Climate Protection by an Alternative Use of Methane—The Carbon Moratorium**

Gerhard Kreysa[a]

Despite a rising output, in the last few decades the known reserves of fossil energy resources have steadily increased. Additionally, there are in all likelihood tremendous reserves of methane hydrate. In view of the climate change, new means must be explored for its use as an energy source. Starting with an assessment of various options for dealing with the carbon cycle and thermodynamic considerations of methane chemistry, a new approach for the use of methane as energy source is developed in this Concept. After thermal methane cracking, only the energy content of the hydrogen is used and the carbon is stored safely and retrievably in disused coal beds. Arguments for the viability of a carbon moratorium of this kind are discussed.

1. The Changed Raw Materials Situation

Since the first oil crisis in 1973, at the latest, the idea that the currently predominant form of the world’s energy supply cannot continue indefinitely has gained ground in politics, the media and public awareness. The famous Reports of the Club of Rome1,2 on the situation of mankind have mainly broached the problem in the context of the evident scarcity of resources. At the same time, however, they disregarded the fact that exploration is an expensive business that can only be financed from current production revenues, which explains why this issue has still not been totally resolved. This fact was acknowledged in the 30-year update3 of the first Club of Rome Report. In the years following 1973, therefore, the annual amounts of newly explored fossil resources almost regularly exceeded the amounts produced. This fact is underscored by Table 1, in which the known supplies of fossil raw materials in 1973 are compared with those of 2006. Although the annual production of the three fossil energy sources, crude oil, natural gas and coal, has almost doubled in the period under consideration, today’s reserves (raw materials that can be produced economically using established technology) amount to 182 % for crude oil and 340 % for natural gas of the values for 1973. The figures from 1973 for coal are not comparable with those from today as coal reserves have meanwhile been defined differently and even at that time the resources were overestimated.4 In 2006 alone, coal reserves increased by 122 % on account of the discovery and corrected rating of new deposits in China and the CIS States.4 Admittedly, such a high annual increase in reserves is the exception, but it still happens. In order to assess these reserves and resources, it should be noted that in 2006 the world consumption of primary energy totalled 455 EJ.5 (In the literature, different factors are given for the conversion of the amounts of the energy sources into energy volume in exajoules. In the present paper, the conversion factors given in the BGR study6 (p. 42 therein) are considered to be reliable and are therefore used.) Table 1 clearly shows that the prophesied crisis of a raw material shortage has not yet come to hit us, which by no means changes the finiteness of reserves. It may, however, explain why, in the wake of the “oil crisis”, the large-scale and successful R&D programs addressing the problem of securing the supply of raw materials7 made little impact on the raw materials base and the energy mix.

A further dramatic change in the resource situation faces us as soon as the ongoing intensive development work on the recovery of methane hydrate from the ocean7 shows its first positive results. Methane hydrate has been found in depths of 100 to 500 m along the continental coasts of almost all the world’s oceans. Estimates of their reserves vary strongly7 up to twice the amount of all the world’s known oil, natural gas and coal deposits (prior to the coal increase of 20066). This would correspond to total methane hydrate reserves of almost 7000 gigatonnes of carbon (Gt C). Admittedly, these figures are extremely uncertain; in other studies they vary between

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<tr>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude oil</td>
<td>3732</td>
<td>6805</td>
<td>3430</td>
<td>163.9</td>
</tr>
<tr>
<td>Non-conv. oil</td>
<td>2026</td>
<td>6891</td>
<td>7866</td>
<td>111.4</td>
</tr>
<tr>
<td>Natural gas</td>
<td>76</td>
<td>58335</td>
<td>255194</td>
<td>141.8</td>
</tr>
<tr>
<td>Coal</td>
<td>121760</td>
<td>21286</td>
<td>255194</td>
<td>141.8</td>
</tr>
<tr>
<td>Sum</td>
<td>127518</td>
<td>37819</td>
<td>335285</td>
<td>417.1</td>
</tr>
</tbody>
</table>

Table 1. Development of world inventories of fossil raw materials from 1973 [1, 2] to 2006 [3].

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76000 Gt C\textsuperscript{[8]} and 3000 Gt C\textsuperscript{[9]}. The lowest estimate of 3000 Gt C corresponds to huge energy reserves of 200000 EJ. Based on the annual consumption of fossil energy sources of 399 EJ in 2006\textsuperscript{[5]} this value results in a reserves-to-production timeframe of around 500 years.

