrow F_2). It should be noted that a combination of auxiliary reformer 4a and pre-reformer 4b is also possible.

5 Furthermore, in the embodiments shown in Figures 3 to 5, gas originating from the CO_2 separation device 7 can be or is returned to the burner of the reformer 4, as indicated by arrow I in Figure 1. For reasons of clarity, however, arrow I is not additionally shown in Figures 3 to 5. The same applies to the "recycling" illustrated in Figure 2, which can also be implemented in Figures 3 to 5, al-
10 though it is not shown again in these figures.

Figures 6 to 8 again illustrate further examples of embodiments of the invention and associated systems in a purely schematic manner. Here, too, some components of the corresponding plants are shown as block elements and there
15 are many similarities with the embodiments described above. The following section will only discuss the differences and otherwise refer to the above explanations, in particular with regard to Figures 1 and 2.

Figure 6 illustrates in more detail the recirculation of PSA tail gas originating
20 from and extracted from the hydrogen purification device 8 and fed to the burner 10 of the reformer 4, which is shown separately in Figure 6. It should be noted that while burner 10 is shown next to reformer 4 in Figure 6 for reasons of clarity, it forms part of reformer 4. The same applies to Figure 7. The supply of PSA tail gas to burner 10 is indicated by arrow I. Figures 6 and 7 also
25 show that DME can be supplied to burner 10 during a start-up phase (see arrow P, which represents the corresponding supply or an associated connecting line). Another difference between the plants shown in Figure 6 is that a cooling and condensation unit 11 arranged between the water gas shift reactor 6 and the CO_2 separation device 7 is additionally shown here. It should be

noted that, even though Figures 1 to 5 do not show one, a corresponding unit may also be present.

Finally, Figure 6 includes dashed arrows Q and R, which represent an energy or heat flow from the cooling device 5 and the water gas shift reactor 6 to the steam generator 2, respectively. Additional dashed arrows also represent an energy flow.

The method and plant according to Figure 7 comprise — analogous to Figure 2 — the extraction of PSA tail gas from the hydrogen purification device 8, its compression in a compressor 9, and its return to the reformer 4 on the inlet side together with DME. It should be noted that, as shown in Figure 7, compressed PSA tail gas is fed to the superheater 3. A corresponding connecting line, indicated by the arrow L in Figure 7, opens up accordingly before the superheater 3. In this case, DME is superheated together with the supplied PSA tail gas in the superheater 3 and then fed to the reformer 4. In the method or plant shown in Figure 7 (compared to Figure 6), gas is returned to the burner 10 of the reformer 4. As can be seen in Figure 7, however, this is not PSA tail gas from the hydrogen purification device 8, as in Figure 6, but hydrogen leaving this device. It is indicated in Figure 7 by an arrow S. The advantage of firing the burner 10 with H_2 is that no CO_2 emissions are produced. In Figure 7, DME can also be used to start up the plant, as indicated by the arrow P to the burner 10.

Figure 8 shows that PSA tail gas can be extracted from the hydrogen purification device 8, compressed in the compressor 9, and returned to the reformer 4, in particular upstream of the superheating device 3, even in cases where the reformer 4 is an electric reformer or an autothermal reformer. Otherwise, Figure 8 corresponds to Figure 7.

Figure 9 shows in a purely schematic, greatly simplified representation a particularly advantageous embodiment of a catalyst bed 13, which can be used in the context of the method according to the invention. Figure 9 shows, by way of example, a reformer tube 12 in which the catalyst bed 13 is arranged. The catalyst bed 13 is divided into two regions, specifically a first upper region 14 and a second lower region 15, which are flowed through successively from top to bottom in the embodiment shown. The direction of flow is indicated in Figure 9 by two arrows. The catalyst bed 13 is provided by a catalyst filling, in other words, it is embodied as such. The first region 14 of the catalyst filling 13 is provided here by an acidic catalyst material, for example gamma aluminum oxide. The second region 15 of the catalyst bed 13 is further provided by a nickel- or cobalt-based catalyst material. As can be seen, the first region 14 is arranged above the second region 15. It goes without saying that a reformer 4 can comprise one or more such reformer tubes 12, of which only one is shown in Figure 9 as an example. All reformers 4 of the embodiments shown in Figures 1 to 8 can have a catalyst bed 13 with two regions 14 and 15, as shown in Figure 9.

