Overcoming the international energy and climate crisis –

Methanol economy and soil improvement can close the carbon cycle[1]

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[1] Published in: Gabriel, S., Radermacher, F. J., Rüttgers, J.: Europa fit machen für die Zukunft, Senate of the Economy - Publisher, 2019

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Content

Abstract

The global energy and climate crisis can be solved in a way that is compatible with growth and promoting prosperity. The now almost panic-stricken public debates about the end of the world, a planned economy for the climate, the electrification of the entire mobility sector, etc. are not in any way doing justice to the multi-dimensionality of the challenge. The approach described, on the other hand, allows Africa, India and other emerging economies to follow China's development model - without massive negative impacts on the climate. Following this approach, the SDGs can be implemented by 2050. Three essential elements have to be combined: (1) Methanol economy, (2) soils as carbon stores and (3) carbon offsetting projects promoting SDG implementation.

The part of the economy based on fossil fuels can be increased by 50% by 2050 with the proposed approach. By recycling carbon on average four times in the context of a hydrogen/methanol economy, CO_2 emissions of the energy sector will be reduced to only about 10 billion tonnes per year (currently 34 billion tonnes per year) - despite significant economic growth. A corresponding investment and conversion program can be realized solely by the fossil energy sector, one of the most powerful economic sectors in the world, by 2050. The necessary investments in methanol and other synthetic fuels amount to around 600 billion EUR per year.

Through persistent protection of the rainforests, massive worldwide reforestation, especially on degraded soils in the tropics, through fostering humus formation for agriculture, especially in semi-arid areas, through the use of biochar, etc., forests and soils can become a carbon sink for the remaining 10 billion tons of CO_2 per year. At the same time, this increases agricultural productivity and will prove necessary anyway for the massively increasing demand for food in an envisioned world in prosperity with 10 billion people. All in all, the carbon cycle can be closed this way. Forestry and agricultural projects play a central role in the *Alliance for Development and Climate* launched by the German Federal Ministry for Economic Cooperation and Development (BMZ) in 2018.

In addition to international climate protection, the alliance also promotes development and thus the social aspect of the path into future. By means of high-quality projects in non-industrialized countries, co-benefits to all SDGs and positive effects on the climate are achieved at the same time. This offers great opportunities for the goal of reaching a world population peak at 10 billion people in 2050, followed by a gradual decline afterwards.

The methanol economy, and synthetic fuels in general are the key to the solution described. They are based on cheap desert electricity from the Earth's sunbelt. Just as the invention of the steam engine 300 years ago was the foundation for fully unfolding the potential of coal to increase the prosperity of humankind, renewable energy technologies combined with the solar potential of large deserts (Desertec 2.0) are the key to getting humankind out of the current impasse regarding development, energy and climate - with a hydrogen/methanol economy as a major basis.

1. A world in prosperity is possible

This paper deals with the future in the fields of energy and climate - a topic that is increasingly dominating the social discourse. In particular the protests of students and young people are shaking up society. The topic is difficult. What should we do? What knowledge is scientifically validated? The contribution by Reinhard Hüttl, Oliver Bens and Bern Uwe Schneider of the German Research Centre for Geosciences GFZ, Potsdam [7], shows how incomplete our understanding of the Earth's climate system still is, how complex things are and that we are repeatedly confronted with surprises.

The following considerations are based on the author's decades-long preoccupation with these topics [15, 16, 17]. They paint a positive picture of the future. This is much to the delight of the author, who **for decades has been searching for a solution of the present type**: A solution that at the same time enables prosperity for 10 billion people and the protection of the environment and the climate system. The open market system and technology are able to deliver. The challenges we face are not being overcome by despair resulting in the renunciation of valuable achievements of our history, but by the performance potential of a technical civilization. Billions of people in Africa, on the Indian subcontinent and in other developing and emerging countries, where population size will double in the coming decades and extreme poverty needs to be overcome, **can replicate China's development model** without simultaneously causing an ecological catastrophe. They can go for megacities, skyscrapers made of concrete and steel, car fleets and airplanes.

2. What to do?

It is initially surprising that all of this could be possible – as well as the implementation of the United Nations' Sustainable Development Goals (SDGs) by 2050 (not 2030) [3, 17]. The fact is that wealth creation in developing and emerging countries is the actual driver of rising CO_2 emissions. As Fig. 1 shows, crucial CO_2 emission increases loom in Africa (and to a considerable extent also on the Indian subcontinent) which will determine the future and lead us into climate catastrophe if no new technical solutions can be developed. The emissions of these countries, with their rapidly growing populations, will then even exceed those of China. And Chinese emissions today are already exceeding those of the United States, Europe and Japan combined. Under these circumstances, how can a climate-friendly path into the future be realized that reconciles prosperity expectations and environmental and climate protection worldwide? The prospect of prosperity for everyone is urgently needed as otherwise social upheavals, even to the point of civil war or even war in general, are likely. And only with prosperity for everyone can we stabilize the size of the world's population. Without an increase in prosperity, many of the objectives for acceptable solutions for the future formulated in Fig. 2 are obviously out of reach. This is different for the reference solution for the future in the areas of energy and climate proposed in this text. **It fulfils all the criteria listed in Fig. 2.**

3. Carl von Carlowitz and the great transformation

A **great transformation** is necessary for the path shown here. Many people talk about it but mean something different than what is meant here. Regularly a "new" human, another ethics, a modest lifestyle are called for. The author does not consider this to be very promising. End of the World scenarios, panic or the propagation of a new view on life and satisfaction will most probably not help.

But what is going to help? Let us draw an analogy: The situation today is reminiscent of the conditions 300 years ago. At that time, **timber** played a key role similar to that of fossil fuels today: energetically, materially and for exercising power (at that time especially warships). The forests back then were in existential danger. In Germany, Carl von Carlowitz addressed the urgently necessary needed requirements - the sustainable management of forests. Similar positions were taken in other countries. The message said the following: Never cut more wood than what was able to regrow. But it was not this discourse that saved the forests although it was very important. Because existential interests in prosperity and power of strong actors and groups cannot be contained by ethical-moral discussions. It can be contained at most by destructive wars, a solution which nobody wants. This is why despite all the debates, the volume of fossil fuels used is still growing worldwide today and will grow in the future as the International Energy Agency shows year after year (Fig. 3). For the same reason, timber consumption was increasing steadily 300 years ago.

However, the great transformation did take place in the end, albeit in a completely different way - with the **invention of the steam engine** [15]. The steam engine was finally capable of fully exploiting the potential of coal, which had been mined and used in small quantities for a long time already before. But with the steam engine, huge quantities of coal could be put to use, which meant, for the first time, a gigantic surplus of energy. Deep vertical tunnels, water pumps, coal and steel as well as railways were the consequences. In Germany, this entailed the development of the Ruhr area with its industrial and military power. After three industrial revolutions, the number of people on earth has increased tenfold in 300 years and (material) prosperity has increased a hundredfold. Now, however, this new technical system in the energy sector is reaching its limits, too, especially because of the climate problem resulting from CO_2 emissions associated with fossil fuels.

4. Is decarbonisation the solution?

No. **The decarbonisation that many are longing for will not take place in the short and medium term**, and in case it does, it will take place in a different way than how the topic is usually discussed (cf. Figs. 4 and 5). This is actually good news. The consequences of decarbonisation as handled in public debates would be an extreme world economic crisis and very likely war and civil war. However, there will be no decarbonisation in the predictable future. The policies of the major powers, especially the USA, are diametrically opposed to such a path. This is described in detail in another publication by the author [16] (see also an interview with Fatih Birol, Director of the International Energy Agency IEA, http://www.taz.de/!5590256/; see also Fig. 3 in this text). In this context, according to a report in the New York Times (April 10, 2019), US President Trump recently signed two new executive orders to make it considerably easier for companies to build pipelines in the USA in the future. His policies seek to rapidly increase the US oil and gas production - **the opposite of decarbonisation**. And all of this despite the fact that the USA are already the world's largest oil producer, having overtaken Saudi Arabia and Russia and increasing their production even further.