In view of the resource situation described, it is evident that this alone has not exerted any pressure to effect a dramatic change in the world’s energy supply. This awakening only arose with the increasingly certain realisation of the anthropogenic share of the greenhouse effect of atmospheric carbon dioxide. Arrhenius\textsuperscript{[10]} was the first to provide a quantitative description of the natural greenhouse effect of CO\textsubscript{2}, while it was not until the end of the 1980s that the focus shifted to the anthropogenic share, mainly attributable to the combustion of fossil energy resources\textsuperscript{[11,12]}. Of the numerous studies that have since dealt with the anthropogenic contribution to climate change and the consequences for our energy system, only a few of the more recent ones are cited\textsuperscript{[13–22]} and referred to herein.

2. Options for Dealing with the Carbon Cycle

Figure 1 shows the simplified carbon cycle with its reservoirs and fluxes that are indispensable to a consideration of the anthropogenic greenhouse effect of carbon dioxide. The annual rise of 3.3 Gt in the CO\textsubscript{2} inventory of the atmosphere corresponds to an annual increase of 0.407 %. Based on today’s CO\textsubscript{2} content of 380 ppm, this percentage results in an annual increase of 1.55 ppm, which agrees well with the value of 1.60 ppm resulting from the upward trend of the Mauna Loa curve over the last 30 years (the concentration of CO\textsubscript{2} in the atmosphere has been measured daily at Mauna Loa Observatory, Hawaii, since 1958). Although today’s climate models are highly differentiated\textsuperscript{[20]} this agreement represents a justification, within certain limitations, of linear balance estimates. If the net atmospheric CO\textsubscript{2} uptake of currently 61 % of the amount released by combustion were to remain constant, after the complete combustion of fossil reserves (1300 Gt coal equivalents corresponds to around 1000 Gt C) this would result in an atmospheric CO\textsubscript{2} content of about 670 ppm. Assuming IPCC’s\textsuperscript{[19]} pessimistic scenarios that a far-reaching continuation of the present development trend would lead to a CO\textsubscript{2} content of 700–800 ppm in 2100, according to calculations by the Max Planck Institute for Meteorology\textsuperscript{[23]} this value is comparable to the linear estimate. If the combustion of 3000 Gt C of methane hydrate reserves is added, according to this simplified calculation it would result in a CO\textsubscript{2} content of at least 1500 ppm. This figure would presumably be even higher because, as a consequence of the temperature increase, the net uptake of the oceans of currently 1.9 Gt C/annum would drop significantly.

It is popular to refer to the possibility of using renewable resources to reduce the anthropogenic emission of CO\textsubscript{2} because the amount of energy that the sun radiates onto the earth exceeds the world’s annual primary energy demand by more than 10000-fold. Table 2 provides a summary of the main data required for a quantitative assessment of this option. It is evident that even if the total agricultural area available today were to be completely exploited\textsuperscript{[24]} the resulting volume of energy potential would only exceed the world’s present demand for primary energy by 6 %. The decisive reason is the low efficiency of photosynthesis. This fundamental claim should be confirmed by a second independent estimation. Energy-efficient plants, such as poplar, willow or grain, produce an annual energy yield of about 180 GJ per hectare per annum.\textsuperscript{[25]} To cover the present global consumption of primary energy by these plants would necessitate a cultivable area of 25.3 million km\textsuperscript{2}. This number represents 28 % more than the total global agricultural area of 19.8 million km\textsuperscript{2} available today.\textsuperscript{[26]} In the best case, therefore, the use of renewable biomass for energy can only make a minor contribution to the world’s energy supply. In view of the increasing world population, this will only exacerbate the moral competition between land for energy crops versus food production.

More recent studies\textsuperscript{[26]} even give reason to fear that in many cases the energetic use of biomass would not contribute to the desired reduction of the greenhouse effect. This seems to apply at least to first-generation biofuels (biodiesel and bioethanol). The requisite nitrogenous fertilization of the fields causes the release of N\textsubscript{2}O whose greenhouse effect is almost 300 times higher than that of CO\textsubscript{2}. Figure 2 shows that with the exception of sugar cane in Brazil the production of biodiesel and bioethanol causes a greenhouse effect that is larger than it would be with conventional fuels through CO\textsubscript{2} emission. Therefore, the production of these biofuels will have to be reconsidered.

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**Table 2.** Usable part of solar radiation for the production of energy crops at the presently available arable land area of the earth.

