Could we fulfil the 2°C climate goal by G-mobility?

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Abstract: Avoiding global methane emission by using the gas for powering the transport sector – a feasibility study of a favourable decarbonisation pathway driven by sustainability

1. FOREWORD

Since I'm not an environmental scientist, climatologist, I wouldn't want to claim about if any relation exist (or not) between the global warming and the level of the greenhouse gases. In my recent study, I am even not going to declare if the global warming is real. However, I believe in the fact: the human being is dependent on hydrocarbons from the very beginning and seems that is impossible to change. Nevertheless, our population is growing continuously without any cease and along with the consumption. It is clear, we have to adapt our behaviour to these facts.

My degree is engineer of transport and I am continuously studying the relation of energy and emission of transport. During these studies, I found one engineering practice as a definitely wrong one. I studied in the school so: let us determinate well and exactly the framework of the problem and then find the engineering solution within that frame. This principle made calculations, design works simpler. Now, in the 21st century we can see how terrible mistakes, bad regulations originated from the simplified frameworks.

Just let me point out one example from our field. The vehicle industry continuously forced to reduce the emission of their vehicles in use (earlier even simpler the fuel consumption). Principally this should drive to higher energy efficiency, which one is of course essential, but it is measured on tailpipe emission, because of simplicity, repeatability. The problem with it the vehicle itself what is (only) a part of systems, first of all a part of an energy system. In this term, the vehicle is simple a device, it converts the stored energy to kinetic energy. The emission, which occurred by the transport is primary related to the energy source, beside of the quality of the device. In case we neglect the background of the energy itself, we can easily miss the targeted reduction and redound a serious emission surplus. This is exactly how today many politically driven regulations curbing the GHG emissions. The widely known example is the Chinese battery electric vehicle-promoting program, where the electric grid is sorely based on coal. Half of the global coal consumption now days to be found in China, what makes there the BEV usage far worse than a petrol one ever could be. Not to forget mentioning, here I'm speaking not only about GHG, but many serious polluting components which are coming out from the power plants.

As I started to write this study, my goal was to find out how relevant, how promising is the methane for the entirely transport sector and how far can we go with the GHG reduction through a well-organized promotion and conversion to the gas fuelling. The transport can act as an extremely good consumer for capturing the methane losses, for boosting the renewable production, but even the up taker can be for the e-technology based synthetic methane, which last one is – as side effect – the most promising tool for power grid management in the future.

Important is to understand by the key players, policy makers, politicians: CNG and LNG powered vehicles are giving so many advantages for the global energy systems that they should spread rapidly. It is not just a second option for alternatives (beside of e-mobility), or an alibi for systems remaining at crude based transport. It is proved, reliable, affordable and first of all a clean solution for each transport sector. To sell the gas might smaller business, than selling electricity. Seems this is the true with the gas-powered vehicles too; compare them to the far more pricey BEV ones. Nevertheless, the world needs simple and cost effective mass solution to keep our global lives going. My conclusion: exactly this can g-mobility provide for us, with a real

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sustainability effect, where even 11 Gt CO_{2e} reduction could be possible.

1.1 Contents

1.2. Abbreviations

BTU = British Thermal Unit, equal to 1.054 kJ

MMBTU = Million BTU, equal to 1.0546 GJ

CH_4 = methane

CO_2 = carbon dioxide

CO_{2e} = Global warming potential equal to carbon dioxide

CNG = Compressed Natural Gas, mainly methane gas from renewable or fossil source compressed to 200 bar (as nameplate pressure, or in some markets 250 bar) kept in gas form

LNG = Liquefied Natural Gas, almost entirely methane gas from renewable or fossil origin, cooled down till the temperature around -162°C, where methane changes it's state into liquid phase

mt = million tons

Gt = billion tons

ppm = particle per million

EJ = Eta Joule, 10^{15} Joule

EIA = U.S. Energy Information Agency, a Washington based agency under the federal Department of Energy

IEA = International Energy Agency, a Paris based autonomous intergovernmental organization, established by a framework of the OECD

NGVA Europe = European Bio- and Natural Gas Vehicle Association, a Brussels based association to promote methane as a fuel

OICA = International Organization of Motor Vehicle Manufacturers, a Paris based organization

DNV-GL = International accredited registrar and classification society with headquartered in Norway, Det Norske Veritas united with Germanischer Lloyd

IMO = International Maritime Organization, a London based intergovernmental maritime agency of the United Nations for regulating shipping

HFO = Heavy Fuel Oil, it has to be heated for the ability of pumping

MDO = Marine Diesel Fuel, it has a higher density as diesel, basically a mixture of distillates and HFO, sometimes also named as IFO (intermediate fuel oil), however IFO has mainly higher HFO content and because of that it has to be heated unlikely to MDO

MGO = Marine Gas Oil, any kind of diesel fuel for maritime, considerably less sulfur content

PtG = Power-to-Gas, system which convert electric power to hydrogen by electrolyze procedure and mostly because of hydrogen is not easily stored, adding to carbon dioxide through a catalytic converter and forming synthetic methane

TtW = Tank-to-Wheel approach, considering only the emission of the vehicle produced itself

WtT = Well-to-Tank, the assessment of the energy exploration, production, transportation and storage

WtW = Well-to-Wheel approach, which is covering the lifecycle of the energy consumed by the vehicle

2. INTRODUCTION – CLIMATE PROTECTION CONSIDERATIONS

There is widely agreed that the increase of the greenhouse gas concentrations in the atmosphere of the earth must be stopped and reversed in order to protect the climate soon. International conventions on the reduction of emission shall be implemented along sustaining the growth of populations and the economy. The task is not made easier by the fact that in addition to the anthropogenic emission sources, the activity of the Earth as well as its flora and fauna also exist and are considerable.

The "Emissions Gap Report" [49] published by the United Nations Environment Programme (UNEP) in late 2017 clearly describes that a sharp break must be reached in the tendency of greenhouse gas emissions increasing year on year, in order to have hopes of bringing the climate change under control (>66 % probability). According to the report, the contributions of the Nations ratifying the Paris Convention shows 13.5 billion tons (Gt) deficit in the reduction of greenhouse gas emissions (CO_2 equivalent) by 2030 compared to the objective of 2°C and there is a 19 Gt gap compared to the even more ambitious 1.5°C. In order to achieve the 2°C, 25 Gt total emission level must be reached by 2050 along a balanced decrease trend and in order to achieve temperature increase not exceeding 1.5°C the total annual extent of greenhouse gas emission must be kept at 7 Gt according to UNEP for mid-century.

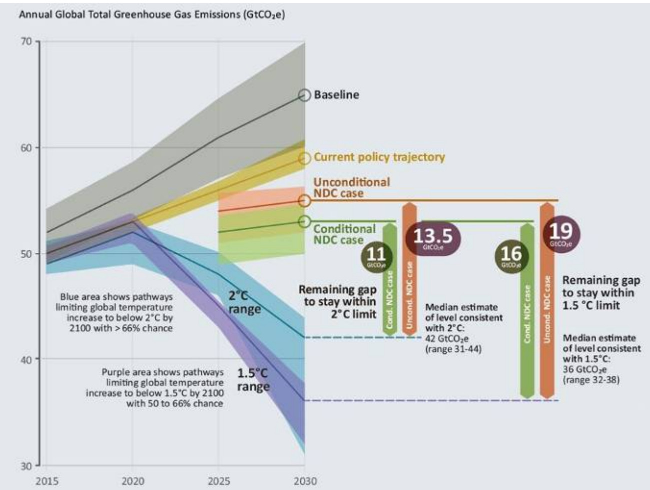

Fig. 2-1: UNEP graph [49] demonstrates the reduction of greenhouse gas emission required for the 2°C and the 1.5°C temperature increase limits comparing with the currently valid tendencies.

The methane balance prepared by Global Carbon Project (GCP) [1] illustrates the complexity of the processes well. From the perspective of climate protection, one of the major greenhouse gases is methane with 12 +/- 3 years life in the atmosphere which has 28 times more greenhouse effect that carbon dioxide in 100 years [2]. According to GCP, the average methane content of the atmosphere increased by 10 tons of methane annually between 2000 and 2012. As a comparison, this is equal to the gas consumption of Slovakia, Hungary and Slovenia combined.

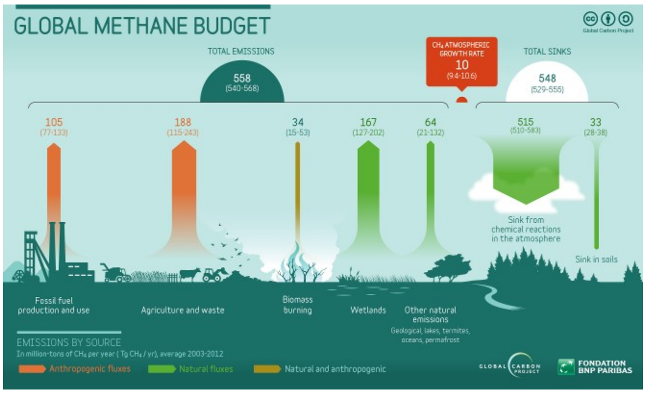

Fig. 2-2: This figure summarizes the research of Global Carbon Project on the changes of the methane content of the atmosphere showing 10 million tons in excess on annual average [1].

In order to achieve the objective of temperature increase not exceeding 2°C by the end of the century, the amount of methane emitted to the atmosphere must be reduced. Among anthropogenic impacts on the one hand in accordance with the exploitation, transmission, storing and use of fossil fuels (not only natural gas but coal and oil also have significant effect) there is a decreasing but still huge amount; approx. one third of the annual natural gas use of the European Union. 59 million tons (+/- 20% inaccuracy) of methane emission is found in relation with wastes among the more detailed survey results. The methane emission of food production and animal husbandry is of 136 mt from which rice cultivation is 30 mt.

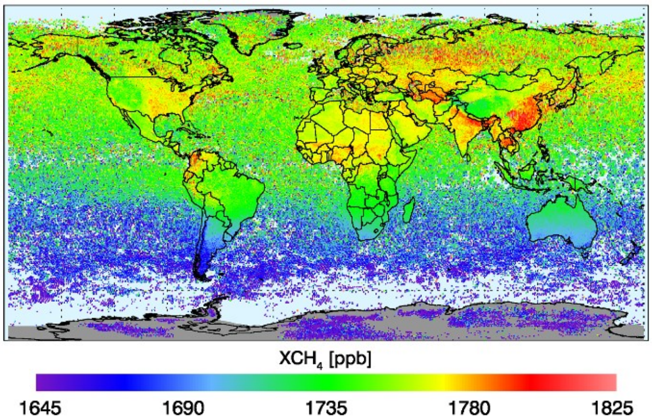

Fig. 2-3: satellite map image of the concentration of methane in the atmosphere [60] using ESA data according to the status of 2015

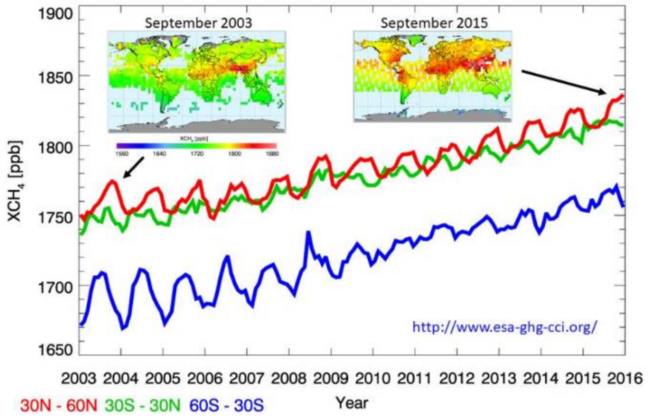

Fig. 2-4: Climate change versus greenhouse gases for sceptics; the ESA figure presenting the change of methane concentration between 2003 and 2016 [61]. The blue diagram shows the area bordered by southern latitude 60° and 30°, the green area is the 30° area to the south and to the north of the Equator while the area between northern latitude 30° and 60° is marked in red, indicating the change of average methane concentration.

Preventing the escape of the energy carrier strong greenhouse gas and using it should have an even more important role in climate protection actions than before; moreover the use of the valuable molecules in terms of energetics may also become economically positive.

Let us first position the 10 mt CH_4 annual increase balance. Accepting the 28 times multiplier, this equals 280 million tons of CO_2 emission at the moment. On the basis of the 2017 survey of Global Carbon Budget between 2007 and 2016 [3] the average CO_2 level in the atmosphere in 2016 reached 402.8 ppm, increasing from 277 ppm in beginning of industrialisation in the mid-18th century.