The world community wants prosperity for 10 billion people. By 2050, in the best case, the size of the world's population could finally stabilize and/or peak. In contrast to the great transformation 300 years ago, which led to a tenfold increase in the world's population and thus catalysed ever new growth dynamics, this time humankind could finally achieve a steady world population at a comparatively high global level of social equality and prosperity. In order to achieve this, global prosperity has to double in 30 years. According to the logic of the present text, the SDGs should and can be implemented by then, but only under strong political leadership [10].

What does this mean for the energy sector? Even with further efficiency gains, as shown in Box 2, it is necessary to double the amount of useful energy compared to today's level. The carbon-based part, which today results in about 34 billion tons of CO_2 emissions and contributes to about 81% of 100% of the total energy (primary energy), will increase by about 50% to a level equivalent to around 50 billion tons of CO_2 emissions. Newer forms of renewable energies, which yet account for significantly less than 5% of the world's primary energy, will then, together with other energies, contribute to 40-45% of useful energy (on a total scale of 200%). In addition, there is a renewable share (essentially solar energy) of 140 % of 340 %, which will "fuel" or enable the recycling of carbon described in Box 1 (see Fig. 7 for an overview). Examining these figures, this is an inefficient process but it is highly effective and obviously superior to the available alternatives. There is a huge energy surplus – **an equivalent to the steam engine in the great transformation 300 years ago**. New renewable energies will be dominating strongly in 2050 and combined with other energies, they will contribute to about 2/3 of the total primary energy (cf. Fig. 7).

5. The Reference Scenario: Methanol Economy

How can we proceed if the goal described is to be achieved? This text is developing a **reference scenario for the world** (see Box 2), the key data of which are described below. It is located centrally in the carbon-to-liquid context and incorporates many discussions among experts, which, however, are debated far too seldom in the political arena. Many studies now address the fact that a climate-friendly solution to global energy supplies must make massive use of synthetic fuels if prosperity is the goal. A study of the World Energy Council Germany of October 2018 [19], as well as the E-Fuels study "The potential of electricity-based fuels for low-emission transport in the EU" [18] by Ludwig Bölkow Systems Engineering and dena (German Energy Agency) should be mentioned in this regard. A joint declaration of the associations BDBe, DVFG, MEW, MVaK, MWV, UFOP, UNITI and VDB, constituting the Alliance for Green Fuels, [1] points to the same direction. They believe the climate targets for transport and mobility can only be reached with low-carbon fuels.

In the public debate today, unfortunately, discourse elites in politics and media are dominant which mostly ignore the global dimension of the challenges and possess little technical knowledge. Instead, they are payed for constantly talking and consequently flood the communication channels with their thoughts around the clock. They particularly like to describe apocalyptic scenarios and refer to students demonstrating on the streets. Politicians who do not agree with their "canon" are often denied the ability to learn and understand, in an expression of great arrogance and know-it-all manner. Yet the program to save the world proposed by these discourse elites with full conviction is of great simplicity and would wreak havoc: "Put an end to coal, off into a world of electric cars and smart grids, switching to bicycles, speed limits, going on holiday at home, no more eating meat, no more flying." Coal is demonized per se. The climate problem is used to force one's own "superior lifestyle" onto other people. This program stands in **stark contrast to what is proposed in this text**. It is also a program of **massive cruelty to developing countries**. Large-scale financial transfers are not envisaged, compensation for the desired cost savings associated with a ban on fossil fuel imports is not planned, international tourism shall cease to exist, and so shall Fair Trade. Although we in Germany are world export champions, we need all the money for ourselves, for our own energy revolution, to show the world how it works. A program doomed to failure.

The reference scenario described in the following is a solution of a completely different kind, which seems reasonable to the author. It aims at energy prosperity, not at managing scarcity. The developing and emerging countries should become winners in globalization and **be able to replicate China's model**. There are also variations or characteristics of a technical nature possible other than those discussed in the reference scenario. For example, **fuel cells in electric cars can also be powered by methanol**. The use of fuel cells saves on the large and heavy batteries of electric cars which are problematic in many respects. This means that the batteries still needed are significantly smaller and – accordingly – lighter. Methanol for the operation of fuel cells is an interesting option and has several advantages to the use of hydrogen which is usually suggested in this context. Electric cars thus become part of the reference scenario, which can be modified in many ways. In this sense, the reference scenario is an option with many facets. It would work. This is how it could be done. But perhaps there is an even better solution. But then, thanks to the reference scenario, we are on the safe side.

In the reference scenario, the crucial point is to **reduce the carbon intensity of the carbon-based energy system component to 20%**. Carbon extracted from the earth - especially coal - is recycled four times on average (cf. Fig. 4 before / Fig. 5 afterwards) before it finally escapes into the atmosphere via individual mobility (combustion engines) and individual heat/ cooling processes (heaters/ radiant heaters and cooling appliances). The remaining 20 % carbon (about 10 billion tons of CO_2 per year) is removed from the atmosphere via biological processes (reforestation, humus formation, pasture farming, application of charcoal and vegetable carbon into soils). The overall system then can become **climate-neutral (in numbers)** (cf. Fig. 5). **The energy and climate problem would then be solved. The decisive steps to implementation could be taken by 2050.** Box 2 gives some information on the investment and implementation programs required for this. Fig. 7 shows the energy situation that then emerges in comparison to the current situation shown in Fig. 6.

Obviously, the economic and technological potential of the possible path into the future is very attractive. Europe has the opportunity to take the lead in such a development. Recycling of carbon via the methanol economy and the use of soils as carbon stores: this is an opportunities program for the world, but also for Europe and Africa, especially in close partnership. The Senate of the Economy has included such development paths in a recommendation for the European elections [6]. Germany should make this a priority of its 2020 EU Presidency activities [6].

6. Why is a 4-fold recycling of carbon carried out?

The recycling of carbon is primarily a method to store solar energy (inexpensively) and to convert it into an easily manageable, multiply usable form. If (1) methanol could always be used in all energetic processes and (2) the CO_2 released by the combustion process could always be captured in a convenient and cheap way, the underlying recycling approach would render us climate-neutral. However, this is not the situation. Many heavy industry processes require fossil fuels as input (but 20% of the current volume would be sufficient here) while CO_2 cannot be captured well from all processes. This concerns, in particular, individual mobility and individual heat/cooling production. For the important processes mentioned in (2), which are dominating the debates today, 20% should also be sufficient. This results in a recycling factor of 4.

It is assumed here that a large part of the heat/cooling production will be covered by electricity in the medium term, e.g. electricity products based on methanol. From a climate perspective, this is a good and affordable solution. Concerning mobility, the author assumes that **electric mobility will play a role, albeit not a dominant one**. In large cities, the approach does have advantages. Energetically, the combination of methanol with **fuel cells** is interesting here. From the author's point of view, it would be a catastrophe - both economically and in terms of prosperity - to fully rely on electric mobility based on large and heavy batteries. It would also end up in a disaster if we would aim for an **all-electric** solution in general.

All of that would be an obliteration of money, just like the wholesale energy-related renovation of all real estate. However, with the right combination of suitable electricity-based and methanol-based engines and heat/cooling solutions, the prospects for the future are good.

It is clear that in addition to the methanol solution in the sense of Desertec, further consideration should also be given to transporting electricity from Africa to Europe. Similar transports will be of great importance inside Africa in any case. Conversion costs into methanol will be less common there than in Europe (and the Global North in general). **In the reference scenario Energy and fuel supply in Africa is therefore much cheaper than in Europe.** This enhances the opportunities for further economic development on this continent. Of course, there is also interesting potential in Europe, especially in Germany, in the field of synthetic fuels/ methanol economics. The Swedish Stena Line ferry "Germanica", for example, has been running on methanol since January 2015 - in an environmentally friendly and profitable way. Methanol products out of metallurgical waste gases are the aim of an ongoing pilot project of the "Carbon2Chem" initiative of Thyssenkrupp AG and the German Federal Ministry of Education and Research (BMBF).

7. The biological side

The methanol economy needs a second side – just like a balance sheet has 2 sides. In the scenario described above, about 10 billion tons of CO_2 have to be removed from the atmosphere every year in the long run in order to achieve a climate-neutral world. Key to this are negative emissions, above all from reforestation and humus formation [4, 5, 14, 16]. The strict protection of rainforests has to go hand in hand with this approach. For more information on this topic, please refer to the *4 PER 1000 Initiative - Soils for food security and climate* (www.4p1000.org) and the *European Biochar Certificate* (www.european-biochar.org), among others.