<table>
<thead>
<tr>
<th>Share [%]</th>
<th>EJ/a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar radiation to earth cross-section</td>
<td>100</td>
</tr>
<tr>
<td>55 % losses in the atmosphere</td>
<td>45</td>
</tr>
<tr>
<td>3.9 % part of agricultural area on earth surface</td>
<td>1.75</td>
</tr>
<tr>
<td>0.5 % efficiency of photosynthesis</td>
<td>0.0088</td>
</tr>
<tr>
<td>World primary energy consumption 2006</td>
<td>–</td>
</tr>
</tbody>
</table>

\[a\] Solar constant: 1.367 Wm\textsuperscript{–2}.

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![Figure 1. Basic data of the carbon cycle\textsuperscript{[23]} (reservoir contents in Gt C, if not indicated otherwise; material fluxes (italicised) in Gt C per annum).](image)
Methane as Energy Source

A further popular possibility for the reduction of CO₂ emissions is carbon capture and storage (CCS) technology for disposal of CO₂ from fossil-fired power plants and other central sources of CO₂ (e.g. steel production). The conceivable use of the ocean for CO₂ storage is looked upon critically by many scientists, and the capacity of the world’s remaining available storage, such as oil/gas reservoirs, saltwater aquifers, coal beds and mines, is hardly likely to suffice for the uptake of CO₂ emissions from methane hydrate combustion. At present, the relevant technology has neither been fully developed nor is it available. The industries concerned regard CO₂ washing merely as a retrofitting option as the technical, legal and regulatory issues of CO₂ storage, which fall not only within the competence of the companies, need to be clarified beforehand.

In view of all the known difficulties in controlling the CO₂ problem caused by carbon-based combustion technology, all the relevant studies and recommendations are unanimous that a lasting world energy supply will be based on solar-produced electricity and hydrogen. Generally, however, the chances for the transformation of the global energy system on these lines are not viewed as realistic until after 2050. The construction of solar-thermal power plants in southern Europe, all around the Mediterranean Sea and in other sunny locations worldwide has been strongly recommended as an important step towards this goal. If such unanimity exists on the target of a solar energy economy, then all the technical options that represent a step in this direction should receive preferential treatment because they are compatible with the future system and in particular because they will make it possible to establish a hydrogen technology.

The tremendous methane hydrate reserves of 200 000 EJ and the natural gas stocks amount to a further 73 168 EJ (37% of methane hydrate reserves), if the reserves, resources and non-conventional sources are included in the calculation (cf. Table 1). Related to the total consumption of fossil energy sources in 2006, this corresponds to a reserves-to-production timeframe of a further 175 years. These figures thus call for a reassessment of the use of methane as a future energy system.

Of course, methane also is a strong greenhouse gas which requires careful handling to minimise leakage losses. However, this applies also to natural gas.

3. The Thermodynamics of Methane

The conventional use of methane for energy (today mainly in the form of natural gas) is based on its complete combustion [Eq. (1)].

\[
\text{CH}_4 + 2\text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O} \quad \Delta H_{1000°C} = -803.5 \text{kJ mol}^{-1}
\]  

Equation (1)

Methane, however, manifests two interesting thermodynamic features that pave the way for a climate-friendly alternative for its use. The production of hydrogen by thermal water splitting is only possible at temperatures significantly above 3000 K (2727 °C) and is, moreover, constrained by the fact that above 2000 K (1727 °C) endothermic dissociation of hydrogen and oxygen molecules into atoms takes place. Methane, by contrast, can be thermally cracked at temperatures above 500 °C (773 K) which are technically quite feasible [Eq. (2)].

\[
\text{CH}_4 \rightarrow \text{C} + 2\text{H}_2 \quad \Delta H_{1000°C} = +91.7 \text{kJ mol}^{-1}
\]  

Equation (2)

Figure 3 shows the calculated temperature dependency of the reaction enthalpy and free enthalpy for methane cracking, while Figure 4 presents the volumetric methane content in equilibrium of this reaction as a function of temperature. The data presented here, which were recalculated for reasons of consistency, are in good agreement with previously reported data.