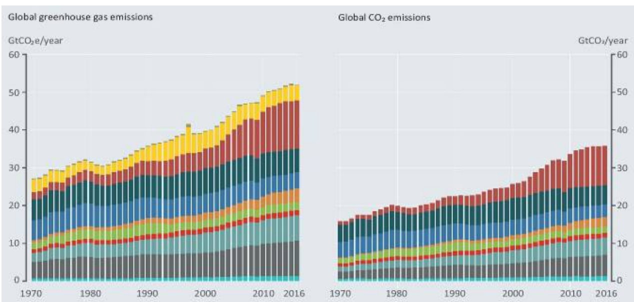

Fig. 2-5: The increase of global greenhouse gas emission of anthropogenic origin in CO_2 equivalent to the left and CO_2 emission to the right year on year [EDGAR v4.3.2, Oliver and Co., 2017]

The CO_2 emission slowed down during crises and gathered speed in between them in the past fifty years and it has increased sharply in the past decade further, where the tendency seems to be changed between 2014 and 2016. According to preliminary data the average CO_2 level of the atmosphere increased to 406.8 ppm, by 36.8 billion tons of CO_2 annual emission (Gt CO_2) (with CO and CH_4 equivalents total). It is due to the fact that the balance of the CO_2 absorbed by the flora, the soil and the seas of the Earth and the emission shows a constant deficit; scientists found 2.2 Gt/annum deficit in the balance in the average of one decade.

Approx. 13% of the CO_2 balance deficit is caused by the annual 10 mt imbalance of the Methane balance. In contrast, the reduction of CH_4 emission by 78 mt would result in stopping the increase of the present CO_2 level. One of the most important question of climate protection is: how it is possible and how much it costs to avoid 78 mt CH_4 emission? Through the analysis of the two major anthropogenic methane emission sources we can arrive to an answer.

The more apparent emitter, fossil energy exploitation and use represent 105 mt on mean value, i.e. close to 150 billion cubic metres methane according to the report. The closing price of gas according to the Dutch market is 18.6 €/MW (14/03/2018); calculating with this, the valued global loss arising from industrial emission is € 27.6 billion annually. According to the IEA [4.] report this amount is enough to implement the technological development required for avoiding such emission. The conclusion may be assumed rough; however the truth of the forecast until 2040 can be checked at least in terms of magnitude.

Starting from the 2016 base, the methane loss reduced to nearly 0 by 25 years of development and systematic maintenance (assuming a linear track), will provide a total of € 345 billion investment coverage from sales at the current price level. (Certainly it must also be examined that the party responsible for the development is not necessarily the same who benefits from the extra arising from the reduction of emission.)

Is this amount enough for avoiding 105 mt methane emission? Or, how much methane emission can be avoided at an economically sustainable, rational cost level? The routes of methane emissions must be seen under the magnifier to get the answers.

But always have to consider the air pollution, which can be greatly decrease through changing the primary fuel source to methane.

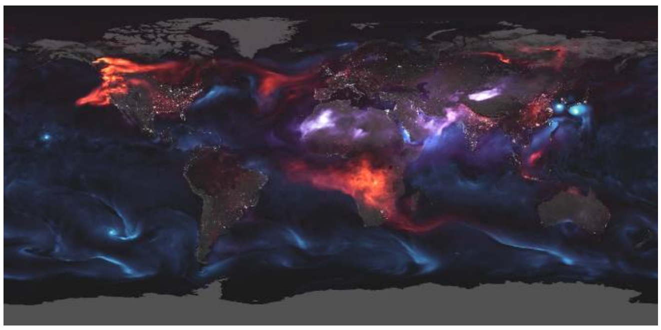

Fig. 2-6: Millions of solid particles and liquid droplets in the air, known as aerosols [image: NASA/Joshua Stevens/Adam Voiland]

3. POTENTIAL TO REDUCE METHANE EMISSION IN FOSSIL ENERGY INDUSTRY

In order to avoid the emission of 105 mt methane into the atmosphere written in the introduction, this chapter goes through the on the analysis of the processes, opportunities and economic feasibility of coal, oil and gas production and transmission.

3.1. Coal production

The Coal 2017 Analysis and Forecast to 2022 report of IEA [8] has registered decreasing global coal consumption for the second year in row, setting the 2016 demand at 5,357 Mt coal equivalent. The 2015 primary energy use value of $145x10^{15}$ BTU, published by ExxonMobil [6] is approximately equivalent with this. The quantity is 26 percent of the total primary energy consumption and giving 44 percent of the energy sources used for global electric power production. The statistics of EIA from the US [7] stated the total production of different coal types at 8,182 million tons. Since this also includes lower quality coal types according to their weight, the figures are estimated to cover each other. It is as remarkable fact that the largest coal miner (since 1983), China produces close to half (46.1 %, 2016) of the global production, 4.6 times more than the second biggest USA and the amount of 3,970 mt used there is also five times more than that of the second largest user, India. China used 50.6% of the world coal consumption in 2016 [56].

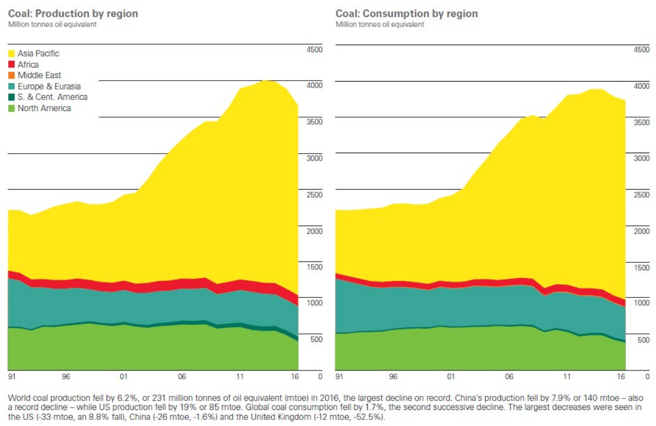

Fig. 3-1: BP statistics [56] well illustrates that coal mining and use has nearly doubled in the past decade due to the growth in Asia where the growth stopped around the middle of this decade.

This situation also offers a good perspective for changing from coal to gas and to solar or wind farms since the Chinese economy works under strong political control and the process has already been started. On the other hand, however the fundaments allow for the conclusion that due to the growth of population in Asia and the GDP per capita makes increase of power consumption in the forthcoming decades, which will be covered by low-carbon intensity developments to be implemented, but the total use of coal power plants will only decrease to a little extent. Therefore ExxonMobil forecasts the same amount of coal consumption for 2040 as in 2015 ($143x10^{15}$ BTU), along with at least 25 percent higher total primary energy use [6] and what is even more remarkable; 25 years later the electricity consumption estimated to be 60 percent higher.

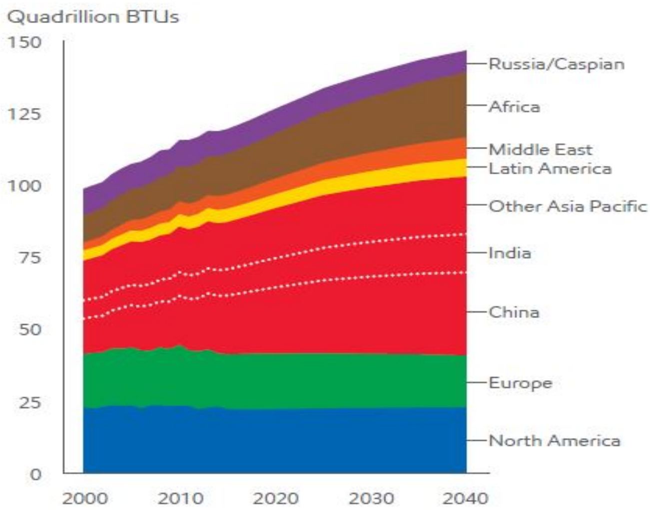

Fig. 3-2: it can be seen in the ExxonMobil report that the changes in the energy consumption of the world until 2040 are mostly caused by China and India and the change of the energy need of Africa must also be seen.

Coal is known to be the cheapest fossil energy source and the conversion of electric power production to natural gas or renewable sources does not only require development, but increasing operational costs too. This must be balanced so that conversion to natural gas with 50 percent lower CO_2 emission compared to coal firing or alternatives with even more favourable CO_2 footprints becomes economically reasonable for the stakeholders. 19.6 billion tons of annual CO_2 emission can be calculated with the current coal use but in addition to this, the methane emission arising from the exploitation must also be counted.

By the emission of methane bound in coal and released during extraction into the atmosphere, coal mining occur 34 % of the methane emission of the energy sector, i.e. 41 mt methane released per annum in the average of 10 years (it is 1.5 billion tons of CO_2 equivalent) into the atmosphere [1]. Statistically 5 t methane is released in the production of 1,000 t coal, which simply mathematically results the CH_4 release of 18.5 mt per annum in China only. The technology is available to collect and purify the gas in underground mines and use it either locally or at more distant premises after liquefaction. Not to forget, within this activity, the emission of significant amounts of the highly toxic mercury can also be prevented.

For this purpose a methane separator and liquefier plant with the capacity of 10,000 t/annum, including the required additional development, can be implemented in Europe between € 8 and 10 million. However the preliminary and small-scale technological development may bring down the investment cost to € 3.5-4 million by 2025 in case of larger (10-100 units) series and considering the industrial development opportunities in China. Based on the recent possibilities, € 375/t/annum minimum specific investment cost can be used as the basis of calculation. It must however be considered that the equipment of different sizes and capacity will become cheaper or more expensive by size only to a little extent, but must calculate with the development of oversized capacity.

According to a Dutch report on Chinese mining, written in 2016 [9], China achieved its objective in 2015 to bring the number of coalmines under 10,000 and they wish to close another more than a thousand outdated mines thus focusing on environment protection and increasing energy efficiency and safety. The report confirms that in 2015 3.7 billion tons (there is a mistake in the report writing million here) of coal was mined and another 2 billion tons of available annual capacity is estimated. (The report highlights the opportunities of the Dutch industry to deploy its advanced technologies, including in the exploitation of methane bound in coal.)

Statistically 370 thousand tons of coal is mined annually per mines on average in China. Theoretically speaking, using a normal distribution gauss curve, 2.5 billion tons of coal is mined from about 3,500 mines. According to the simplified statistics therefore in case of the technological development of 3,500 mines, 12.6 mt/annum methane emission can be avoided and partially used. The investment cost of this counted on the above specific investment is € 4,725 million however calculating with the construction of 3,500 units of the technology we arrive to the amount of € 12,125 million. This is annually € 1,312.5 million investment with ten years of evenly distributed development.

Considering the energy requirement of the technology, the total extraction efficiency achievable in the future can be conservatively estimated at 60 %, which also means that the development implemented on the 3,500 mines will result in 7.56 mt/annum marketable LNG. This drives to € 1,987 million income per annum, calculating at the quote prices. Ignoring the fact, that LNG quotes - though fluctuating - may have significant extra prices on the Asian market compared to the European or even more to American quote prices, conservative present value of the marketable gas as sales revenue compared with the amount of investment required, we can conclude that the gas sold in the 8th year already exceeds the amount of the investment on that year and in the 14th year the entire investment returns. Considering that the life cycle of investments may be calculated for 20+ years (calculating with the stop of devices after 20 years) the maximum € 5 billion investment requirement of the inflexion point of the cumulative balance curve will result in 5.2 times return by the end of the 30 th year. (See Annexes I Table B/1)

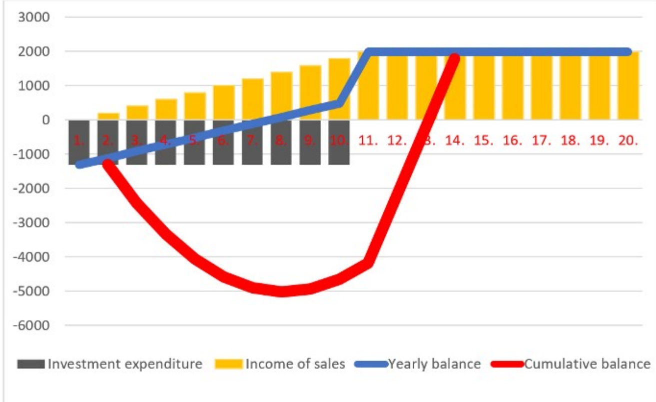

Fig. 3-3: Revenue curve of the total investment for that ten years, which required to establish infrastructure to collect and liquefies the methane release at Chinese coalmines and the revenue achievable by the sale of methane within 20 years.

If we extend the example to the other half of the coal production of the world, on the basis of coal mining estimated constant until 2040 the following conclusions must be considered. The coal production of China was 46.1 percent of the world production in 2016 [56]. It was double than the total (23.1 %) of the other three large coal miner countries of the Asia-Pacific region (India, Australia, and Indonesia). The rest of the world shared on the 30.8 % in 2016 [56]. Although the present (2015) regional consumption data and the forecasts for 2040 show the stagnation of the global coal consumption, but there are a very strong change foreseen in the territorial use [6]. 72.5 % of the $145x10^{15}$ BTU consumption going to be given by the Asia-Pacific region and $14x10^{15}$ BTU increase is expected here (increasing its share to 83 % in the global consumption), while Europe and North America together will see a $17x10^{15}$ BTU decrease (resulting the decrease in the share of global consumption from 19.3% to 7.7%).