What can be said about this approach also from an economic point of view? Here it is important to recognize that corresponding investments in soil and reforestation are necessary anyway if a growing, more prosperous world population is to be supplied with food at a significantly higher volume and quality than today, while the process of "civilisation" will simultaneously result in massive land use change of good agricultural land for buildings and infrastructure. Therefore, the quality and productivity of the remaining global agricultural land has to be significantly improved. Furthermore, new soils need to be activated, e.g. in semi-arid areas (like on the edge of the Sahara) where there is hardly any competition for land use. Plants will then hardly be used for generating bioenergy in the future any more. Farm animals will again graze on pasture land on a much larger scale than today.

The closing of the carbon cycle has to be cross-financed, especially in order to accelerate the conversion process greatly. Binding carbon in soil (or alternative forms of CO_2 sequestration) can be documented by certificates. All actors participating in the carbon and methanol cycle will – reasonably – have to co-finance the closing of the carbon cycle. This can generate substantial additional financial resources for the agricultural sector (potentially several hundreds of EUR per hectare) and will be (co-)financed by users of fossil energy sources and methanol (in the reference scenario). As of today, 20-30 EUR per ton of CO_2 are sufficient on the side of the aforementioned actors. Some of these funds are already being exhausted today and are a low price to pay when it comes to preserving today's civilisation and basically continuing, even considerably expanding its business model. The funds can be tapped centrally. About 1-1.5 trillion EUR per year are at stake. Part of these can be invested in soil improvement, reforestation programs and strict protection of rainforests. Reforestation can quickly generate a lot of negative emissions. This saves time and helps to reduce the risk of reaching **tipping points**. Tipping points are obviously the greatest risk humankind is currently confronted with in the context of climate change because once such a point is exceeded, climate change becomes irreversible. As long as this has not happened, we can still come up with some ideas. That is why saving time is so important after we have already wasted a lot of time - or spent it on hardly smart activities.

8. The anchor substance methanol

The core of the reference scenario solution is recycling of carbon via the **anchor substance methanol**. Methanol (see Box 1 on methanol economics and Box 3 on the costs) is a key substance in the opinion of the author and many other observers - an ideal storage medium for solar energy, hydrogen, oxygen and

CO_2. There are many ways to produce methanol, as depicted in Fig. 8. In the context of the reference scenario (also in view of addressing the climate problems), the initial process is the electrolysis of water and thus in particular the production of **large quantities of hydrogen**, which is then further combined with CO_2 to form methanol. Hydrogen is produced preferably (but not exclusively) and inexpensively with solar energy from the sunny desert regions of the world, at best near the sea. The latter also matters in so far as water is needed for cooling purposes in energetic conversion processes. Such desert areas can be found in many parts of the world, mostly in poorer countries, e.g. the Sahara, the Arabian Desert, the desert in Namibia, the desert areas in southern Iran or the Atacama Desert in Chile. Desert areas in the south of the USA, China, India and Europe can also be considered.

The hydrogen produced with desert electricity is combined with CO_2 to form methanol. CO_2 can be captured inexpensively in large-scale industrial applications and transported across large distances after liquefaction. Methanol is as easy to transport as petrol and much safer as a substance. In water, for example, it decomposes naturally. In addition, it is a much cleaner alternative to petrol and diesel for combustion purposes. Essentially the same transport and infrastructure can be used for methanol that is used today for oil, petrol and gas.

Power plants can be run on methanol and CO_2 can be captured for around 30 EUR per ton. In the reference scenario, the production costs of a double ton of methanol (energetically equivalent to one ton of oil/ petrol) are 500 or 700 EUR (depending on the price of electricity). This translates to about 40 or 56 EUR cents per double litre. The costs are competitive with today's petrol, even if it is taken into account that one ton of petrol comprises about 1330 litres and one ton of methanol about 1270 litres. Subsidies are not required - but regulation regarding permissible admixtures is needed.[3] Note that the current market price in China (and also in India) is lower (less than 30 EUR cents per double litre). However, their manufacturing process is harmful to the climate.

The methanol production costs in Germany today are 2-3 times higher than in deserts in the Earth's sun belt (far more than 1.50 EUR cents) due to the unsuitable solar situation and the significantly higher regulation costs for electricity in the German system. These higher costs are related to much higher costs for space and significantly higher costs for securing the stability of the entire grid under conditions of volatile electricity inputs. The situation is much simpler for methanol production in Africa. It can react flexibly to the availability of electricity, volatility problems are significantly lower. In addition to the production costs mentioned above, taxes, just like today, make up the largest part of the final price.

[3] The clear recognition of methanol admixtures as climate-neutral components of **fleet CO_2 emission calculations** in the automotive industry would be important (if the methanol admixed was produced from CO_2 recycled form large-scale industrial processes). Admixing methanol to petrol is possible up to 15% with only minor problems. This would reduce CO_2 emissions by 8%. The current pressure on the automotive industry can be considerably reduced by such an approach. This would greatly facilitate a methanol economy. In the EU, the regulatory situation is rather dismissive, barely transparent and in flux. In recognition discussions, a distinction is also made between biogenic CO_2 and CO_2 from other sources. There is no convincing justification for this. Extraneous interests or a specific framing seem to play a major role. There is an urgent need for action here.
If the problems with admixing methanol to petrol are regarded as too difficult, methanol to gasoline (MtG) is an alternative. 2 tons of methanol allow for 1 ton of MtG. This is, however, about 50 EUR cents per litre more expensive than a double litre of methanol.

9. Europe and Africa can go ahead on their own

The reference scenario described here (and many variants of it) can be tackled immediately by Europe in partnership with Africa for the benefit of both sides. This is a big advantage. There is no need for global consensus as in climate agreements. **The approach is rooted in the paradigm of a Marshall Plan with Africa** [3, 9, 17]. Africa has a lot to offer to Europe. Not only the solar potential of large deserts but also the lands for massive reforestation and soil improvement, such as semi-arid areas on the edges of deserts. In the process described, Africa can realise the **megacities** it needs. The same applies to heavy industry, chemicals, electricity, fuel production, etc. All this can be built and/or used and paid for.

Sea and groundwater desalination can solve the continent's water problems at acceptable prices and in a climate-neutral way. Hundreds of millions of jobs will be created, particularly in agriculture, forestry, and associated refining processes as well as in the methanol economy. The "risk list" in Fig. 2 can thus be worked through step by step. In conjunction with the biological side, the methanol economy in the reference scenario is then able to "deliver".

10. What are the key elements for the reference scenario?

It is important to realize that the proposal made is only possible thanks to progress made in renewable energies. In addition, there has to be a massive use of energy sources in the sun belt of the great deserts. This is the **Desertec idea** which the Club of Rome (German Section) has been championing for a long time. While the direct transport of electrical energy from Africa to Europe, for example, can remain an issue, the resistance of all kinds against it is considerable. With methanol (Desertec 2.0), this kind of thwarting by certain interest groups is no longer possible. The very same infrastructure already in place today for oil and gas can be used. The vast industrial complex built on fossil fuels can remain active and even expand (by 50 % until 2050). From the author's point of view, Saudi Arabia could become the largest investor. But all major corporations of this economic sector will take part.

On the positive side, Europe and Africa can also go ahead on their own, as already mentioned. The technological potential opens up massive options for those involved, especially for Europe [6]. Needless to say, all SDGs are promoted positively in the reference scenario. This is obviously the case with every goal, except for SDG 14 "Life below water". However, since the soil activities planned will reduce the pollution of the seas with contaminants, progress can be expected even here.