The second thermodynamic feature stems from a consideration of the combustion reactions of carbon and hydrogen [Eqs. (3) and (4)].

\[
\text{C} + \text{O}_2 \rightarrow \text{CO}_2 \quad \Delta H_{1000°C} = -395.8 \text{kJ mol}^{-1}
\]  

Equation (3)

\[
2\text{H}_2 + \text{O}_2 \rightarrow 2\text{H}_2\text{O} \quad \Delta H_{1000°C} = -499.4 \text{kJ mol}^{-1}
\]  

Equation (4)
By using the reaction shown in Equation (4) to provide also the endothermic reaction enthalpy of methane cracking (Equation (2)), the energy yield from hydrogen combustion is reduced to 407.7 kJ mol\(^{-1}\). After autothermal cracking of methane from its combustion heat of 803.5 kJ mol\(^{-1}\), this results in 49.3\% (395.8 kJ mol\(^{-1}\)) being stored in the carbon and 50.7\% (407.7 kJ mol\(^{-1}\)) in the remaining hydrogen. Given sufficient availability of methane (cf. Section 1), as is the case with non-conventional natural gas reserves and, in all probability, most notably with methane hydrate, these thermodynamic circumstances open up a new option for the energetic use of methane. In contrast to technologies like CCS, it is relatively simple to store the carbon generated by methane cracking either temporarily or permanently. Former coal mines, particularly open-cast lignite mines, would be suitable for this purpose. (With lignite power plants, only the direction of the freight trains would be reversed.) The energy content of carbon would not be lost forever, because it could be optionally used in the future, if the carbon dioxide content of the atmosphere was to be reduced by some effect. Hydrogen can be used centrally as a fuel in gas power stations for electricity generation or it can be used non-centrally in a variety of ways, including fuel cells in domestic heating and transport. From hereon in, this novel CO\(_2\)-free concept is referred to as the "carbon moratorium" because basically it means putting a stop to paying for our energy requirements with carbon combustion and its detrimental consequences for the climate.

In principle, the process of autothermal cracking proposed here is transferable to other hydrocarbons. Admittedly, the usable energy content of the hydrogen produced in relation to the combustion heat of the cracked hydrocarbon decreases with decreasing hydrogen content in the molecule. This is exemplified in Table 3 for some typical oil hydrocarbons. As a result of its oxygen content, CO\(_2\)-free cracking of coal is not possible (by analogy, this is even more valid for biomass) as only part of the oxygen reacts with the hydrogen content of coal and the carbon is also partly oxidised. Depending on the reaction path and the composition of the coal, the energy content of the hydrogen formed would only amount to 5 to 9\% of the heating value of the coal applied. Therefore, for purely thermodynamic reasons the technical applicability of the carbon moratorium should be limited exclusively to methane.

### 4. Evaluation of the Carbon Moratorium

Figure 5 again clearly illustrates the availability of fossil energy sources in the context of the carbon moratorium. The carbon content of methane hydrate alone could cover the world’s current primary energy needs for more than 200 years. In addition, the non-conventional natural gas resources would provide hydrogen for over 50 years. This should leave sufficient time to create a new world energy system based on solar electricity and hydrogen.

For an initial economic evaluation, reference is made to the specific investment costs of various types of power plants, compiled according to reference [33], in Table 4. Other neutral studies arrive at analogous data.\(^{34}\) Natural gas power plants, which in principle do not differ from hydrogen power plants, represent by far the most cost-efficient type of power station. The difference in cost to a lignite power station with CCS is 1300 € per kW electricity. This cost advantage should suffice to finance the pertinent methane cracking plant and even part of the additional raw material costs. In contrast to CCS, methane cracking is a technically well-established process for the

### Table 3. Energy content of hydrogen after autothermal cracking of hydrocarbons.

<table>
<thead>
<tr>
<th>Hydrocarbon</th>
<th>(\Delta H_{\text{comb}}) [kJ mol(^{-1})]</th>
<th>(\Delta H_{\text{hydrogen}}) [kJ mol(^{-1})]</th>
<th>Degree of utilisation [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>methane</td>
<td>-803.5</td>
<td>-407.7</td>
<td>50.7</td>
</tr>
<tr>
<td>propane</td>
<td>2055.4</td>
<td>-868.1</td>
<td>42.2</td>
</tr>
<tr>
<td>cyclohexane</td>
<td>-3719.9</td>
<td>-1345.3</td>
<td>36.2</td>
</tr>
<tr>
<td>toluene</td>
<td>3791.7</td>
<td>-998.7</td>
<td>26.3</td>
</tr>
<tr>
<td>benzene</td>
<td>-3184.7</td>
<td>-749.0</td>
<td>23.5</td>
</tr>
</tbody>
</table>
production of carbon black which can be drawn on. Thermal methane cracking has already been intensively investigated on a laboratory and pilot-plant scale for the use of solar high-temperature heat. Depending on flow conditions in the reactor, the apparent activation energy is between 147 and 162 kJ mol$^{-1}$, while the frequency factor varies between 1.07 × 10$^{12}$ and 7.54 × 10$^{10}$ The autothermal cracking process proposed here will require different process control from that of the solar-thermal process which should be the subject of more detailed investigations.