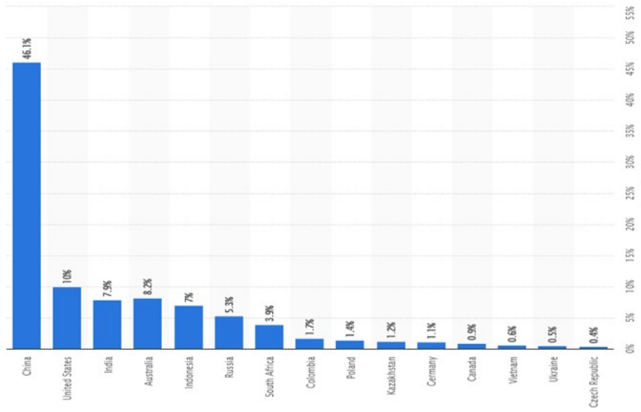

Fig. 3-4: Global coal mining in 2016 [56].

From all of the above it can be concluded, that the simple statistical calculation is worth extrapolating to the Asia-Pacific region outside China. Accordingly, India, Indonesia and Australia jointly requiring 50 percent of the investment demand seen in China, may prevent 6.3 mt/annum methane emission.

To sum up, the development opportunity seen in coal mining, if my calculations are correct, 18.9 mt/annum methane emission can be prevented with an investment becoming profitable in less than 15 years. As a result of which the global methane balance may become negative and a quarter of the CO_2 balance deficit (mentioned in the introduction) can be prevented through this way with positive economic results.

3.2. Crude oil and natural gas exploration

The methane balance [1] reports the emission of 79 mt methane (in the range of 69-88 mt) on average for the decade between 2003 and 2012 in relation with the crude oil and natural gas industry, noting that the surveys worldwide show multiple differences in details due to methodology. There are also multiple differences in the level of specific emission between different parts of the world. While the gas coming to the surface along with crude oil extraction is mostly (up to 99 %) released by flaring to the atmosphere converting the gas into CO_2, in case of natural gas, along with extraction, the leakage of the compressor stations, transmission lines and user points, or the ventilation performed during maintenance also cause methane emissions.

In the past years several studies pointed out that due to the practically negligent extraction methods, the 1-2 % gas loss can even multiplied in case of certain gas producers. Calling attention to missing data, in the calculation model used for shale gas extraction, a very high, 4.3% loss rate was simulated, partly based of satellite observations.

Global Carbon Budget [3] calculated 9.9 +/- 0.5 GtC, i.e. 36.27 +/- 1.83 billion tons of CO_2 emission to fossil fuels and the industry in 2016. 40 % of this resulted from coal, 34 % from oil, 19 % from gas consumption and 0.7 from gas flaring. The latter meets the 254 mt CO_2 emission with the tolerance of +/- 13 mt.

According to the figures of the Global Gas Flaring Reduction Partnership (GGFR) started by the World Bank, the amount of natural gas flared in 2016 assumed to 150 billion cubic metres globally [11]. GGFR is giving a detailed presentation of the flared amounts of the individual producer countries as well as the flaring intensity in terms of the oil equivalent of the extracted energy sources.

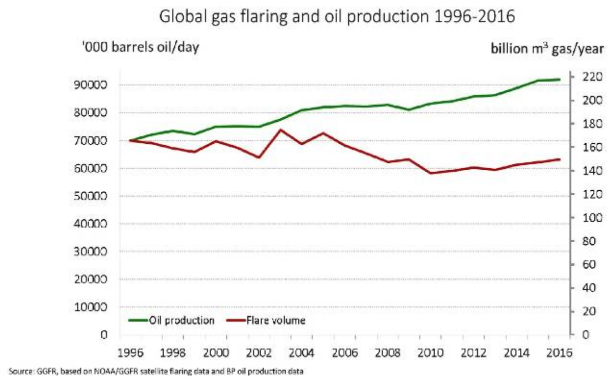

Fig. 3-5: Change of crude oil extraction and amount of related flaring of the world between 1996 and 2016 [11]

If we calculate the two above figures on the amount of flaring with the density of 150 billion cubic metres of methane of 25°C, i.e. 0.657 kg/m^3, and the complete burning of 2.54 $kgCO_2/kgCH_4$ then we arrive at 250 mt CO_2 emission. This shows a good equivalence with the specification (data of GCB) of the total global CO_2 emission not more accurately than millesimal.

We must footnote Lisa j. Hanle's graph specifying the emission of greenhouse gases on the basis of the burning efficiency of flaring. The efficiency of associated gas flaring changes on the basis of the composition of the gas, the quality of the torch and the strength of the wind in several studies (like in the presentation of Professor Johnson [32]) it is estimated at average 95 % which is probably not true for the extractors at the end of the range. (I.e. the extractors at lower technical level operate less effective torches while the technically and economically advanced extractors use more effective torches.) Calculating with 95 % efficiency of the 150 billion cubic metres we arrive at the release of 5 mt methane and from the flaring, calculating with the associated gas mixture with higher density than clear methane (0.717 kg/m^3) the result is the production of 259.5 mt CO_2.

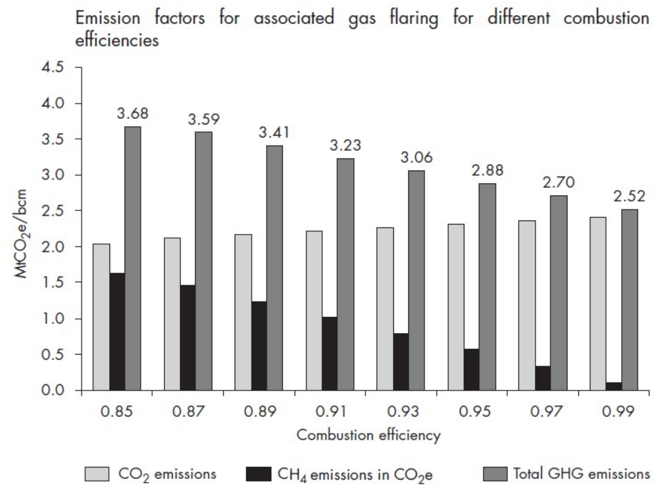

Fig. 3-6: CO_2, CH_4, and total greenhouse gas emission of flaring in the rate of efficiency [31]

The reasons for the flaring process applied along oil and natural gas extraction can be divided into three basic cases: routine, security and non-routine flaring. Routine flaring includes primarily the following:

a) gas torch from the oil-gas separator of the extraction plant,

b) torch for the elimination of gas separated in other storing and processing facilities,

c) flaring the amount of gas exceeding the capacity of the gas infrastructure.

Flaring for security purposes may take place due to draining gas due to an accident or for accident prevention purposes or burning bad quality, not usable gas mixtures. Non-routine flaring serves for the purpose of releasing gas required due to the maintenance, repair or conversion of the installed equipment at the well, including system start processes.

It is apparent that the amount on security and non-routine flaring may be reduced by the development of technological processes applied, but it hardly to stop them totally. Contrary, routine flaring may be almost completely terminated by technological developments. Global Gas Flaring Reduction Partnership (GGFR) started by the World Bank in 2002, has recently issued a proposal aiming to achieve zero routine gas flaring by 2030. They shall also finance the initial, preparatory stage of the projects to be started for this purpose. Nevertheless GGFR describes in detail in their publication on the global overview of the regulation of associated gas release and flaring [11], that the only a small part of the extracting countries regulate the release or flaring of gas.

Examining the 44 most significant emitting countries in the data taken by GGFR between 2013 and 2016, system level conclusions can be drawn. There is a huge difference in the amounts of gas flared per extracted crude oil and natural gas, showing a systemic relation with the political stability, technical and social development of the extracting country. The 44 countries together represent 97 percent of flaring emission and almost 98 % of the world o&g production. It can be concluded that in countries with developed extraction culture, like for example Saudi Arabia or Norway, the amount of gas flared per one barrel of extracted oil unit is around half cubic metre. While on the other end of the scale, there is even 60 cubic metres loss per barrel of oil equivalent, in countries like Syria, Yemen or Uzbekistan, but there are extremely high values in Cameroon and the D.R. of Congo as well. In case of Syria and Yemen the severe condition of the oil industry is also represented by the dramatic decline of extraction. (See Annexes I Table B/2)

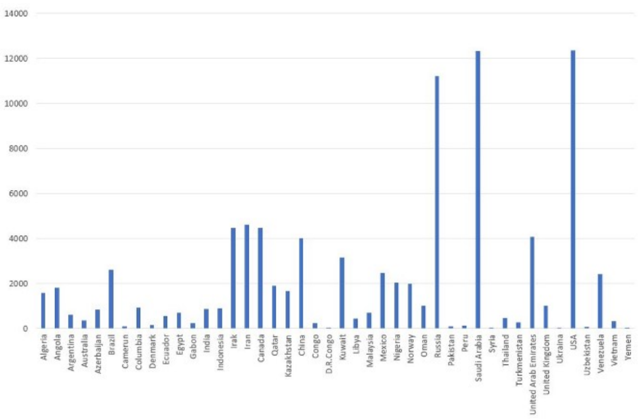

Fig. 3-7: Extraction of oil in the 44 countries examined, thousand barrels per day in 2016 [11]

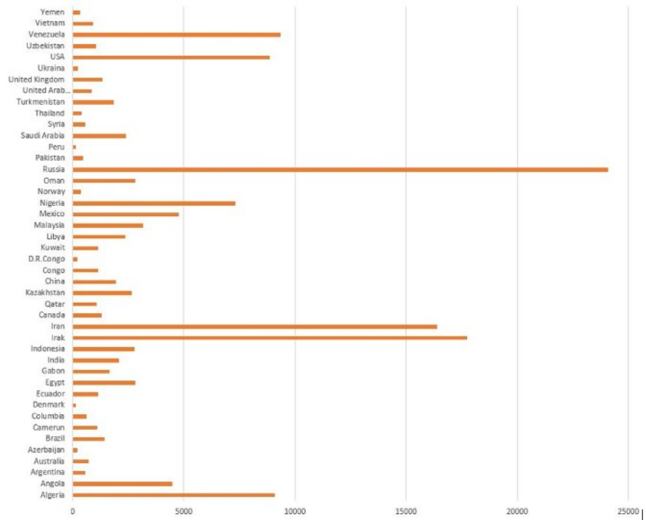

Fig. 3-8: Amount of flaring gas, related to extraction in the 44 countries examined in 2016 [11]

In order to survey the possibilities of intervention, I put the 44 countries in 7 categories on the basis of extraction losses calculated on the basis of energy production. (See Annexes I Table B/3 – B/4) Cases below 0.5 percent can be assessed as "excellent" extraction category. Along with positive and constant increase in 2016, 21.34 % of the total production of the countries examined originated from these countries, and they only represented 2.59 % of the flared amount. If the loss falls between 0.5 and 1 percent, then the production categorized as "good". The production in this category shrank between 2013 and 2016 essentially by the same amount that the production increased in the excellent category, representing 12.88 % of production and 3.01 % of total flaring in 2016. Flaring at the global average (1.1 % loss) and in a little worse range of 1-3 percent of the energy source may be classified as " global average" result. 24.23 % of total production and 11.8 % of the amount of gas flared fell in this category in 2016. Assessment "below average" means 3-5 % energy loss due to flaring, which covered 19.13 % of the examined total production and 25.55 % of flaring in 2016. Classifying 12 of 44 countries as "unfavourable" due to the significant amount of energy loss of 5-10 percent where 19.43 % of energy source was produced as well as 44.59 % of the gas flared came from these countries. In other words, one fifth of the production caused almost half of the gas flared. The production of 9 countries was primarily and permanently "bad" between 2013 and 2016 falling in the energy loss range between 10 and 20 percent. Only 2.77 % of production came from this category (in 2016), however it represented 8.97 % of flaring in the countries examined. It should be noted, that Algeria and Libya fell just above the border of the category (10.7 and 10.2 %) with significant amount of extraction. The production of the 5 countries above 20 % energy loss may be called "catastrophic". Along with insignificant production of 0.23 % (only 0.14 % in 2013) it represented 2.23 % of the environment pollution. (See Annex I Table B/5 – B/6)

Table 3-1: Qualification of flaring rates of extracting countries on energy base

Excellent	**F% < 0.5**
Good	**0.5 < F% < 1**
Global average	**1< F% < 3**
Worse than average	**3< F% < 5**
Unfavourable	**5 < F% < 10**
Bad	**10 < F% < 20**
Catastrophic	**20 < F%**