Lastly, the **social dimension** of the topic remains. The **Development and Climate Alliance**, launched by the German Federal Ministry for Economic Cooperation and Development (BMZ) at the end of 2018, opens up many interesting links and opportunities [17]. Its focus is on co-benefits in SDG implementation, i.e. social goals (e.g. promoting women's rights, education for everyone, slowing population growth, greater prosperity) but also ecological goals (biodiversity, water budget). More prosperity by itself will not be enough to make progress in these areas. Questions of wealth distribution are always difficult. The Alliance can make a big difference here and hopefully help to ensure that the world's population reaches its peak in 2050 at 10 billion people. The reference Scenario will foster economic development in developing and emerging countries (example China). Inequality between countries will decrease. In terms of inequality within countries, this is not clear. T**herefore, this new Alliance has a major role to play and should be raised to the European level by 2020 at the latest on the occasion of the German EU Presidency.**

Box 1. Methanol economy

Methanol is a particularly interesting substance, cf. Fig. 8. Methanol is a kind of synthetic gasoline but with practically no harmful side effects. Gasoline is considerably more toxic and dangerous than methanol. When handled correctly, there is no danger of explosion and combustion does essentially not result in soot, ash or particulate matter. The beneficial qualities of the simplest alcohol molecule, methanol, have long been recognized in the chemical industry. Today it is the second most produced and traded liquid in the world after crude oil. It can be produced from coal by gasification and then admixed to gasoline. This is commonplace in China, with q quota of usually at least 15%, often much more. China does this in order to save on foreign exchange reserves for oil imports. The climate does not benefit from this. Methanol can also be produced from methane. In some contexts this can be a good solution for the climate.

In the reference scenario, methanol is produced from electricity, CO_2 and water in a synthesis process which has already been technically mastered. Some German companies are among the world leaders. In contrast to bioethanol, this process does not compete with agricultural lands and can be run either in large, centralized facilities or in small, decentralized ones. Methanol is an ideal partner of renewable energy. Note: The energy density of methanol (as an energy storage) is 50 times higher than that of modern batteries (and half the energy density of gasoline). Therefore **energetic liquids** are obviously a better solution for storing energy than batteries and thus important for the preservation of our prosperity.

Since the processes of storing, refuelling and using methanol are very similar to those of the usual liquid fuels (diesel and gasoline), we can continue using the existing infrastructure. It should also be emphasized that using methanol as a fuel in vehicles with gasoline engines requires only limited retrofitting.

Methanol, after further processing, can replace all 14 liquid and fossil fuels in use today (regular and super-grade gasoline, diesel, heating oil, kerosene, etc.). Thereby a much simpler, more ecological and economically effective global energy supply is possible.

The methanol economy has a long history. In the current (German) discussion it falls within the scope of *e-fuels* and *Power-to-Liquid* activities. In a remarkable study [19], the World Energy Council (German section) has clarified that without progress in the area of e-fuels, a sustainable solution to global energy and climate issues is not possible.

Many aspects of the methanol economy are covered in a large publication about methanol from 2014 [2]. Two of the authors are important discussion partners providing impetus for the present text: **Prof. Dr. Dr. Heribert Offermanns, long-time Head of Research at Degussa and Dr. Ludolf Plass, long-time Head of Research at Lurgi**.

The methanol economy has its roots in Germany at RWTH Aachen University. In a historical overview [11], Heribert Offermanns points to the Institute of Technical Chemistry at RWTH Aachen University, the three institute directors Walter M. Fuchs, Friedrich Assinger and Wilhelm Keim (Wilhelm Keim's motto is "CO_2 as a raw material") and a very successful, wide-ranging research program.

Simultaneously, the US Nobel Prize winner George A. Olah is addressing the topic in his book "Beyond Oil and Gas: The Methanol Economy" [13]. Unfortunately, he does not appreciate the many years of work in Germany, but this is (unfortunately) not uncommon in the sciences. Much more important from the point of view of the present text is the fact that G.A. Olah heads a second, broad international anchoring of the methanol economics topic. An important concern of G.A. Olah's is the argument that a future climate-neutral energy base will not directly build on the use of hydrogen but on a two-step process: first the production of hydrogen using inexpensive solar energy, then the conversion of this hydrogen into methanol by combining CO_2. From an economic point of view, this requires the **availability of extremely cheap solar energy** (more precisely: climate-neutral energy) to produce hydrogen and thus indirectly methanol, preferably by combining hydrogen and CO_2.

The considerations of Offermanns/Effenberger/Keim/Plass in [12] are also interesting in this context. They propose to establish heavy industry in North Africa on the basis of cheap coal (e.g. from Latin America) for Africa's development and to convert the CO_2 emitted there into methanol, using inexpensive solar energy from the Sahara. On the coast, pure oxygen and hydrogen would be produced by electrolysis, forming the basis for methanol synthesis in further processes. Such approaches are also being discussed today as *Desertec 2.0* in the wake of the Desertec debates, in which the Club of Rome (German section) has been and still is significantly involved. In this regard, it is especially worth recalling the contributions of the deceased Gerhard Knies.

It should be noted that the original Desertec proposals did not fail because of fundamental problems regarding feasibility or investors' reluctance. The problems have been completely different. On the one hand, the German Renewable Energy Sources Act (EEG) made it impossible to sell solar energy from North Africa to Germany, insofar as the high subsidies for solar energy and its preferential feed-in into the power grid were limited to solar energy produced in Germany. This way, one can cleverly bar competition and inhibit innovations in developing and emerging countries, which are – allegedly – all that important. On the other hand, blocking the construction of power lines is another form of resistance to "electricity competition". We can still observe this today in the construction (or actually non-construction) of urgently needed power lines in Germany.

That is why the Desertec approach, which is particularly important for promoting prosperity in Africa and substantially increasing energy supplies in North Africa, needs an alternative means of transport. This is possible in the context of Desertec 2.0 by means of the power-to-liquid approaches described above, in particular the methanol economy. This is one of the sources for the considerations in the present text.

Box 2. The reference scenario: 2020 - 2050

The reference scenario is based on today's world GDP of around 80 trillion USD with 7.5 billion people. Today, 81% of our energy needs are met by primary fossil energy sources. Currently, these are producing 34 billion tons of CO_2 per year. Significantly less than 5% of the total primary energy is coming from newer renewable energy sources [8].

In the scenario, world GDP will have increased to around 140 trillion USD by 2050, i.e. almost doubled. The highest economic growth rates can be found in the developing and emerging economies. This is necessary to implement the SDGs by 2050. The Chinese path is being replicated.

Contrary to the usual studies on our energy future today (demanding sustainability), the carbon-based parts of the energy used, above all energy liquids, continue to play a central role. This part increases by about 50%, which would correspond to about 50 billion tons of CO_2 per year with today's technology. However, by recycling CO_2 four times, the actual emissions are only around 10 billion tons of CO_2 per year. In other words, the CO_2 intensity of the carbon-based energy share plummets to 20%. 80% are of the secondary type and climate-neutral in this sense (cf. Fig. 7).

The fact that the approach described does not drive the fossil fuel sectors into collapse is positive, indeed decisive (cf. Fig. 2). Decarbonisation at the expense of these large industries is not taking place; on the contrary, there is a growth potential of 50%. In this context, however, the sector needs to be considerably restructured. This is feasible by 2050. A good and peaceful future is fostered as a result. A lot of money is at stake here. The world's largest corporation in this sector alone, Saudi Aramco, made a profit of 110 billion USD last year (2018) - about 11 times Germany's total official development assistance. Massive losses in these industries would lead to the collapse of the world economy. This does not happen in the scenario. The sector is growing and can therefore finance the conversion required to recycle carbon. Saudi Arabia will probably be leading the way because of its great investment power but all other large energy corporations in the world will also be involved in this business. A lot of money is at stake. It can be earned in many parts of the world. And the market is expanding considerably.

Global primary energy consumption today is estimated at around 100 billion barrels of oil equivalent. The price per barrel is fluctuating heavily. It currently stands at around 70 USD. This means a value of about 7 trillion USD per year for today's entire global primary energy consumption, this central segment of the economy, i.e. about one twelfth of the current global GDP of 80 trillion USD.

Given the significantly higher global GDP in 2050, the world will probably need twice as much energy as it does today, especially due to the comparatively low energy efficiency in the economies catching up. The energy supply proportions will shift in favour of newer renewables, especially wind and sun (see Fig. 7). This transformation will take place primarily in the desert-sun belt of the world. But many other countries are also going to participate. Carbon-based forms of energy will probably still outdo renewables in terms of useful energy in 2050, but will do so only to a small extent (about 60:40). Yet on top of that, a large volume of renewable energy from the desert-sun belt will be used for carbon recycling and methanol production. This volume is estimated at 140% (at a total volume of 340%). In the reference scenario, these 140% are used to produce hydrogen and methanol. This is an energy-intensive process that tends to be inefficient. But it is worth it. It solves the volatility problem of renewables and creates stored energy in form of methanol or other synthetic fuels, which are easy to warehouse and transport and usable in multiple ways. It is the key to a prosperous world and to overcoming the energy and climate problems. By analogy, the activation of this potential corresponds to the role played 300 years ago by the invention of the steam engine, replacing wood with coal in the great transformation of that time.