As for the raw material costs, the expenditure for natural gas, methane hydrate and for the storage of the separated carbon should be considered in total. The costs of carbon disposal, for example, in a disused open-cast lignite mine, should not exceed those of lignite production. At the present time, the costs of methane hydrate production are not quantifiable as the appropriate technology still remains to be developed. At the Leibniz Institute for Marine Sciences (IFM), Germany, the SUGAR project is pursuing an interesting approach to replace the methane in the gas hydrate by CO$_2$ and thus to combine hydrate degradation with CO$_2$ sequestration. One positive economic spin-off is that the carbon moratorium should at least in part safeguard mining jobs.

With respect to the at least temporary waiving of the energy content of the carbon in methane, which is still retrievable, it should be noted that, also with CCS technology, the separation, transport and deposition of the CO$_2$ entail a considerable amount of energy (reduced efficiency by up to 14%) that is lost forever.

5. A Preliminary Economic Estimate

A preliminary economic analysis of the methane carbon moratorium (MCM) process is given, comparing the final electricity production costs of this process with those of conventional fossil power stations with and without CCS technology. The methodology used here for the economic analysis is in close agreement with those of other studies. A more detailed consideration of future electricity costs of fossil power stations also accounting for different scenarios of price development can be found in reference [41]. Assuming that the costs of the transportation and storage of 1 t carbon are not higher than the price of 1 t lignite, they can be easily calculated. Given a lignite price of 4.30 € per MWh$_{th}$ (thermal) and a heating value for lignite of 9630 kJ kg$^{-1}$ results in a lignite price of 11.50 €/t. In the MCM process, a thermal hydrogen energy of 407.7 kJ mol$^{-1}$ corresponds to 12 g carbon. Therefore, 1 t carbon yields 9.437 MWh$_{el}$ of hydrogen energy. With a gas power station efficiency of 0.58, a carbon production of 0.182 t per MWh$_{el}$ results. Multiplying this value with the lignite price of 11.50 €/t yields costs of 2.09 €/MWh$_{el}$ for the transport and storage of the produced carbon. This value is quite low compared with CCS costs of 10 to 25 €/t or the costs of CO$_2$ emission certificates of up to 40 €/t.

Table 5 contains the basic data which was used for the economic evaluation of the MCM process. The investment costs correspond to Table 4. Owing to the energy efficiency of about 0.5 of the MCM process, the gas price has been doubled. For power stations without CCS, CO$_2$ emission certificates with a price of 40 € per tonne of CO$_2$ are assumed.

The results of the economic analysis are compiled in Table 6. For the capital costs, an annuity of 11% has been assumed. For the application of the CCS technology, the costs for the transportation and storage of the CO$_2$ has to be assumed as

Table 4. Specific investment costs of different types of power stations.

<table>
<thead>
<tr>
<th>Power station</th>
<th>Spec. invest. costs [€/kW$_{el}$]</th>
<th>Efficiency [€/MWh$_{el}$]</th>
<th>Fuel costs [€/MWh$_{el}$]</th>
<th>CO$<em>2$ emission [€/MWh$</em>{el}$]</th>
<th>Operating hours [h]</th>
<th>CO$_2$ certificate price [€/tCO$_2$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>ignite</td>
<td>1300</td>
<td>0.36</td>
<td>4.30</td>
<td>400</td>
<td>7500</td>
<td>40.00</td>
</tr>
<tr>
<td>hard coal</td>
<td>1100</td>
<td>0.40</td>
<td>7.20</td>
<td>335</td>
<td>5800</td>
<td>40.00</td>
</tr>
</tbody>
</table>
natural gas    | 600                             | 0.58                     | 15.00                    | 202                         | 5000             | 40.00                       |
|lignite with CCS | 1700                         | 0.22                     | 4.30                     | 400                         | 7500             | 0.00                        |
hard coal with CCS | 900                            | 0.44                     | 15.00                    | 202                         | 5000             | 0.00                        |
|natural gas with CCS | 1400                        | 0.58                     | 30.00                    | 0                            | 6000             | 0.00                        |

Table 5. Basic data for the economic analysis of various fossil power stations, including the methane carbon moratorium (MCM) process.