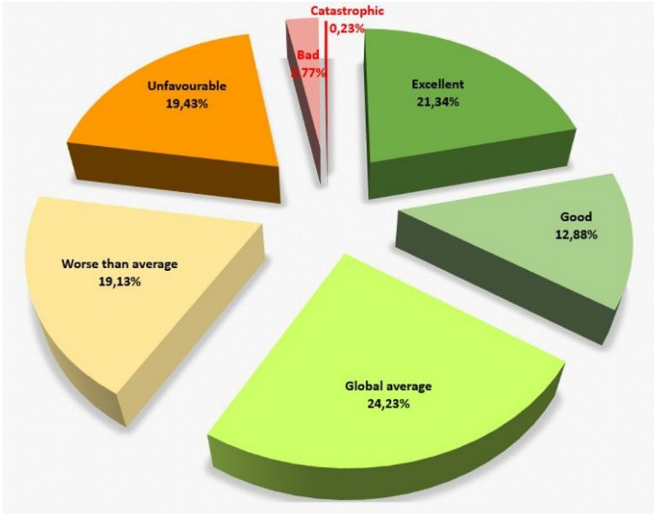

Fig 3-9: Division of global exploration in the rate of specific flaring

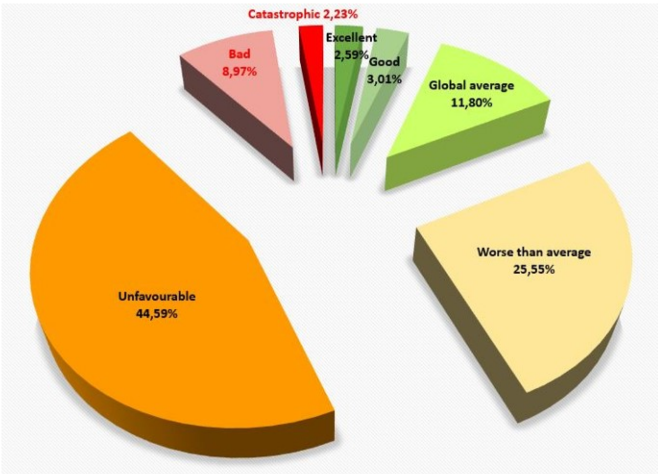

Fig. 3-10: Division of the global amount of flaring related to exploration according to the rate of flaring

From the figures it can be concluded that the technological development to be implemented in the countries representing two thirds (65.5 %) of the total extracted amount (from average to bad categories) may influence nine tenth (90.9 %) of the flaring emission. Bringing the extraction of these countries to the excellent level, i.e. to 0.4 percent loss (like UAE, Azerbaijan) would result in the prevention of flaring of 120 billion cubic metres, i.e. 4/5 of the current amount.

Needs to be noted, the overall cost of the necessary technological development can be determined only with allowing a significant deviation. The technical possibilities applicable for avoiding flaring are practically the following.

Smaller routine flaring is mostly avoided by the use of gas generators, especially if the produced electricity can be used locally. This method allows for the use of hydrocarbon chains longer than methane in the gas. With well-sized redundant design the "non-routine" flaring can be brought to minimum. Used the cost of a 1 MWh "name-plate" nominal capacity generator set for the analysis, assuming that the specific investment cost per annual consumption in cubic metres is not significant in case of lower capacity generator sets either, however the size can be reduced close to zero and on the other hand the multiplication of capacity becomes unreasonable at 2-4 times the size. The specific investment cost of a generator set suitable for the annual consumption of approx. 150 thousand cubic metres of gas in case of use for ten years results in the cost of 27.57 €c/m^3. (See Annex I Table B/8).

This allows for using a magnitude larger amount of gas if a compressor equipment is installed in the system to collect the gas. A generator set capable of producing electric power and a separator to separate gas component differing from methane are also required for this. The investment may become operable if the storage and transmission of compressed gas is also appropriately provided. The suitable system can be established with a 400 Nm^3/h capacity compressor and at approx. 2.7 €c/m^3 specific cost. The upper limit of the annual gas neutralization with this is 3.5 million cubic metres. A smaller compressor is possible with little cost reduction, and with worse utilization the specific cost increases to 10.8 €c/m^3 in case of a quarter of the capacity. In case of 1000 Nm^3/h capacity the flaring of 8.8 million cubic metres of gas can be avoided. The cost of constructing the system is more than double however the specific cost is 2.27 €c/m^3. Although the final goal of compressing natural gas may also be input to the gas pipe network, this results in the loss of significant compressing investment. This solution is still used in many cases in order to provide supply for consumers during service outage or network maintenance when the efficiency is not the primary aspect. This way of utilization however cannot provide stable consumption for the other side continuously produced compressed gas. A practical consumer could be the market of CNG vehicles, which wishes to use the compressed natural gas in this form, but typically at another location as it is produced. In order to ensure the amount of the produced gas is consumed, the conversion of individual consumers as well vehicle fleets to CNG fuel can be planned and encouraged up to certain limit.

Primarily due to distribution, storage and wider opportunities, instead of larger compressor capacity it may be practical to calculate with the implementation of a "nano" or "micro" scale liquefier plant. Although the development of the system is significantly more expensive and it is not only due to the far more expensive liquefier equipment, but the higher level gas separator unit too. It is important however, that a fifth of the shipping needs to be take place at the liquefied gas compare to the same amount of compressed of gas, which does not only become important for the reduction of operation cost significantly but also for the aspects of sustainability. The system of 15 t per day (tpd) capacity may avoid flaring of 7 million cubic metres gas annually at the specific system investment cost of 6.4 €c/m^3, which includes the cost of storage and transmission equipment, just like the compressor system.

The specific cost of implementation of the LNG route significantly improves by the increase of size. A small size system can be implemented at the investment cost of 4 €c/m^3 and a medium size system can be implemented at the cost of 3.4 €c/m^3. The basis of calculation for the previous one was given by a system size of 22 million cubic metres gas capacity while the bigger one is a 55 million cubic metres gas capacity system.

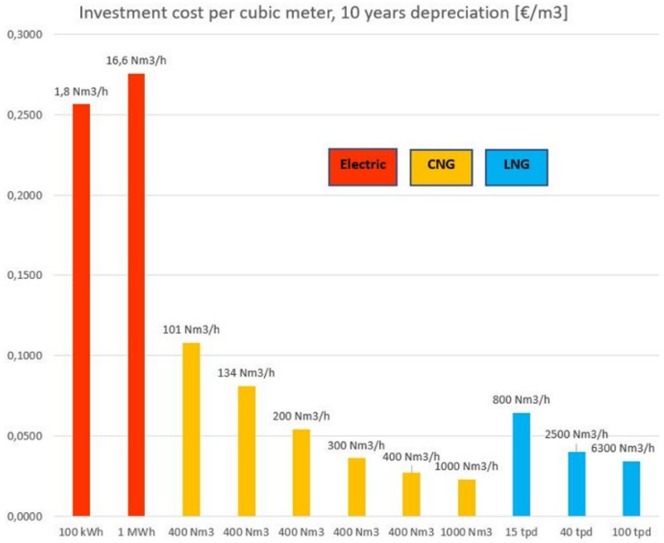

Fig. 3-11: Different gas utilisation technologies and specific implementation cost per cubic metre of the amount of gas in Euro, calculated for ten years of operation.

Assuming that the delivery of an average oil well is 100 t/day, and on the basis of the above categorisation of producers, a "global average" classified producer has to ensure the collection of 50-150 m^3/h/well amount of gas. Smaller compressors can be used in this category. According to the statistics of EIA on wells in the USA [12], from a total of 446 thousand operating oil and gas wells, 24.1 % of production came from 1,474 wells, which delivering above 109 t/day on average, while 52.8 % of production came from 36,000 wells, delivering 6.8-109 t/day in 2016. The source of the remaining 23.1 % of production is almost 408 thousand oil wells of even lower delivery. Statistically 3.5-10.5 m^3/h amount of flared gas to be avoided is resulted at a "global average" producer of 6.8 t/day. Naturally the number and delivery of wells in the USA cannot be extrapolated either along geological or technological aspects to the other 43 examined producer countries, however we assume that it offers a result with acceptable tolerance for the calculation of specific costs with a statistical approach. (See Annex I Table B/9).

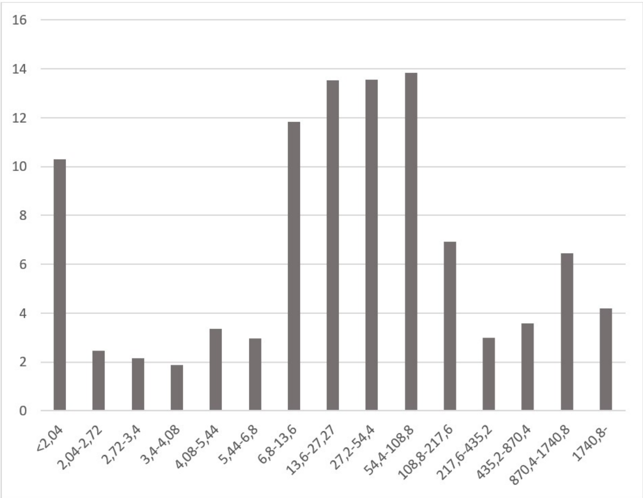

Fig. 3-12: Percentage distribution of total deliveries of oil and gas fields recorded in the USA according to the categorisation of ton/day production

According to the delivery range of oil wells in conformity with the data of EIA the average delivery between the lower and upper limit of the range multiplied by the number of wells I calculated in the rate of the total gas flaring data of the different categories of production places in 2016. The producing countries categorised as excellent (up to 0.5 %) and good (up to 1 %) were left out of the survey since only a very little number of the technical developments constituting the scope of the survey are missing in these countries. The data of the 5 countries categorised as catastrophic was also left out of further analysis since the public situation in these countries do not provide a development environment expected by international standards. On the basis of this, put of the total amount of 146 billion cubic metres of gas released or flared in the 44 examined countries in 2016, I made calculations for the utilisation of 132.7 billion cubic metres per annum. Ignoring the high number of small size wells (362.4 thousand such oil wells are operated in the USA according to the figures of the EIA) producing 0-15 barrel equivalents per day, I used 89.7 % of the production for further calculation. (See statistics based theoretical calculations Annex I B/10 – B/15).

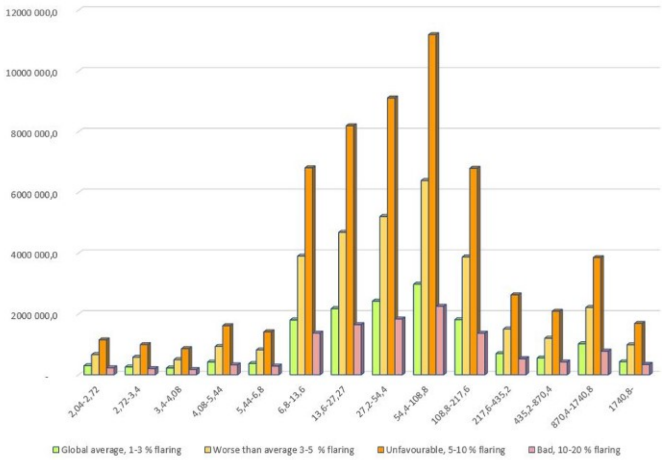

Fig. 3-13: Retrievable gas calculated on the basis of well size and flaring quality, thousand cubic metres per annum TNm^3/a)

The specific investment costs based on the well sizes, multiplied by the total gas amount data, summarised on the basis of 2016 classifications and add a 33 % capacity excess as an average target value, delivered the conclusion: a total of EUR 216.5 billion investment may be necessary to avoid most of the 119 billion cubic metres of routine flaring. (See Annex I Table B/7, B/16).