List of reference signs

	1	DME vaporization device
	2	Water vapor generation device
5	3	Superheating device
	4	Reformer
	4a	Gas-fired auxiliary reformer
	4b	adiabatic pre-reformer
	5	Cooling system
10	6	Water gas shift reactor
	7	CO ₂ separation device
	8	Hydrogen purification device
	9	Compressor
	10	Burner
15	11	Cooling and condensation unit
	12	Reformer tube
	13	Catalyst bed
	14	First region
	15	Second region

CLAIMS

1. Method for producing hydrogen from DME (dimethyl ether) by reforming, **characterized in** that the reforming is carried out at a pressure in the
5 range from 15 bar to 70 bar, preferably in the range from 20 bar to 40 bar, and at a reformer outlet temperature in the range from 750°C to 1050°C, and a nickel- or cobalt-based catalyst material is used for the reforming process.
2. Method according to claim 1, **characterized in** that a catalyst bed with
10 at least two layers is used, wherein at least one layer comprises or consists of an acidic catalyst material, in particular gamma alumina, and at least one further layer comprises or consists of a nickel- or cobalt-based catalyst material, or wherein two layers comprise or consist of a nickel-based catalyst material.
- 15 3. Method according to claim 1 or 2, **characterized in** that a catalyst bed is used which comprises a first and a second region, wherein the first region has a first catalyst material and the second region has a second catalyst material different from the first catalyst material, and wherein the catalyst bed is embodied and arranged in a reformer used for the reforming process (4) such
20 that the first and second regions are flowed through successively by the DME and/or by a product formed from the DME during the reforming process, preferably wherein the first catalyst material is an acidic catalyst material and the second catalyst material is a nickel- or cobalt-based catalyst material, and/or wherein the first region is arranged upstream of the second region, and/or
25 wherein the catalyst bed is arranged in a preferably vertically arranged reformer tube of a reformer (4) used for the reforming process.
4. Method according to one of the preceding claims, **characterized in** that the catalyst bed comprises or is embodied as a catalyst filling.

5. Method according to one of the preceding claims, **characterized in** that a CO₂ separation process is carried out after the reforming process, preferably wherein the CO₂ separation is preferably carried out by chemical scrubbing, in particular amine scrubbing in one or two stages, and/or by physical scrubbing, in particular based on methanol and/or DME, and/or by a membrane process and/or by an adsorption process and/or with a CO₂ separation rate of at least 55%, preferably with a CO₂ separation rate in the range of 80% to 99%.
6. Method according to claim 5, **characterized in** that after the CO₂ separation, a hydrogen purification is carried out, in particular wherein a gas originating from the hydrogen purification, which preferably comprises H₂ and CH₄ and CO, is compressed and fed to the inlet side of a reformer (4) used for the reforming process, in particular together with the DME, preferably wherein the hydrogen purification is carried out by pressure swing adsorption and a tail gas from the pressure swing adsorption is compressed and fed to the inlet side of the reformer (4) together with the DME.
7. Method according to claim 5 or 6, **characterized in** that the CO₂ separation is carried out by or includes a condensation process, preferably wherein the cold required for condensing the CO₂ is provided by means of an open or closed refrigeration circuit containing DME as a refrigerant.
8. Method according to one of the preceding claims, **characterized in** that a reformer (4) embodied as a steam reformer is used, wherein the steam reforming is carried out in particular at a reformer outlet temperature in the range from 750°C to 950°C, preferably 775°C to 950°C.
9. Method according to claim 8, **characterized in** that a fired, in particular gas-fired, steam reformer with a burner is used, in particular wherein the flue gas is partially condensed, in particular wherein heat integration of the flue gas

takes place and the partial condensation of the flue gas takes place in a final stage of the heat integration, and/or wherein the condensation enthalpy is used to heat DME, combustion air, and/or water.

5 **10.** Method according to one of claims 5 to 7 and claim 9, **characterized in** that gas originating from the CO₂ separation process is fed to the burner and used as fuel for the burner.