<table>
<thead>
<tr>
<th>Power station</th>
<th>Spec. invest. costs [€/kW$_{el}$]</th>
<th>Efficiency [€/MWh$_{el}$]</th>
<th>Fuel costs [€/MWh$_{el}$]</th>
<th>CO$<em>2$ emission [€/MWh$</em>{el}$]</th>
<th>Operating hours [h]</th>
<th>CO$_2$ certificate price [€/tCO$_2$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>lignite</td>
<td>19.1</td>
<td>11.9</td>
<td>31.0</td>
<td>1.1</td>
<td>– 44.4</td>
<td>75.5</td>
</tr>
<tr>
<td>hard coal</td>
<td>20.9</td>
<td>18.0</td>
<td>38.9</td>
<td>0.8</td>
<td>– 33.5</td>
<td>72.4</td>
</tr>
</tbody>
</table>
natural gas    | 13.2                            | 25.9                     | 39.1                     | 0.3                         | – 13.9           | 53.0                        |
lignite with CCS | 27.9                            | 19.5                     | 47.4                     | 1.8                         | 45.5             | 92.9                        |
hard coal with CCS | 32.2                           | 27.7                     | 59.9                     | 1.3                         | 32.2             | 92.1                        |
natural gas with CCS | 19.8                           | 34.1                     | 53.9                     | 0.5                         | 11.5             | 65.4                        |
|MCM            | 25.7                            | 51.7                     | 77.4                     | 0.0                         | 2.1              | 2.1                         |
25 €/t. To calculate the amount of CO₂ emissions, the following fuel-specific data were used: lignite 400 g/kWh th, hard coal 335 g/kWh th, natural gas 202 g/kWh th, and methane 197 g/kWh th. The column with the primary costs represents the electricity costs without considering any CO₂ removal from conventional power stations or CO₂ emission penalties. In this context, the MCM route is the most expensive, which is not surprising because it is the only one without any CO₂ emissions. The last column of Table 6 contains the total electricity costs resulting from the different power stations and process options. It shows that the MCM process is cheaper than the corresponding coal option with CCS. The costs for MCM are even comparable to those of coal power stations without CCS, but this is, of course, due to the assumed costs for CO₂ emission certificates.

Because natural gas power stations are the cheapest, the MCM costs are 22% higher than those of a gas power station with CCS. Bearing in mind that the MCM process uses only about the half of the energy content of methane, this is quite a promising result. Of course, this economic evaluation is only suitable for showing a principle tendency because many of the basic data used, such as fuel prices, CO₂ emission certificates and the costs of transportation and storage of CO₂, depend on the unpredictable economic and technical future development.

6. Conclusions

The advantages of the carbon moratorium are summarised briefly as follows:

1. Half of the energy content of methane is used CO₂-free. The energy share of carbon is not lost forever; it can be stored retrievably without difficulty.
2. All the processes required to implement the concept are known in principle and have been tested. They certainly need to be adapted and the costs optimised.
3. The MCM concept offers a means of establishing a CO₂-free hydrogen technology on an industrial scale. Its initial application exclusively in power plants basically demands no new infrastructure.
4. The additional decentralised use of hydrogen in other areas can be built up and extended stepwise, thus already creating good conditions today for a gradual transition to a large-scale hydrogen technology in the future.
5. With the exception of the methane cracking plants, in principle all investments in this concept can also be applied to a future solar economy. Thus, in the transitional period the investments required for plants and infrastructure that have no future are already reduced to a minimum.

The extent of the contribution that a methane-based carbon moratorium can make to climate protection will depend on how quickly and to what degree the change in the resource situation described is oriented towards an even greater availability of methane. One technically and economically mature means of achieving a carbon moratorium is, of course, nuclear energy whose increasing use is doomed to failure in several countries by the lack of social acceptance and political creativity. As, despite potential CO₂ sequestration, coal-fired power plants are also increasingly encountering social and political opposition, the methane-carbon moratorium may be able to make an important, socially acceptable contribution towards closing the fossil gap, which remains despite the use of nuclear energy and regenerative energy sources. The above-mentioned sacrifice of 18% of the hydrogen energy for autothermal methane cracking would not apply if it were possible to use the process heat of the high-temperature nuclear reactor or solar high-temperature heat from hелиostat power plants. Then, despite the renunciation of carbon combustion, the energy efficiency of methane would increase from 50.7 to 62.2%.

Keywords: carbon · environmental chemistry · methane · sustainable energy · thermodynamics

[23] Data source: Leibniz-Institut für Meereswissenschaften (IFM-GEOMAR), Bundesanstalt für Geowissenschaften und Rohstoffe (BGR).

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