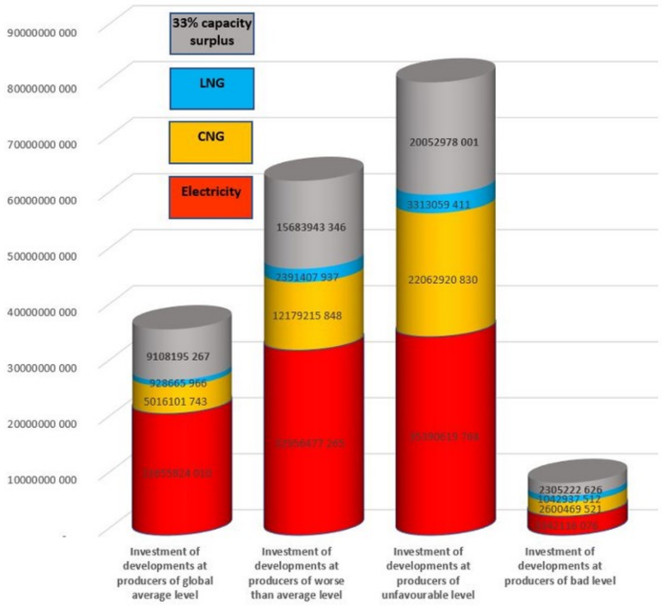

Fig. 3-14: The total investment of avoiding flaring, based on the global production and converting it into energy source, is € 216.5 billion divided according to the routes and the quality of flaring and adding the cost to cover 33 percent excess capacity development

In parallel with the result, in the first nine months of 2017, Europe imported 345 billion cubic metres of natural gas [14], the value of which is € 24.5 billion at the stock exchange (UK

NBP, GBP price of April 2018 [15]). It means that at the current prices, the development would return after 25.5 years of operation ignoring the maintenance costs. The situation in real is somewhat better, because by producing CNG or LNG we receive from natural gas a transport fuel, of which even the wholesale pricing is much higher than the listed commodity. LNG delivered directly to the consumer or to the filling station in Europe, can be calculated at the net wholesale price of € 600/t and the price of CNG is worth keeping at the same level, even if it is more expensive to transport. It means, that out of 119 billion cubic metres, 85 billion cubic metres can be sold as fuel (the calculation resulted in 75.2 % CNG and 24.8 % LNG according to the distribution of quantity), therefore € 36.6 billion worth of fuel can be sold. Beside of CNG and LNG, approx. 147 TWh electric power can be marketed, or the purchase thereof can be avoided from the producer, of which the PAN-EU Q4 2017 [14] average wholesale price is € 7.3 billion. The above results of course depend on the market, so the result may only become valid for all the examined producer countries, by additional footnotes.

In that case, instead of avoiding the flaring of 119 billion cubic metres, only aim to implement developments for transport fuel, the financial return comes closer. The total investment value for the 85 billion cubic metres remaining after selecting the from the above investment the CNG and LNG pathways, calculated to be € 76.5 billion, included the 33 % capacity surplus. This may practically return by the revenue of only 2 years.

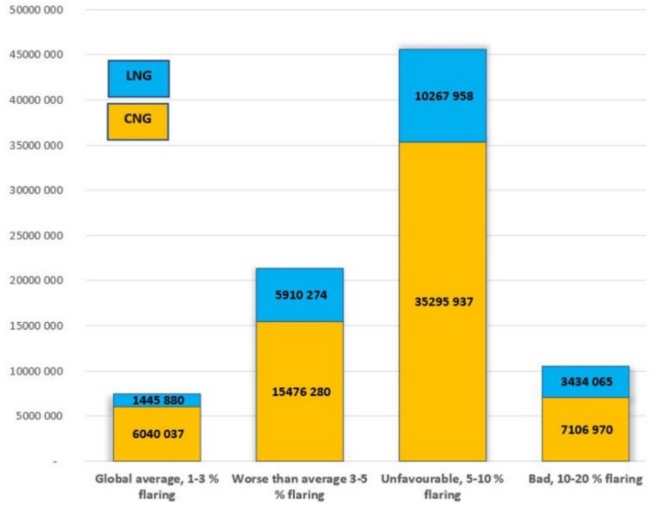

Fig. 3-15: Amount of gas flaring avoidable by investments for transport purposes calculated on the basis flaring quality, thousand cubic metres per annum (TNm^3/a)

Another important supplement to the calculation is that the system must become users for consume the fuel of course. The above 85 billion cubic metre, equal to 61 million tons of natural gas per annum is not less energy than 16.5 times of conventional fuel used in Hungary today. The cost of developing the related infrastructure and the preparation of consumers must also be calculated. Nevertheless, it must also be taken into consideration that replacing traditional fuels by 61 million tons of natural gas fuel will reduce the amount of CO_2 emitted through the exhaust pipes by close to 35 million tons yearly. So on the one hand avoiding the flaring of 61 million tons results 3 mt in methane emission decrease and 147 million tons of CO_2 emission decrease (calculated at 95 % flaring efficiency) while the vehicles pollute another 35 million tons CO_2 less to the atmosphere, resulting in a total of 182 million t less CO_2 emission per annum. Referring back to the introduction of this paper, the deficit of the annual CO_2 balance is 2.2 Gt/annum, what is not more than 12 times more than this. Beside of, the amount that can be saved by using the associated gas of oil extraction as fuel instead of flaring is one third of the 10 mt deficit of the methane budget.

3.3 Gas transmission, storing, distribution and utilisation systems

The natural gas consumption of the world will be 43 % higher by 2040 than it was in 2015 says EIA [7] and ExxonMobil [6], the latter indicating 21 % higher value already by 2025. Half of the increase in consumption is due to electric power production which increase will exceed the growth of nuclear power generation to a little extent as well, and outperforming the combined expansion of renewables too, according to the prognosis. In addition to the construction of the required capacities, the intense growth may also ensure the modernisation of significant numbers of supply systems and thus the reduction of methane losses. The increasing demand also ensures the smooth marketability of the CH_4 which performed by ecological developments through avoided emission.

The ageing of the systems and the materials used in the construction of early transmission infrastructure embrace the possibility of gas leakage. In the description of the natural gas infrastructure modernisation programme of the United States [17], out of the total amount of 2.06 million km main transition and distribution pipes in 2015, the amount of cast iron was only 42 thousand km, untreated steel pipe was 64 tkm and other galvanised steel without additional finishing was 25.6 tkm (all this refers to less than 12 inches dia.). The renewal process has been continuously delivered according to the data presented since 1990 and the amount of critical pipes has decreased to half. In the report the chief engineer of State Pennsylvania [19] stated the rate of cast iron pipes to be replaced is higher (27 %) under their management (5,800 km) and the untreated steel pipe (14.4 thousand km) in the distribution network, but these pipes are responsible for 95 % of the gas leakage. This presentation took place in 2007, according to the data found, so the two reports may not cover each other in time, but in 2015 [17] the length of critical pipes in Pennsylvania was already 4.3 thousand km / 13 thousand km. According to the inventory of the Environment Protection Agency (U.S. EPA) the 731 mt anthropogenic methane emission of the US constitutes 11 percent of the total greenhouse gas emission, a quarter of which is occurred by the oil and natural gas industry. The natural gas distribution system is responsible for 1.5 percent (11.1 mt) of the total emission and half of that is caused by the transmission and distribution pipeline operator sector. 5.5 mt natural gas is lost in the distribution pipelines per annum at 27,244 bcf consumption which equals 553 mt natural gas. The replacement of pipes is planned for $ 1 million per mile at least in several sources [17, 19] i.e. the necessary modernisation of the distribution pipelines means at least € 0.5 million per kilometre. The replacement of 106 thousand km requires € 53.5 billion expenditure by a statistical approach. Divided for 20 years' gas saving, avoiding methane gas emission costs 0.35 €c/m^3 from which the investment will not turn into positive return even after deducting the sales price.

The study analysing the Ukrainian distribution system [16] relying on Eurostat data, describes the gas loss of the EU and the situation of certain member states and Ukraine. However, the concept of gas loss does not cover only the gas loss arising from the porosity of the transmission and distribution system but also measurement errors and theft. The example of Ukraine is extremely apparent as the 2.6 % average loss was in the range between 0.1 and above 6 percent in 2014 among the 41 gas distribution companies. According to Eurostat data, this value is around 1.7 % in Hungary too; approx. double of the EU average.

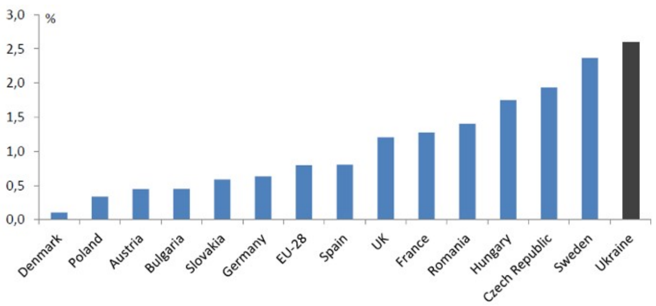

Fig. 3-16: Diagram presenting the gas loss of the gas transmission and gas distribution pipelines per transmitted amount in European countries [Eurostat data]

The loss of main transmission lines is an important question especially if so much gas is transmitted as in the Russian pipelines. As the latest available study, the 2007 publication of the Wuppertal Institute reported [18]; several international groups had surveyed the condition of the Russian Northern and Central pipeline. Russia has approx. 150 thousand kilometres of high capacity transmission lines. The approx. 5,000 km transmission from the Western-Siberian extraction sites and the Central-European distributors mostly takes place on pipelines constructed between the 1960's and 90's and the compressor stations are of similar age too. Measurements made in the second half of the 90's indicated almost 1 percent loss. Nevertheless the study notes that the documentation supporting the data is "somewhat" deficient.

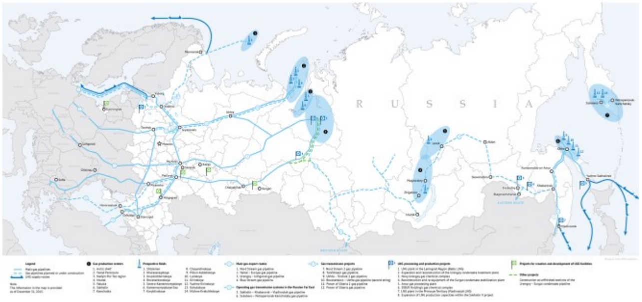

Fig. 3-17: Russian transmission line system in 2015 [Gazprom]

As a result of the survey, a total amount of 3.38 billion cubic metre of methane release, i.e. 2.4 mt was indicated for 2003. 55 percent of this arises from the leakage of compressors and only 11 percent from the leakage of the pipeline while 17 percent of the total emission can be reduced by pipeline repair operations. The almost 50,000 cubic metre annual loss on each MW compressor capacity is due to the old equipment and is many times more than the industrial standards. The measurement resulted in 2,425 cubic metres loss per kilometre of the pipeline per annum while repair and maintenance shows 3,749 cubic metres. In that year Russia exported approx. 133 billion cubic metres to Europe and Turkey (it means that the transmission system resulted in 2.5 % emission). Russia achieved records in gas transmission in 2017 after 2016 again, exceeding 190 billion cubic metres. In the event that no technological development was achieved in nearly 15 years in the Russian transmission system, the methane loss related to the European export may have been increased by 1 mt.

Gazprom manages 575 thousand km distribution pipelines in Russia [20] three quarters of the entire Russian network. According to the measurements of Gazprom in 2000, the emission of the network was 232 mt CO_2 equivalent including the 10 billion cubic metres of methane escaping. Other calculations add up the recent CO_{2e} footprint of Russian gas industry activity to 300 mt. The IEA study describes ambitious Russian gas loss reduction objectives. The 2004 report of the Russian gas sector indicated 298 mt CO_2 equivalent emission from which the methane loss of transmission lines and compressors was 6.2 billion cubic metres and the loss of the supply system reached 5.3 billion cubic metres. On the contrary, the objectives for 2012 intended to reduce methane emission to 5.1 billion cubic metres (minus 4.9 billion cubic metres from 2000). The plan presented the following notable numbers.

687.4 billion cubic metres of gas was transmitted on Russian high pressure transmission lines in 2004 (i.e. the loss was 1.64 %) to 2,400 km to the Russian and to 3,400 km to European customers on average. Over 4,000 machines (44.2

GW total capacity) of 263 compression stations provided the transmission pressure of the system. It is typical for the machines that according to 2004 Gazprom data, 13 % was over 100 thousand hours of uptime and another 49 % was over 50 thousand hours. This age is not only problematic because of the leakage but also because of the approx. 28 % average efficiency. To compare, TransCanada indicated the average efficiency of transmission compressors in Canada at 35 percent for the same year. According to the estimation in 2002, two third of the transmission lines are from times before 1973 while, based on other data from Gazprom, 58 % of the gas transmission lines was older than 20 years in 2004. The methane emission to be avoided in relation with gas transmission in the modernisation plan is 2.6 billion cubic metres (by replacement of compressors, introduction of advanced maintenance technologies and cleaning the pipelines) and the amount of gas used by flaring shall be reduced by another 7.2 billion cubic metres (from 40.8 billion cubic metres) thanks to more efficient operations. Avoiding the emission of 1 billion cubic metres of methane was seen as possible by 2012 as a result of decreasing the leakage in the distribution system (from 5.3 billion cubic metres). According to the IEA study many times more money was spent in the five-year reconstruction program between 2002 and 2006 than in the previous period, i.e. $ 8 billion was spent on these developments, closing $ 2.5 billion expenditure per annum by 2004.