If we look at the 340% energy production in 2050, the new renewables will have exceeded the carbon-based fuels in volume. Together with other energy sources, they will provide 2/3 of the primary energy supply. Fig. 7 gives a general overview.

What is the magnitude of the world energy system conversion in 2050 according to the reference scenario? In 2050, the world's current primary energy level of about 14 billion tons of oil equivalent should be in the form of methanol or other synthetic fuels. The path towards that has to be shaped. We are talking about 28 billion tons of methanol (14 billion double tons) in 2050.

Today's largest methanol production facilities can synthesize (only) a little more than 10,000 tons per day. An annual output of 4 million tonnes is possible. The costs per facility of such size are around 3 billion EUR. Over the next 35 years, a total of around 7,000 facilities of such size will be required in the reference scenario, which translates to around 200 new plants every year. The total annual costs will thus amount to 600 billion EUR. These are orders of scale that the energy sector is already investing annually today, among other things for the exploration of new oil and gas fields. Such activities would be largely of no use in the future. The conversion is a great challenge, but achievable. This is particularly true when the high revenue potentials in the methanol production sector are taken into account.

The following exemplary considerations show that the conversion can be financed: In Germany, around 40 million tons of fuel are used in the transport sector every year. These emit around 120 million tons of CO_2, about 1/8 of Germany's total emissions. If it is hypothetically assumed that half of this would be replaced by 20 million double tons of methanol (equivalent in energy terms), about 60 million tons of CO_2 could be saved every year. The necessary amount of methanol would require about 10 large methanol power plants with a total investment volume of 30 billion EUR. However, these costs are not supplementary - they are rather replacing other investments and being earned in the market.

In comparison, the German "coal compromise" (*Kohlekompromiss*) means that a grown market structure is destroyed to achieve - due to the interaction with the EU certificate system – imprecisely quantifiable savings of some modest, two-digit million tons of CO_2 per year. What is more, compensation of 40 billion EUR needs to be paid to the affected federal states over the next 20 years. A further 60 billion EUR will come along on top over the same period to support other affected stakeholders (cf. https://www.insm-oekonomenblog.de/20687-klimaschutz-mit-marktwirtschaft-wie-die-politik-den-kohleausstieg-guenstiger-und-klimafreundlicher-gestalten-kann/). A huge waste of urgently needed financial resources.

Box 3. What are the methanol production costs in North Africa?

The methanol production costs are essentially determined by the electricity costs for electrolysis and thus the production of the hydrogen required. This is the dominant cost factor. In the reference scenario, these costs amount to around 200-400 EUR per double ton of methanol under the conditions of using cheap desert electricity. The calculation is based on a solar electricity price of 1 or 2 EUR cents per kilowatt hour. For such a favourable price it is crucial that the land costs almost nothing, the sun shines practically always (high capacity utilization in the facilities) and the provision/ regulation costs for electricity are low.

What is the situation of methanol in terms of costs? For a double ton of methanol, about 370kg of hydrogen (H_2) and 2.7 tons of CO_2 are used as input. The amount of electricity required to produce the hydrogen is about 19,000 kilowatt hours (kWh). At a price of 1 EUR cent per kWh, this is about 200 EUR, at a price of 2 cents per kWh, around 400 euros. In addition to the electricity costs, depreciation of around 100 EUR on local installations needs to be factored in for each double ton of methanol. About 30 EUR per ton need to be taken into account for capturing and purifying the CO_2, another 30 EUR for the transport of CO_2 (including liquefaction) from Europe to Africa, about 20 EUR for the transport of methanol from Africa to Europe per double ton. The transport costs for methanol are lower than those for CO_2 because methanol is a liquid.

Since a double ton of methanol requires around 2.7 tonnes of CO_2, each double ton of methanol requires an additional 2.7 x 60 EUR for CO_2 production and transport, i.e. around 160 EUR. In total, the estimated price of methanol is 500 or 700 EUR per double ton. Since one ton of methanol corresponds to about 1250 litres, the price is 40 or 56 EUR cents, respectively, per double litre of methanol. This tends to be lower than today's gasoline prices. Subsidies do not appear to be necessary in this respect. Note that the market prices for methanol in China and India are significantly lower today but their production is not climate-friendly. In Germany, due to the significantly higher costs of producing and distributing (regulatory costs) renewable electricity, and thus the much higher costs of producing hydrogen, methanol production in Germany comes at a total cost of at least 1.50 EUR per double litre of methanol (before taxes).

All in all, this results in a cycle. In the reference scenario, CO_2 can be captured in heavy industry in Europe, liquefied and transported to the coast of North Africa. There, the CO_2 is combined with hydrogen in order to form methanol, which is then transported back to Europe. Of course, the latter expenditure is omitted when using the electricity or methanol in Africa. These are good prerequisites for implementing a **Marshall Plan with Africa**.

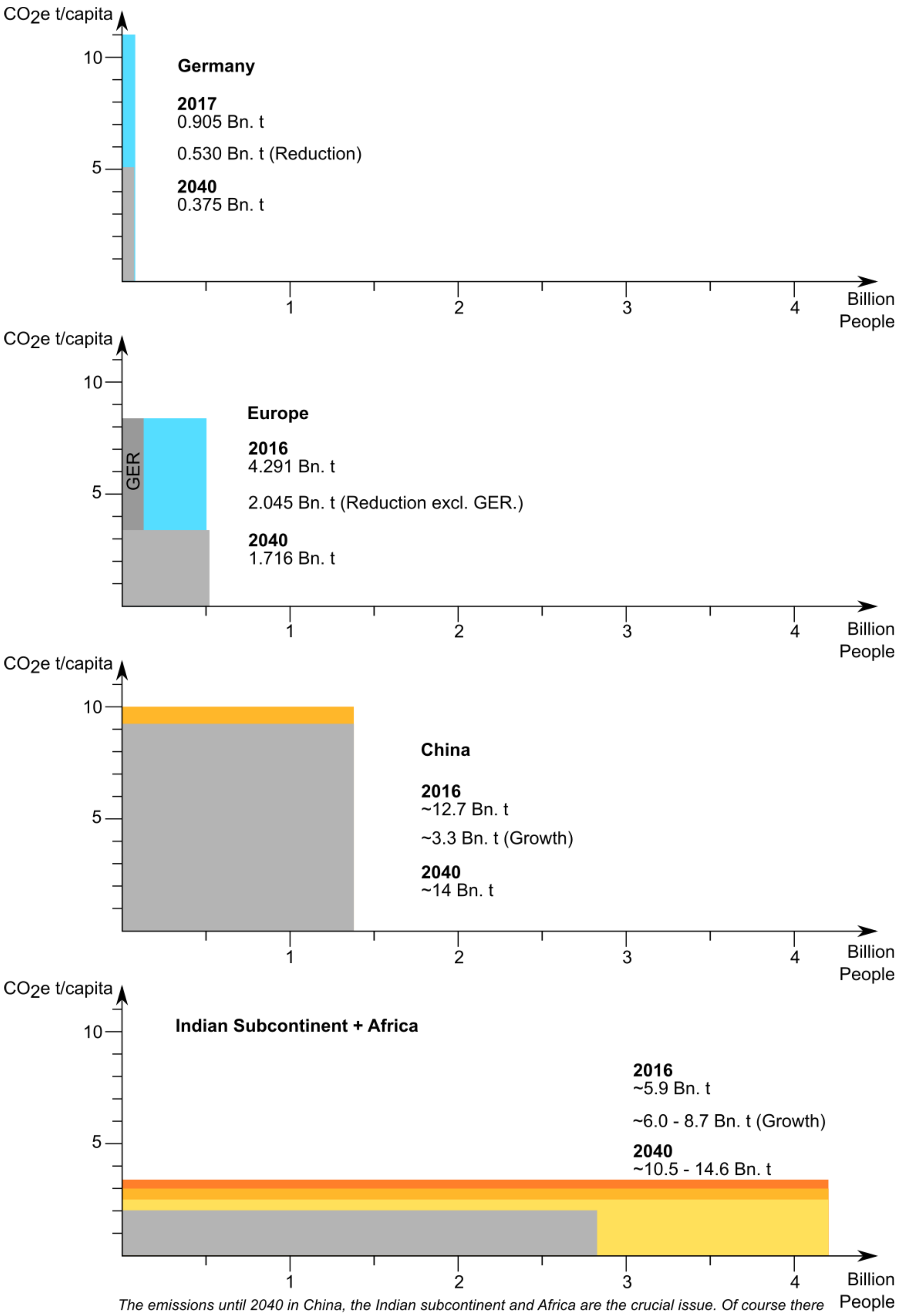
As mentioned above, the efficiency of methanol production is about 70%. In consequence, an electricity volume of 140% has to be produced to obtain 100% of a desired amount of energy. It can thus be expected that the renewable electricity required for CO_2 recycling purposes, and thus for the production of methanol, corresponds to about 140% of the current world energy consumption (2019). This is evident from the following:

The current 81% share of fossil fuels will grow by about 50%. Of these 50%, 80% are formed by methanolisation, a total of about 100 % of today's energy consumption. Since the efficiency of methanol production is about 70%, about 140% of electricity volume is needed to produce the desired amount of methanol. This involves 20 billion tons of oil equivalent. This requires about 272,000 terawatt hours of electrical energy. The amount of energy used in 2050 thus reaches 340% compared to 100% today.

The apparent inefficiency of this process is not a problem, **but rather at the core of the solution**. Because renewable energy is very cheap in the sun deserts of the world, a much higher volume of carbon-based energy liquids than what is available today will be provided in this way (100:85). The total cost per 2 litres of methanol will be below today's costs per litre of petrol. The electricity costs refer to today's primary energy volume (oil equivalent) of 14 billion tons. This means that the additional electricity aspect of 140% is already covered. At a price of 200 or 400 EUR of electricity costs per double ton of methanol, this results in 2.8 or 5.6 trillion EUR, respectively (alternatively 3.1 or 6.2 trillion USD). These billions and billions offer huge income opportunities to those countries with favourable conditions for electric methanol production. **Africa should be able to benefit with at least 1-2 trillion USD per year.** That would be a good step forward in terms of the Marshall Plan with Africa.

The trillions mentioned should be seen in comparison with today's expenditure on fossil fuels. They make up about 81% of the current world primary energy supply (oil equivalents) of about 14 billion tons, thus about 11 billion tons of oil equivalents of primary energy. Today, around 7.7 trillion USD are put up per year worldwide for this. In the scenario up to 2050, there will be major transformations in this area.

Carbon-based energy sources will still provide the largest share of useful energy in 2050 (125:75), with useful energy doubling. If, however, the 140 % renewables for methanol production are added, the figure is 125:215, i.e. renewables (together with other energy sources) dominate the picture with a share of almost 2/3 (cf. Fig. 7).



The emissions until 2040 in China, the Indian subcontinent and Africa are the crucial issue. Of course there are uncertainties on the projections and they strongly depend on future political measures and economic development. For the indian subcontinent (India, Pakistan, Bangladesh) + Africa three scenarios for possible emission increase are shown.

Fig. 1 Per capita CO_2e emissions today and projected (2040), with possible reductions in blue, expected increases in yellow/ orange), relative to population growth. The looming, massive surge in emissions in Africa and on the Indian subcontinent are dominating the picture.

What needs to be achieved?

(Objectives of a sustainable solution,
especially for the climate)

- Stabilising world population at 10 billion [4]
- Creating 20 million new jobs a year in Africa
- Not bringing any country into existential economic crisis situations
- Preventing a "nuclear winter" as a result of a low intensity nuclear war

- Keeping the huge industries based on fossil fuels intact

- Achieving balance sheet CO_2 neutrality (e.g. via carbon recycling)
- Preserving rainforests (industrialized countries should pay for that)
- Organising massive reforestation in the tropics (industrialised countries should pay for it)
- Keeping soils intact and improving them (develop them into carbon sinks)

- Feeding humanity (reversing desertification, improving soil management)

- Preventing a two-class society in Europe
- Gradually overcoming the global two-class society

Fig. 2 Objectives of a sustainable solution

[4] This can only succeed with increasing prosperity and realization of the SDGs.

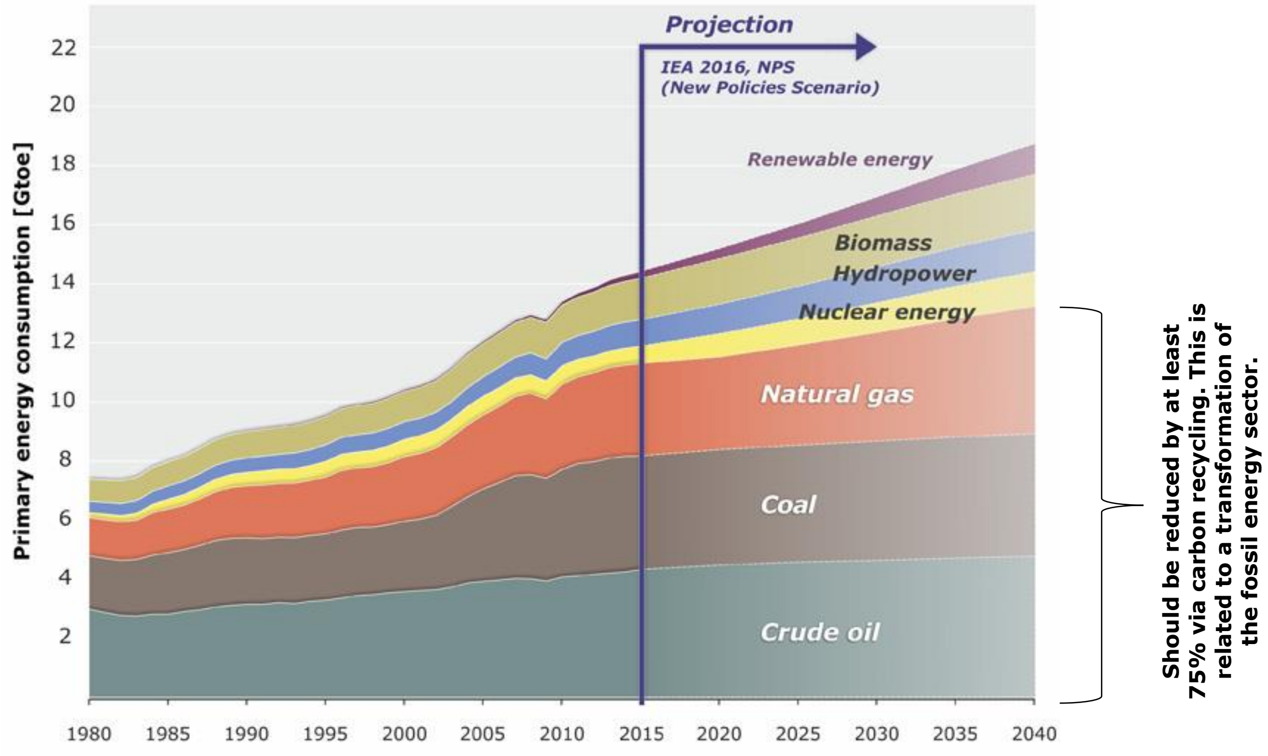


Fig. 3 Projected global energy consumption

Source: Graphic modified, originally retrieved from Federal Institute for Geosciences and Natural Resources (BGR),Energy study 2016, scenarios according to IEA 2016: World Energy Outlook. Paris, France.