10 **11.** Method according to claim 9 or 10, **characterized in** that part of the hydrogen produced is fed to the burner and used as fuel for the burner.

12. Method according to claim 6 and claim 11, **characterized in** that hydrogen is extracted after hydrogen purification and fed to the burner.

15 **13.** Method according to one of claims 1 to 7, **characterized in** that a reformer (4) embodied as an autothermal reformer is used, wherein the autothermal reforming is preferably carried out at a reformer outlet temperature in the range from 950°C to 1050°C.

20 **14.** Method according to one of the preceding claims, **characterized in** that a gas-heated auxiliary reformer is used, wherein synthesis gas obtained in the reformer (4) is fed to the auxiliary reformer for its heating, preferably wherein the auxiliary reformer is connected upstream of the reformer (4) or connected in parallel to the reformer (4), and/or wherein the auxiliary reformer is embodied as a steam reformer.

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15. Method according to one of the preceding claims, **characterized in** that an adiabatic pre-reformer connected upstream of the reformer (4) is used, preferably wherein the pre-reformer comprises an acidic catalyst material or a

Ni-based catalyst material with a higher Ni loading than the catalyst material of the reformer (4).

5 **16.** Method according to one of the preceding claims, **characterized in** that the synthesis gas obtained by reforming is cooled.

10 **17.** Method according to one of the preceding claims, **characterized in** that the synthesis gas obtained by reforming is subjected to a water gas shift reaction, preferably after cooling.

15 **18.** Method according to one of claims 5, 6, 7, or 10 and claim 17, **characterized in** that the CO₂ separation is carried out after the water gas shift reaction.

20 **19.** Method according to one of the preceding claims, **characterized in** that the DME is supplied in liquid form and is vaporized before entering the reformer (4), preferably wherein a thermal energy storage device is used to provide the energy required for vaporization during a start-up phase, and/or wherein the vaporized DME, in particular mixed with water vapor, is superheated before entering the reformer (4).

25 **20.** Method according to claims 16 and 19, **characterized in** that, in particular after a start-up phase, the liquid DME is used to cool the synthesis gas, preferably by passing the synthesis gas obtained by reforming and the liquid DME through a common heat exchanger in which the synthesis gas is cooled and the liquid DME is vaporized.

30 **21.** Method according to one of the preceding claims, **characterized in** that no combustion of a purge stream takes place.

22. Plant for producing hydrogen from DME (dimethyl ether) in a method according to one of the preceding claims, with a reformer (4), **characterized** in that the reformer (4) is embodied to carry out reforming of DME at a pressure in the range from 15 bar to 70 bar, preferably in the range from 20 bar to 40 bar, and at a reformer outlet temperature in the range from 750°C to 1050°C, preferably in the range from 750°C to 950°C, and the reformer (4) comprises a nickel- or cobalt-based catalyst material, and that a DME evaporation device (1) is provided upstream of the reformer (4).
23. Plant according to claim 22, **characterized in** that the reformer (4) comprises a catalyst bed with at least two layers, wherein at least one layer comprises or consists of an acidic catalyst material, in particular gamma alumina, and at least one further layer comprises or consists of a nickel- and/or cobalt-based catalyst material, or wherein two layers comprise or consist of a nickel-based catalyst material.
24. Plant according to claim 22 or 23, **characterized in** that the reformer (4) has a catalyst bed comprising a first and a second region, wherein the first region has a first catalyst material and the second region has a second catalyst material different from the first catalyst material, and wherein the catalyst bed is embodied and arranged in a reformer (4) used for the reforming process such that, during operation, the first and second regions are flowed through successively by the DME and/or by a product formed from the DME during the reforming process, preferably wherein the first catalyst material is an acidic catalyst material and the second catalyst material is a nickel- or cobalt-based catalyst material, and/or wherein the first region is arranged upstream of the second region, and/or wherein the reformer (4) has a preferably vertically arranged reformer tube in which the catalyst bed is arranged.

25. Plant according to one of claims 22 to 24, **characterized in** that the catalyst bed comprises or is embodied as a catalyst filling.