Considering the missing data and report, the success of the programme achieved by 2012 is difficult to assess. The 2016 Environmental Report [21] published by Gazprom indicated the total hydrocarbon emission of the Gazprom Group at 1.6 mt in 2012 and the methane emission is only a part of that. The figure does not correspond to the emission levels concluded from other results, e.g. IEA survey (since the methane only figures in 2004 indicated five times higher value). Nevertheless the company reported another 9 percent reduction of hydrocarbon emission between 2012 and 2016. It can be read in other series of data that the CO_2 equivalent emission related to transmission was reduced from 106.2 mt to 82.2 mt in this period presenting significant improvement (although the data cannot sufficiently cover each other) compared to the 174.4 mt CO_{2e} emission value estimated for 2004 [20]

The IEA report prescribes saving 3.5 billion cubic metres of gas (emission and use together) for 2004, pointing out that the modernisation programme may be accompanied with extremely favourable financial return. The revenue from the sales of gas in the programme provides 3 years of return on average for the developments.

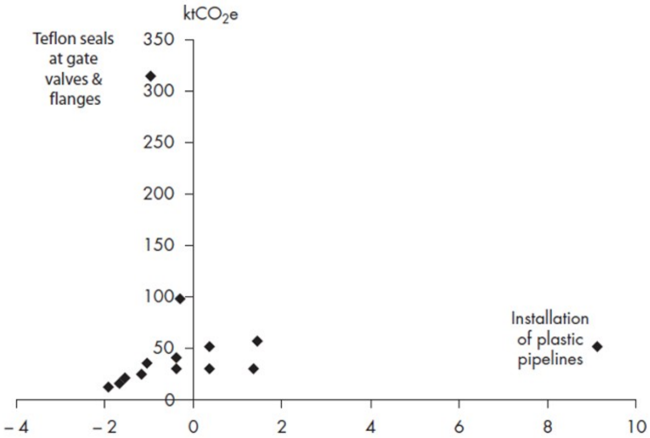

Fig. 3-18: Reducing the leakages of the gas transmission system has mostly positive economic results, IEA concluded in the development programme survey prepared for the Kursk region

To feel the size of the methane emission reduction plan outlined by IEA on the Russian development programme until 2012, we must note, that it is over one third of the 10 mt deficit of the Global Methane Budget (written in the introduction). If we add the amount of gas, which can be gained by the efficiency improvement through changing the old compressors, we conclude 12.1 billion cubic metres of methane, i.e. 1.5 years' gas consumption of Hungary.

Statistically, it can be summarized from the above data and figures that the amount of methane emission resulting from the leakage of transmission and distribution pipelines is approx. 1-2 percent of global gas consumption, most probably close to 2 percent. Knowing that the Canadian transmission and distribution system may have achieved 0.1 % loss already in 2001, developments in this field driven by environment protection and economic considerations, may lead to approx. 1 percent decrease of emission compared to the present level in the gas transmission and gas distribution systems of the world. On the basis of 3,630 billion cubic metres [22] of global natural gas consumption in 2016 this could drive to minimum 30-40 billion cubic metres (21.5-28.6 mt) methane emission decrease. At mean value, the 30-40 billion cubic metres of methane is a quarter of the total 105 mt CH_4 emission related to fossil fuels and one third of the 79 mt reported methane emission of the oil and natural gas industry.

Further increasing the efficiency of equipment may result in significant saving too, which may be partially implemented together with developments to eliminate leakages. Assuming that the average efficiency of the current global transmission line compressors reaches 33 %, achieving 38 % average efficiency may be set as a realistic objective in this field. Starting from the 2004 Russian data (~6 % gas consumption in transmission), the total energy used for transmission may be reduced from 5.04 % at 33 % efficiency to 4.38 % gas usage at 38 % efficiency in total, which is not less than 24 billion cubic metres decrease in global gas consumption. This improvement results another 47 mt CO_2 emission decrease.

The Russian survey serving a good example, that in case of high loss, the technical developments aiming to avoid it will make a financial return in a short period. Naturally, fixing small leakages and smaller efficiency improvements resulting higher specific costs and longer return times. Therefore, we cannot undertake to provide global expenditure analysis in this field based on literature.

3.4. Potential in avoiding methane emission in the energy industry

To sum up the conclusions of this chapter so far, we may arrive to the following results.

The technological and economic possibility to avoid the emission to the atmosphere of the Earth and use 18.9 mt of methane related to coal mining.

The use of 119 billion cubic metres of gas, equal to 85.3 mt methane seems to be economically viable from the amount currently flared in oil and gas extraction. The natural gas-based use for transport purposes may be 85 billion cubic metres from this (119 billion cubic metres), therefore the emission of 3 mt CH_4 and 182 mt CO_2 arising from flaring can be avoided.

Developments to eliminate the losses of the natural gas transmission and distribution system may result in avoiding the emission of 25.1 mt methane. Efficiency improvements can evade the use of 17.2 mt methane, i.e. 47 mt CO_2 emission decrease may be achieved.

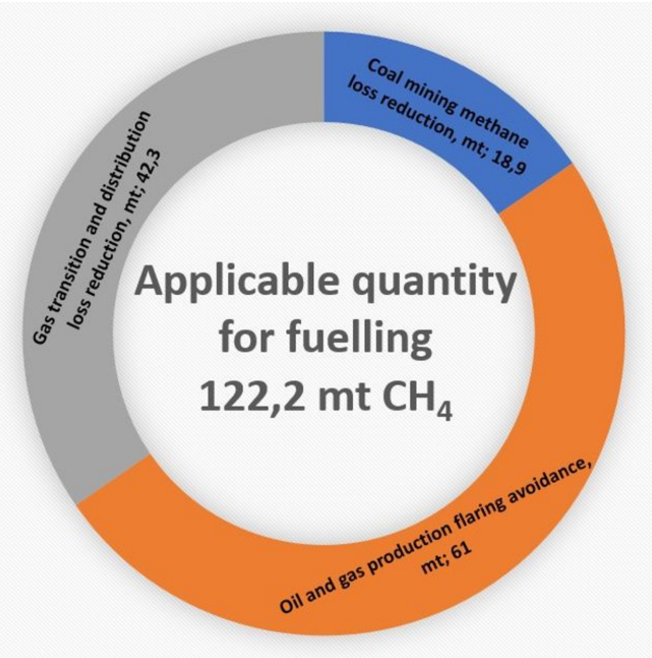

Fig. 3-19: The development of the production and distribution of the three fossil fuels altogether may result a reduction of 122.2 mt natural gas loss and fuel for transport

By the joint development of the three fields of the energy sector, focussing on the progress of using methane for transport purposes, we can calculate with 122.2 mt methane used as fuel. The 105 mt methane emission caused by the energy industry written in the introduction may be reduced by 47 mt in total and another 229 mt CO_2 emission to the atmosphere may be avoided along use for transport purposes. The improvement of CO_2 balance arising from the less CO_2 intensively burning methane instead of the crude based fuels, the amount of which is in the range of 30-65 mt (subject to the increase of efficiency of average gas engines, median value of 47 mt CO_2 emission avoidance used later). (See Annex I Table C/1 – C/2).

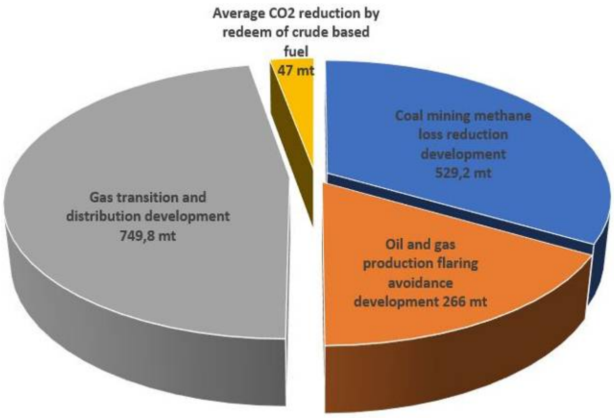

Fig. 3-20: Developments to avoid emission and the resulting decrease in greenhouse gas emission arising from the use of the natural gas obtained as fuel may reach 1,592 mt CO_{2e} greenhouse gas equivalent

It can therefore be concluded that by the development of our energy systems and using for transport purposes, the annual balance of greenhouse gas emission may improve by 1.59 $GtCO_{2e}$ which is not less than 72 percent of the annual average 2.2 $GtCO_2$ greenhouse gas balance deficit.

4. FUTURE VISION OF THE USE OF METHANE IN TRANSPORT

To answer the question whether the global transport use for 122.2 mt methane or even higher amount can be developed, the market opportunities must be examined and the economic bases of conversion must be surveyed. This chapter looks for the answer to this question.

4.1. Road use of CNG and LNG fuels

Looking at road vehicles from the side of the amount used we can form an image along the bottom-up approach.

Possibilities of spread and consumer characteristics must be examined along categories.

Table 4-1: The road vehicle categories identified as consumers and the average mileage and fuel consumption data taken into consideration in the calculations

#	Vehicle category	CNG/ LNG	Specific consumption [kg/100km]	Annual mileage [km]	Annual consumption [t]
1.	M1 – Passenger car	CNG	5.5	20,000	1.1
2.	M1 – Taxi	CNG	6	80,000	4.8
3.	N1 – light commercial vehicles, vans below 3.5 t	CNG	7.5	50,000	3.75
4.	N2 – lorries between 3.5 and 12 t	CNG	13.5	80,000	10.8
5.	M3/I,II – public transport service bus	CNG	45.0	80,000	36.00
6.	M3/III – long distance bus	**LNG**	25.0	100,000	25.0
7.	N3 – Communal and distribution trucks	CNG	40.0	50,000	20.0
8.	N3+O4 – Long haulage HDV	**LNG**	25.0	125,000	31.25

Estimations may be prepared through examining the statistics and spreading scenarios available for global spread. The International Organization of Motor Vehicle Manufacturers (OICA) presents the change of the number passenger cars and commercial vehicles between 2005 and 2015 and the sales figures until 2017 by continents and countries [39]. Additionally the latest manufacturing data is also available divided in the categories of passenger cars, light commercial vehicles, buses and heavy trucks. It is necessary to describe some of the figures and conclusions drawn to interpret further calculations. (See detailed statistics from global vehicle markets and productions in the Annex II)

1.28 billion vehicles were registered in 2015 and an annual average growth of 3.7 % was achieved in ten years. 947 million of this is passenger cars showing 3.78 % of increase on average since 2005. The global passenger car market grew to 70.8 million by 2017 from 45.4 million 12 years before representing 3.84 % expansion for the same years. Meanwhile the market of commercial vehicles expanded from 20.4 million to 26 million including light and heavy duty vehicles (+56 %) and buses (+27.3 %) as well. The North American figures (NAFTA) but especially the data from the USA and Canada must be understood since there is a strong shift between the categories of passenger vehicles and commercial vehicles (PV and CV) compared to the rest of the world. The statistics including Mexico show 13.5 million commercial vehicles sold while 7.8 million vehicles were registered in the line of passenger cars in 2017. The number of 468 thousand heavy vehicles indicates that approx. 13 million of the 13.5 million commercial vehicles are light commercial vehicles including the pick-ups called truck and the large off-road vehicles; the number of these produced in the NAFTA countries is 11.3 million, i.e. the import from other continents is close to 1.7 million. 174 thousand heavy vehicles were produced in the EU and 13.6 thousand buses (the production of this category is not registered separately in the NAFTA region). The EU statistics present a production of 1.6 million light commercial vehicles and the size of the entire commercial vehicle market was 2.5 million, while the total vehicle market was 18.1 million in 2017, a little below the 21.2 million result of the NAFTA market. All this knowledge is needed in estimating fuel consumption data.

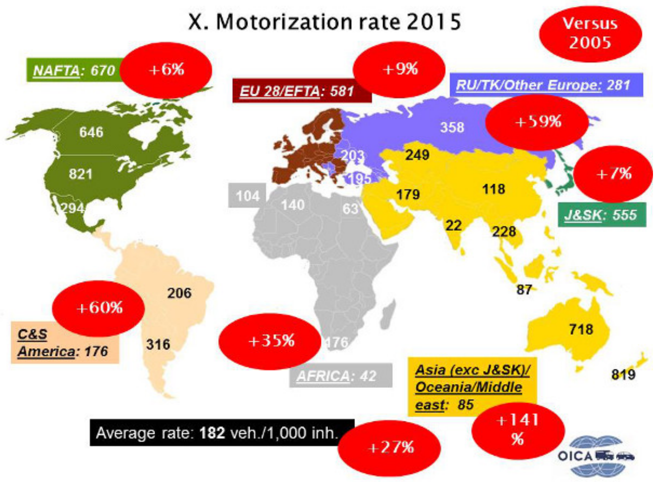

Fig. 4-1: Number of road vehicles per 1,000 persons in 2015, change since 2005 in red [OICA]

The rate of expansion of the vehicle market in the past decade will surely be continued so the calculating with 3.8 % annual growth of production and sales capacity, the number of vehicles forecasted by 2030 is 2.2 billion. The increase of the number of vehicles is primarily provided by the regions, where car penetration is currently lower. This is well justified by the expansion of the Chinese and Indian markets. The population of China is not only the largest in the world but it has grown to become the largest car market of the world in a few years by now. While only close to 4 million passenger cars were sold in 2005, 6.3 times more, i.e. 25 million were sold in 2017. The car market of India only grew modestly in shade of the Chinese market, since it reached 2.9 times the size seen in 2005 and with its 3.2 million size is just behind the 3.4 million units sold on the largest European market, Germany. The motorization rate of these two countries was 118 and 22 cars in 2015 for 1,000 residents, which is only a fraction of the 500-800 units in the economically developed countries. In addition to Asia, in case of continuing economic growth, the strong increase of the number of vehicles should take place in South America and Africa.