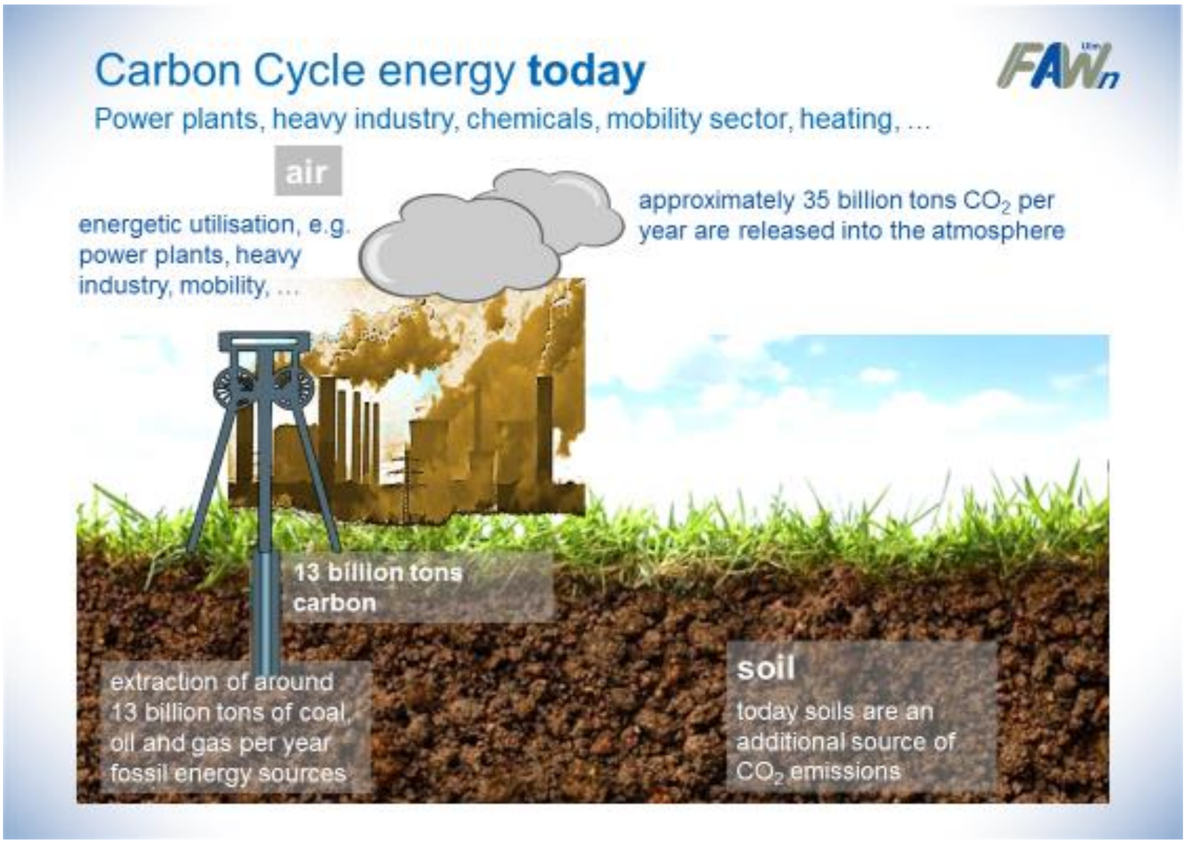


Fig. 4 Today's carbon cycle

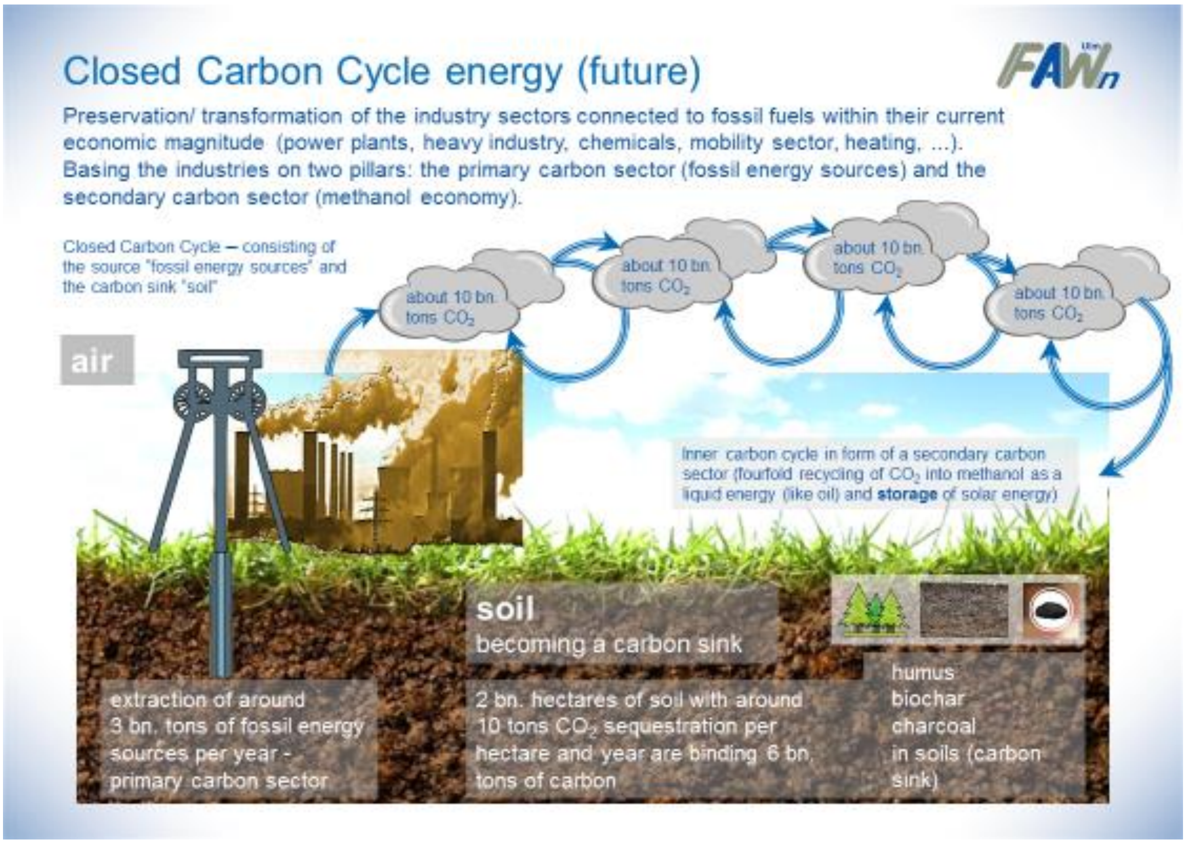


Fig. 5 Future "closed" carbon cycle

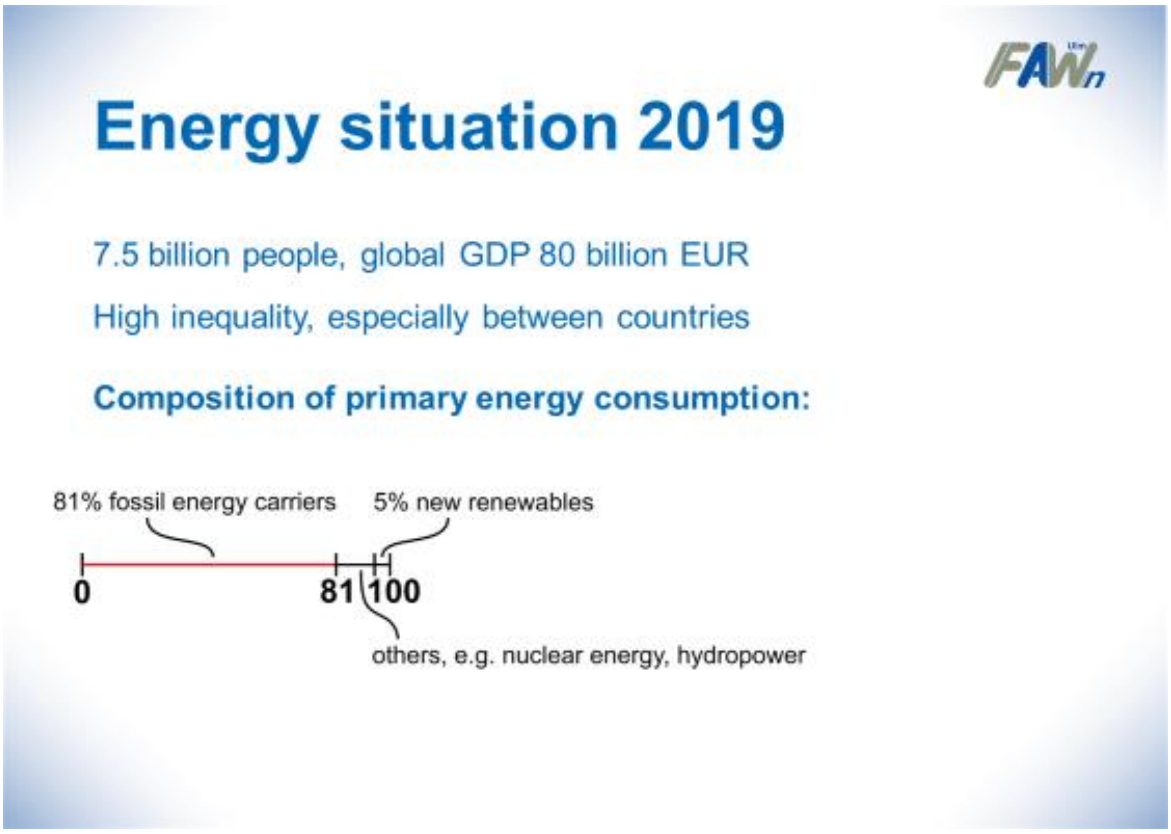


Fig. 6 Energy situation 2019

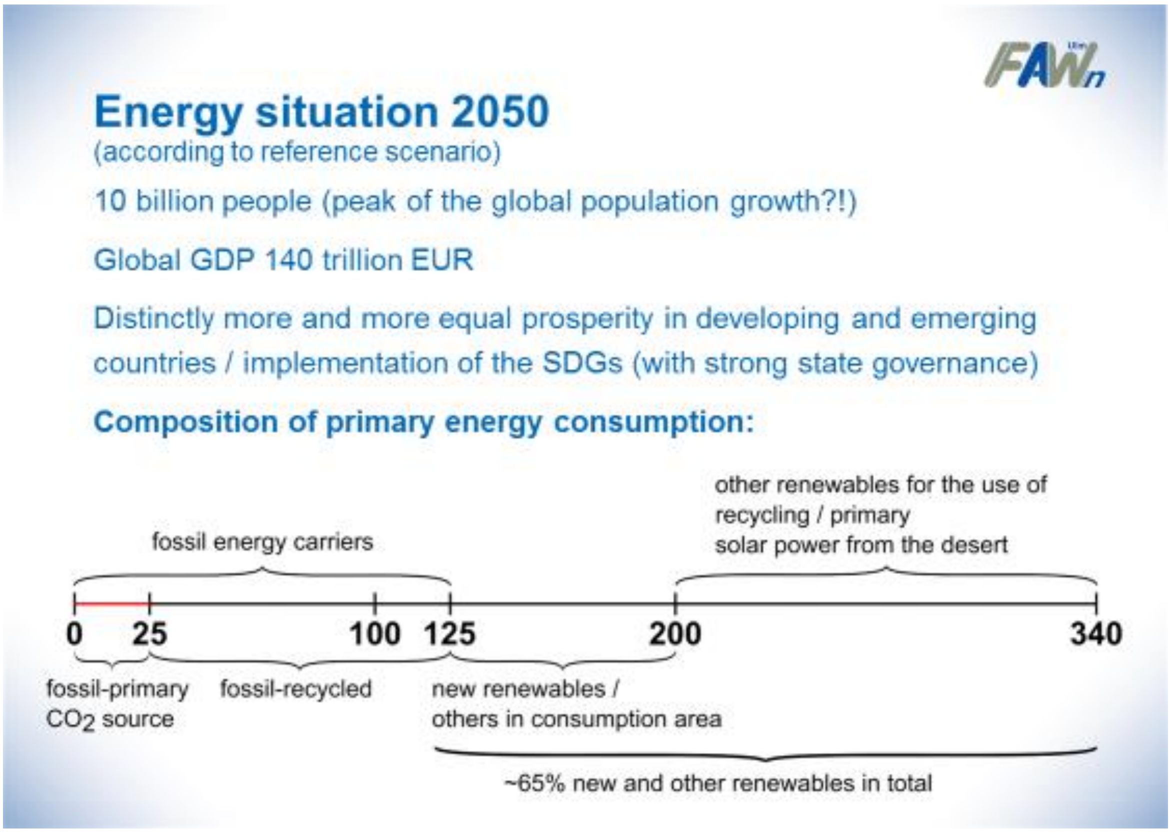


Fig. 7 Energy situation 2050

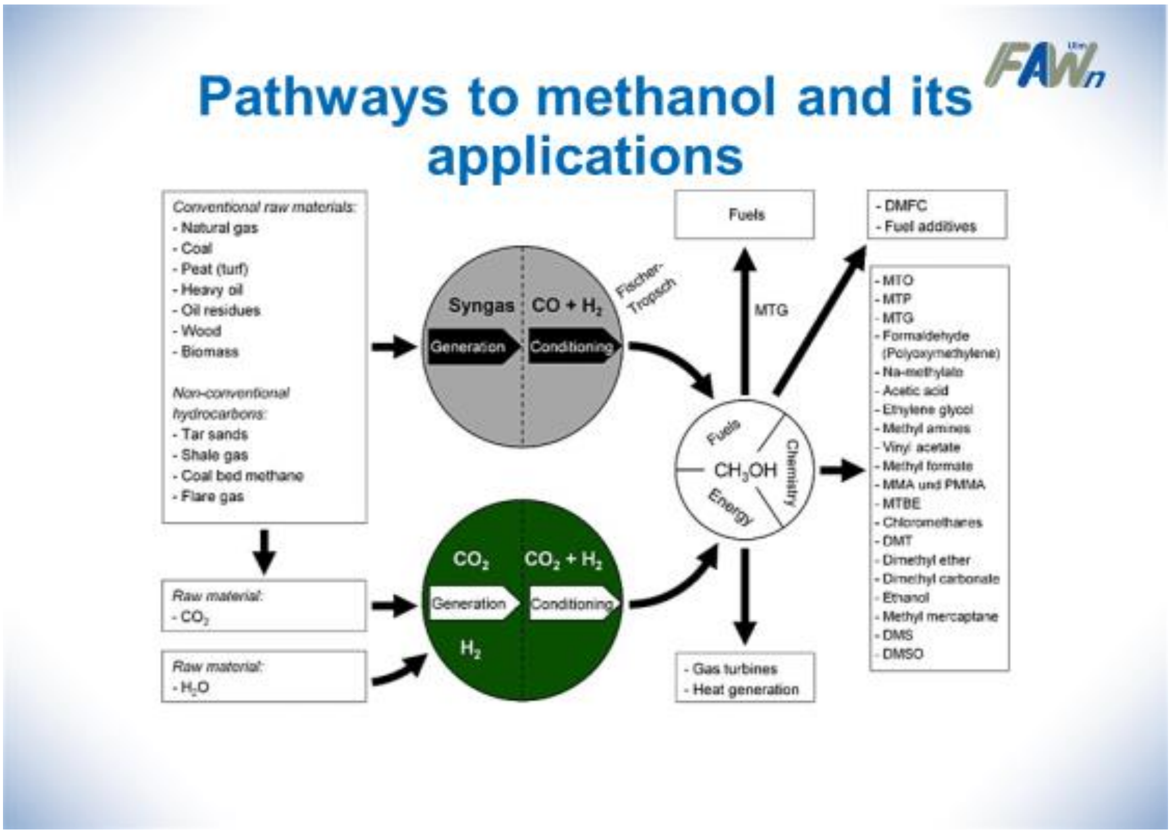


Fig. 8 Pathways to methanol (CH3OH) and its applications

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Acknowledgements

The author is grateful to Mr. Heribert Offermanns and Mr. Ludolph Plass for the many suggestions about the methanol economy, without which this text would not have been written. He would also like to thank Mr. Jürgen Dollinger and Mr. Michael Gerth of FAW/n for their support in data acquisition and calculations in the scenarios. Many thanks also to Mr. Frithjof Finkbeiner and his son Felix (both Plant-for-the-Planet) for the many years of cooperation in the areas of re-/afforestation and Desertec. Finally the author would like to thank Prof. Estelle Herlyn (FOM) for her critical support and many important comments.