26. Plant according to one of claims 22 to 25, **characterized in** that a CO₂ separation device (7) is provided downstream of the reformer (4) in order to separate carbon dioxide (CO₂) from the synthesis gas obtained by reforming, preferably wherein the CO₂ separation device (7) is embodied for separating CO₂ by chemical scrubbing, in particular amine scrubbing in one or two stages, and/or by physical scrubbing, in particular based on methanol and/or DME, and/or by a membrane process and/or by an adsorption process, and/or that the CO₂ separation device (7) is embodied to provide a CO₂ separation rate of at least 55%, preferably a CO₂ separation rate in the range from 80% to 99%.

27. Plant according to claim 26, **characterized in** that the CO₂ separation device (7) is embodied for CO₂ separation by a condensation process, preferably wherein the CO₂ separation device (7) is embodied to provide the cooling required for condensation of the CO₂ by means of an open or closed refrigeration circuit containing DME as a refrigerant.

28. Plant according to claim 26 or 27, **characterized in** that the reformer (4) is embodied as a steam reformer, in particular, wherein the reformer (4) is embodied as a fired steam reformer with a burner, preferably, wherein a condensation device is provided for partial condensation of the flue gas, in particular in a final stage of flue gas heat integration.

29. Plant according to claims 27 and 28, **characterized in** that at least one connecting line connecting the CO₂ separation device (7) and the burner is provided, via which gas originating from the CO₂ separation device (7) can be fed to the burner.

30. Plant according to one of claims 22 to 27, **characterized in** that the reformer (4) is embodied as an autothermal reformer.

31. Plant according to one of claims 22 to 30, **characterized in** that a gas-heated auxiliary reformer is provided, wherein the auxiliary reformer can be heated by means of synthesis gas obtained in the reformer (4), preferably wherein the auxiliary reformer is connected upstream of the reformer (4) or connected in parallel to the reformer (4), and/or wherein the auxiliary reformer is embodied as a steam reformer.

32. Plant according to one of claims 22 to 31, **characterized in** that an adiabatic pre-reformer (4b) is provided upstream of the reformer (4), preferably wherein the pre-reformer comprises an acidic catalyst material or a Ni-based catalyst material with a higher Ni loading than the catalyst material of the reformer (4).

33. Plant according to one of claims 22 to 32, **characterized in** that a cooling device (5) for cooling synthesis gas obtained by steam reforming is provided downstream of the reformer (4), preferably wherein the cooling device (5) comprises or is formed by a heat exchanger and the heat exchanger has at least one line for synthesis gas and at least one line for DME.

34. Plant according to one of claims 22 to 33, **characterized in** that a water gas shift reactor (6) is provided downstream of the reformer (4).

35. Plant according to one of claims 22 to 34, **characterized in** that a hydrogen purification device (8) is provided downstream of the reformer (4), preferably wherein the hydrogen purification device (8) comprises at least one pressure swing adsorption reactor and/or wherein a connecting line connecting the hydrogen purification device (8) and the reformer (4), via which a

gas originating from the hydrogen purification device (8), preferably comprising H_2 and CH_4 and CO, in particular a tail gas from the pressure swing adsorption, can be fed to the reformer (4) on its inlet side, in particular together with the DME, and a compressor for compressing the gas originating
5 from the hydrogen purification device (8) is provided.

36. Plant according to claims 28 and 35, **characterized in** that the reformer (4) has a burner and at least one connecting line is provided between the hydrogen purification device and the burner, via which a gas originating from the
10 hydrogen purification device (8) can be fed to the burner.

37. Plant according to one of claims 22 to 36, **characterized in** that a thermal energy storage device is provided, via which the DME vaporization device (1) can be fed.
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38. Plant according to one of claims 22 to 37, **characterized in** that a superheating device (3), preferably supplied with electricity, is provided upstream of the reformer (4), , the superheating device (3) in particular being connected downstream of the DME vaporization device (1).
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39. Plant according to one of claims 22 to 38, **characterized in** that a steam generating device (2) is provided upstream of the reformer (4), preferably wherein the steam generating device (2) can be supplied via a thermal energy storage device.
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40. Plant according to claim 38 and claim 39, **characterized in** that the superheating device (3) is connected on its inlet side to an outlet of the DME evaporation device (1) and to an outlet of the steam generation device (2) in order to be able to superheat a mixture of evaporated DME and steam.