Fig. 4-2: Volkswagen Polo TGI, equipped with a modern 1,0 litre turbo spark ignited engine, optimized for CNG [image: Volkswagen]

In the gas-fuelled vehicle spread plan of NGVA calculated for the EU [38] forecasts 15 million vehicles. The estimated penetration of CNG or LNG fuelled vehicles is 5 % in passenger cars, 11 % in light commercial vehicles, 6 % in heavy trucks and 16 % in buses. In case of fulfilling these objectives, the annual gas fuel consumption will increase to 54.7 billion cubic metres in the EU. (See also Annex III Table D/11 – D/14).

Table 4-2: Estimated number of unit considered in the study on the basis of own expert assessment, slightly differing from the publication of NGVA Europe

Vehicle category	CNG/ LNG	Specific consumption [kg/100. km]	Annual mileage [km]	Annual consumption [t]	Registered in 2030 [pcs]	Total annual consumption [t]
M1 – Passenger car	CNG	5.5	20,000	1.1	12,500,000	13,750,000
*M1 – Taxi	CNG	6	80,000	4.8	500,000	2,400,000
N1 – light commercial vehicles, vans below 3.5 t	CNG	7.5	50,000	3.75	1,500,000	5,625,000
*N2 – lorries between 3.5 and 12 t	CNG	13.5	80,000	10.8	25,000	270,000
M3/I,II – public transport service bus	CNG	45	80,000	36	147,000	5,292,000
*M3/III – long distance bus	**LNG**	25	100,000	25	3,000	75,000
*N3 – Communal and distribution trucks	CNG	40	50,000	20	25,000	500,000
N3+O4 – Long haulage HDV	**LNG**	25	125,000	31.25	350,000	10,937,500
Total						38,849,500

*As opposed to the objective of NGVA Europe for vehicles, the categories have been further divided.

In contrast with the target values of NGVA Europe on spread in the global distribution of vehicles forecasted for 2030, 33 % penetration for taxis and also higher, 12 % spread for long haulage heavy vehicles is taken into consideration, based on certain estimations which predict an approximately 30 % market share in the semi-trailer sector by 2030, where the fuelling infrastructure exists. In this vehicle category, the acceptance and support of LNG-fuelled vehicles is very high, life cycle is short, and therefore penetration growth can take place very rapidly.

Table 4-3: OICA statistics on the global number of vehicles and estimate for 2030 including gas-fuelled vehicles (in italics)

Vehicle category	Global number of vehicles 2015 [pcs]	Global production 2017 [pcs]	*Global number of vehicles 2030 [pcs]*	*Global number of NGVs 2030 [pcs]*
M1 – Passenger car	947,080,000	73,456,531	1,657,390,000	86,299,500
out of this – passenger car	940,080,000	71,456,531	1,645,140,000	82,257,000
out of this – taxi	7,000,000	2,000,000	12,250,000	4,042,500
M3 + N1 + N2 + N3	335,190,000	23,846,003	561,443,250	64,097,950
M3 – Bus	4,490,000	316,258	7,857,500	1,257,200
out of this M3/I, II. public transport service bus	3,700,000	266,258	6,475,000	1,036,000
out of this M3/III – long distance bus	790,000	50,000	1,382,500	221,200
N1 – LCV, vans <3.5 t	272,500,000	19,387,815	476,875,000	52,456,250
N2+N3 – H&MDV	58,200,000	4,141,930	101,850,000	10,384,500
out of this – Long haulage HDV	40,700,000	2,941,930	71,225,000	8,547,000
out of this N2 – MDV 3.5t<m<12t	9,000,000	600,000	15,750,000	945,000
out of this – distribution &communal veh.	8,500,000	600,000	14,875,000	892,500

Table 4-4: Amount of fuel consumed by the estimated number of NGV vehicles in 2030

Vehicle category	Specific consumption [kg/100 km]	Annual mileage [km]	Annual consumption [t/j]	*Global number of vehicles 2030 [pcs]*	*Global number of NGVs 2030 [pcs]*	*Global annual consumption 2030 [t]*
M1 – Passenger car				1,657,390,000	86,299,500	
out of this – passenger car	5.5	20,000	1.1	1,645,140,000	82,257,000	90 482 700
out of this – taxi	6	80,000	4.8	12,250,000	4,042,500	19 404 000
M3 + N1 + N2 + N3				561,443,250	64,097,950	
M3 – Bus				7,857,500	1,257,200	
out of this M3/I, II. public transport service bus	45	80,000	36	6,475,000	1,036,000	37 296 000
out of this M3/III – long distance bus	25	100,000	25	1,382,500	221,200	5 530 000
N1 – LCV, vans <3.5 t	7.5	50,000	3.75	476,875,000	52,456,250	196 710 938
N2+N3 – H&MDV				101,850,000	10,384,500	
out of this – Long haulage HDV	25	125,000	31.25	71,225,000	8,547,000	267 093 750
out of this N2 – MDV 3.5t<m<12t	13.5	80,000	10.8	15,750,000	945,000	10 206 000
out of this – distribution &communal veh.	40	50,000	20	14,875,000	892,500	17 850 000
					150,397,450	**644,573,388**

Based on the result of the calculation line (see also Annexes Table D11-D14), the infrastructure network will be required to ensure the fuel supply of 150.4 million gas-fuelled vehicles globally by 2030. The annual amount used is 645 mt i.e. approx. 900 billion cubic metres. 42.3 % of the consumption is expected in the form of LNG which is 272.6 mt. The coming LCNG technology will probably change this rate of CNG and LNG use significantly because it is more practical to serve CNG fuel from LNG in many cases than using the traditional compressor technology. Such cases are for example 1. providing higher capacity demand sized for supplying fleets, 2. the availably gas pipeline capacity or pressure is insufficient or 3. the infrastructure becoming uncompetitive due to the high distance to the location of the planed station; any of such reasons may make the use of LCNG technology more favourable for investors.

For calculation the CO_2 saving possibility based on the amount of NG fuel used, it is worth to have the basis of the efficiency of the next generation engines from the actual research and development stage instead of the currently marketed ones. Considering that hybridisation spreading with the objective of improving the efficiency of the drive-chain is not connected to the fuel of the internal combustion engine, the gas engines will sooner or later be paired to the hybrid drive chain, just like the petrol or less frequently diesel engines. Therefore, this consideration is not included in determining the extent of CO_2 decrease.

Several researches are demonstrating that gas engines can reach the efficiency level of the advanced diesels in the category of road vehicle too. The latest published results of the HDGAS project stated a remarkable 14 percent CO_2 reduction compared to the industrial benchmark gas engine family, newly entering the market by optimized spark ignition engines [54]. Also a dual-fuel engine from the research provided good prospects, on the engine test indicated 45 % thermal efficiency, available at a wide range of load and this result is better than the current diesel benchmark [55].

Fig. 4-3: display of a next coming gas engine technology from FPT on the HDGAS Project closure event. The direct injected, crown-type ignited engine, variable valve timing engine runs in test benches with stoichiometric as well lean-burn principle and produce 2200 Nm, 370 kW beside of 14 % reduction in GHG, compare to the existing one [image: HDGAS Project]. Direct gas injection, as well pre-chamber solutions are coming, latest bench test results are demonstrating at small 1-1,5 liter engine category, that 44 % peak efficiency is possible, which goes above todays diesel values

Because of this, it is worth calculating with that CO_2 saving potential, which is coming out from the molecule, opposed to assuming the yet less significant CO_2 saving between the currently produced gas engine / diesel engine. It means that due to the better hydrocarbon relations of the energy source, the decrease of CO_2 is 25 % in the perfect burning process. The road transport sector will result in avoiding the emission of approx. 546 mt CO_2 by using an estimated amount of 645 mt natural gas in 2030 compared to the scenario without the alternative fuels. (See Annexes III Table D/20)

4.2. Possibility of using LNG in railway

While the bottom-up method brings acceptable results in case of road vehicles, it is almost hopeless to calculate with a similar categorisation in case of the railway or water transport sector. On the other hand, the bases for top-bottom planning are available. Transition to LNG fuel is qualified as a major achievement in both sectors like the stepping from coal firing steam machines to diesel engines happened. In addition to reducing environmental load, operators are driven towards LNG by economic interests.

In case of railway in the EIA survey, the seven major railway companies in the USA examined the chances of converting their diesel consumption equalling approx. 9.5 mt LNG. It has been concluded that the unit investment cost over $ 1 million [55] returns on more favourable energy prices, therefore the conversion may even take place quickly. In case of reference spread, the use of LNG is around 20 % by 2030 while in case of intense spread even 50 % offset may occur by 2030 and the conversion process may almost be completed in the USA around 2035.

Fig. 4-4: Beside of others Florida East Coast Railway employs LNG powered locomotives. It shows not only highly remunerative figures, but clean air and far lower engine noise level is also proved [image: Michael Maiullari/Trains Magazine]

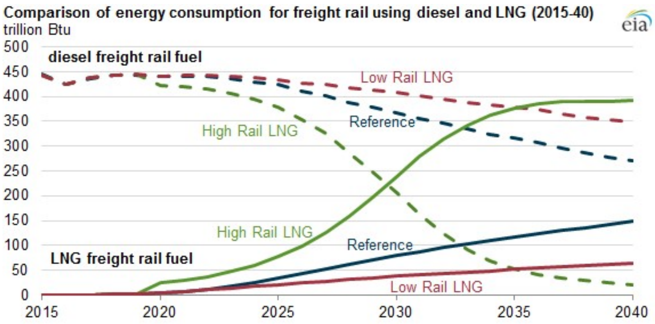

Fig. 4-5: The trend of the energy-mix at the non-electrified railway traction in the USA, according to the three scenarios of the EIA

Similar change is expected in case of the Russian railways as well, thanks to the policy framework which supporting the transform to gas fuel. The changeover from diesel to LNG fuel of the Chinese and Indian railways may bring even more intense transformation, where India has already taken the first steps too. Europe is expected to start this process after 2020 apart from some isolated experimental stages. To sum up, globally around 20 percent of the diesel fuelled railway traction is expected to be redeemed with LNG by 2030 along with air pollution, noise reduction and primarily economic interests.

Data can be studied in more details in the annually published handbook of the International Union of Railways and IEA [41]. Global railway energy consumption was specified in 2,200 PJ for 2015 out of this 56 % was the rate of oil-based energy sources. The most important 5 areas, the EU, the USA, Russia, India and China, constitute three quarters of the railway energy consumption and 82.2 % of CO_2 emission, i.e. the railway transport by the rest of the world does not achieve one fifth of the CO_2 emission.

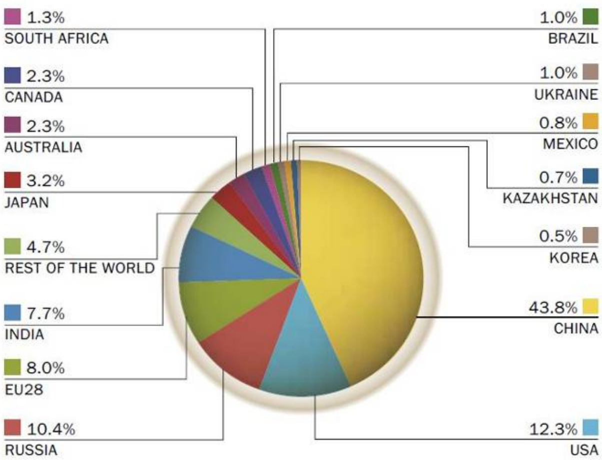

Fig. 4-6: The distribution of CO_2 emission related to railway transport in 2015 according to the major emitting countries, where greenhouse gas related to the consumed electricity and heat production is also indicated among the figures (Susdef, IEA (2017a))

The following details may be known about the five largest railway markets from the handbook.

Table 4-5: Data of the global and the five largest railway markets, 2015 [41]

Railway traction, 2015	Energy consumption [PJ]	CO_2 emission [mt]	Proportion of oil-based energy [%]	Oil-based energy consumption [PJ]	Proportion of electric power [%]	Electric power consumption [PJ]	Rate of electrified tracks [%]	Length of railway [thkm]
Global	2,200	336	56	1,232	38.8	853.6	31	
EU-28	269	26.64	31.8	85.542	67.6	181.844	62	350
USA	530	41	94	498.2	4.6	24.38	n.a.	460
Russia	246	35	27.4	67.404	72.6	178.596	63	123
India	179	26	66.2	118.498	33.8	60.502	62	123
China	461	147	29.3	135.073	48.6	224.046	46	144

The global energy consumption of railways did not change significantly between 2005 and 2015, thanks to the improvement of efficiency equalling the rate of growth of transport performance. On the contrary the total energy consumption in the EU decreased by approx. 15 percent while in India it increased by 50 percent. Transport capacity decreased in China by 2015 and consequently the energy consumption decreased by over 10 percent. Starting from all these, it seems to be logical to determine the expected amount of available LNG consumption with constant energy consumption data for 2030.

Table III-6: Energy data of the global and the five largest railway markets estimated for 2030

Railway traction forecast, 2030	Energy consumption [PJ]	Proportion of oil/gas-based energy [%]	Out of this proportion of gas [%]	Oil/gas-based energy consumption [PJ]	LNG consumption [PJ]
Global	2,300	56	20	1288.0	257.6
EU-28	269	31.8	12	85.5	10.3
USA	530	94	20	498.2	99.6
Russia	246	27.4	25	67.4	16.9
India	300	66.2	30	198.6	59.6
China	461	29.3	25	135.1	33.8

To summarise the result of the calculation; based on the redeem of approx. 20 % of global diesel railway traction by 2030, 5.72 mt LNG consumption is expected, which results in close to 4,8 mt CO_2 emission decrease (see Annexes Table D/15 - D/16).

4.3. Vision of LNG consumption in navigation

Companies follow two ways in navigation, especially in maritime shipping to comply with the stricter and stricter emission requirement with their equipment. The diesel engine may become acceptable by using the much more expensive (see 29. diagram drawn by DNV-GL [44]) low-sulphur diesel oil (registered as MDO or MGO in certain cases) instead of the heavy bunker oil (HFO or IFO 380 and IFO 180 according to viscosity), with exhaust gas recirculation (EGR) and/or scrubber which takes a lot of space from the cargo. All these are never returning expenditures, nevertheless causing increased fuel consumption therefore the CO_2 emission increases. Instead of this, there is great opportunity to move towards to LNG fuel. In addition to the obvious new shipbuilding, the retrofit conversion of the engine and ship to change operating mode may also be possible in most cases at younger vessels. This process has clearly started at marine navigation. The long, even 40-50 years life cycle of vessels with the long manufacturing times results a long way to convert the navigation sector. Additionally the dual-fuel burning process is a frequently chosen technology, burning either gas or even diesel fuel by compression ignition. If economic interest requires, the operator may even return to diesel during the long life cycle of the vessel.

Fig. 4-7: Five-year figures of bunker fuels, Brent oil and gas prices [52]

Looking at the data of MarineTraffic.com, they currently do the AIS following of 828,430 marine or river vessels in their system. This probably includes all larger vessels apart from small sailing ships and motorboats including "water buses" on the Danube irrespectively of whether they actively run in traffic or permanently stand. The International Maritime Organization (IMO) practically represents the entire global maritime shipping. Their third study on the greenhouse gas emission of shipping prepared in 2014 [42] provides detailed information about current and forecasted emission; 72.7 thousand active vessels are listed in their detailed table for 2012 in different categories. According to their analysis the amount of CO_2 emitted by international shipping was 796 million tons in 2012 representing 10 percent increase to the estimated 885 million tons in 2007 before the economic crisis. However, the forecast of IMO for the middle of the century shows at least 50 % but up to 250 % increase in the reference scenario thanks to the increase of shipping demand.

According to data examined in more details, the entire shipping industry emitted 938 mt CO_2 and by examining the CH_4 and N_2O emission, 961 mt CO_{2e} greenhouse gas in 2012. In six years' average, shipping caused 2.8 percent of the annual anthropogenic greenhouse gas emission. It is declared in the introduction of the study that in the examination of fuel consumption data the bottom-up and the top-bottom methodology shows relatively large difference in consumption and therefore uncertainty in CO_2 emission. The carbon dioxide emission of the entire shipping industry according to the top-bottom methodology is in the range of 739-795 mt while according to the bottom-up methodology it is between 915 and 1135 mt. According to these two methodologies respectively it covers approx. 247 mt and 325 mt average fuel consumption.

The bottom-up methodology allows for the estimation of the consumption and emission of vessel types.

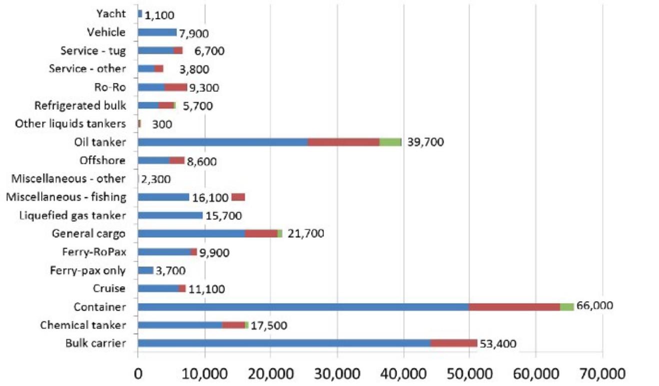

Fig. 4-8: Fuel consumption (in thousand tons) for 2012 examining each vessel type by the bottom-up method, including the consumption of the main engine (blue) auxiliary engine (dark red) and boiler (green) [42]

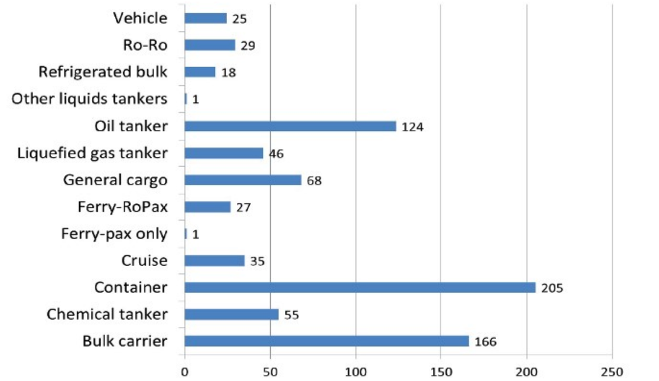

Fig. 4-9: CO_2 emission of international shipping (in million tons) by vessel types in 2012 [42]

To prepare the top-bottom survey, only the purpose of shipping (e.g. international, domestic or fishing) is available in addition to the amount of fuels consumed so it is not possible to provide a more sophisticated analysis.

Table 4-7: Top-bottom summary of CO_2 emission of maritime shipping examining individual purposes of shipping on the basis of registered fuel consumption in the period between 2007 and 2012 [42]

Marine sector CO_2 emission							
	Fuel type	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
International shipping	HFO	773.8	802.7	736.6	650.6	716.9	667.9
	MDO	97.2	102.9	104.2	102.2	109.8	105.2
	LNG	13.9	15.4	14.2	18.6	22.8	22.6
International total	**All**	**884.9**	**920.9**	**855.1**	**771.4**	**849.5**	**795.7**
Domestic navigation	HFO	53.8	57.4	32.5	45.1	61.7	39.9
	MDO	142.7	138.8	80.1	88.2	98.1	91.6
	LNG	0	0	0	0	0	0
Domestic total	**All**	**196.5**	**196.2**	**112.6**	**133.3**	**159.7**	**131.4**
Fishing	HFO	1.6	1.5	0.9	0.8	1.4	1.1
	MDO	17.0	16.4	9.3	9.2	10.9	9.9
	LNG	0	0	0	0	0	0
Fishing total	**All**	**18.6**	**18.0**	**10.2**	**10.0**	**12.3**	**11.0**
Total CO_2 emission		**1,100.1**	**1,135.1**	**977.9**	**914.7**	**1,021.6**	**938.1**

CO_2 emission of shipping by fuels in 2012 based on the IMO report:

HFO 75.57 %; MDO 22.03 %; LNG 2.41 %. Using that formula for perfect burning which applied by IMO (HFO: 3,114 $kg_{CO2}/kg_{greenhouse\ gas}$; MDO: 3,206 $kg_{CO2}/kg_{greenhouse\ gas}$; HFO: 2.75 $kg_{CO2}/kg_{greenhouse\ gas}$), the amounts of fired fuel are the following: HFO 227.66 mt. (9721.1 PJ), MDO 64.46 mt. (2771.78 PJ), LNG 8.22 mt (452.1 PJ). Consequently the replacement of heavy oil by LNG to some extent may be realistically planned. The use of high sulphur content HFO must be dramatically reduced along emission requirements while low sulphur content (LS) does not treat the NO_x and PM problem so LSMDO is only a partial solution. It is assumed that HFO will completely disappear from shipping before 2050 although IMO has much more careful estimates about this as the share of HFO fuel will be 40 % in 2050 even according to their high LNG spread scenario. The dynamics of conversion to MDO and LNG will change by time in favour of LNG due to better operational costs and the easer and simple availability of the infrastructure.

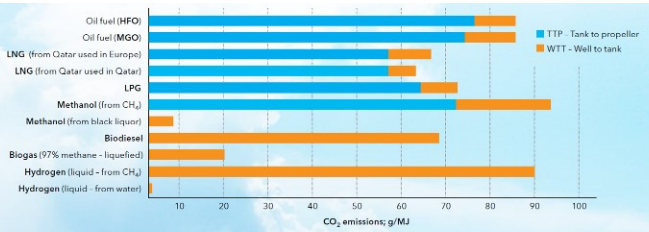

Fig. 4-10: Diagram of fuel alternatives ensuring DNV-GL emission reduction according to the WtW approach dividing the greenhouse gas emission of the vessel and related to the provision of the energy source [52]

The vision of the dynamics of the conversion is strengthened by the committed climate protection efforts of IMO which may result in further regulatory measures [45] in order to reduce the CO_2 emission of shipping by 50 percent by the middle of the century, supporting commitments of the Paris Climate Convention. The target value seems to be achievable at least for equivalent shipping quantities. The PERFECt LNG Ultra Large Container Carrier (ULCC) concept formed by DNV-GL with several outstanding participants is built on an LNG-fuelled gas and steam turbine-generator system drive principle. Compared to a conventional diesel drive, the vessel may achieve 50 % CO_2 reduction based on WtW. This is established so that the locally produced and filled LNG itself provides 27.5 % decrease while the connected steam generator system has 60 % efficiency compared to the currently outstanding 48 % efficiency of diesel engines and the redesigned main engines also run with 5 percent better efficiency than those of the currently operating vessels. Adding 3 percent better streamline and 5 percent better utilization results in halving the CO_2 emission, also practically eliminating sulphur, nitrogen and particle pollution. The new concept may significantly reduce the previously planned life cycle of operating vessels by its operation cost reducing capability and this facilitates the acceleration of spreading LNG.

Fig. 4-11: A retrofit bunkering ship by AGA, fuelling the hybrid-LNG powered Viking Grace Ro-Ro ship in Stockholm every morning. The Viking Grace has approximately 50 t daily consumption, while 150 t storage tank on-board. The refuelling takes less than an hour, including connecting [image: Author]

COmbined Gas turbine Electric and Steam (COGES) [62] called by GE as the future of drive-line system, also included in the PERFECt study. To use the thermal energy, a steam generator unit is connected to the gas turbine unit, to which a steam turbine generator unit is connected. The 30 MW system is approx. 60 percent smaller than two-cycle diesel engines of the same performance, resulting in no less than 4,000 square metres increase of cargo area; moreover it is also 40 percent lighter contributing to a significant increase of useful load.

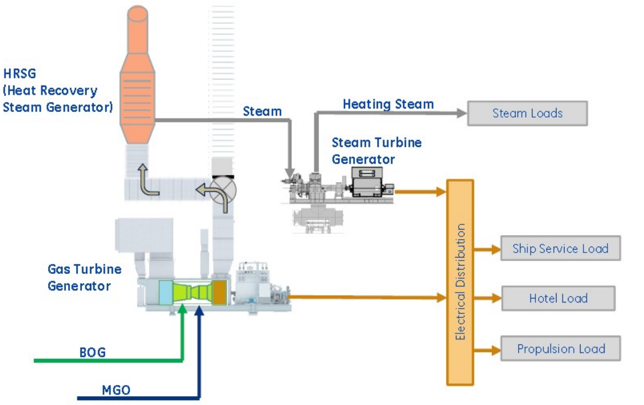

Fig. 4-12: The gas turbine in the GE COGES system in case can be operated with MGO bunker oil too, and the total efficiency can exceed 60 percent [62]

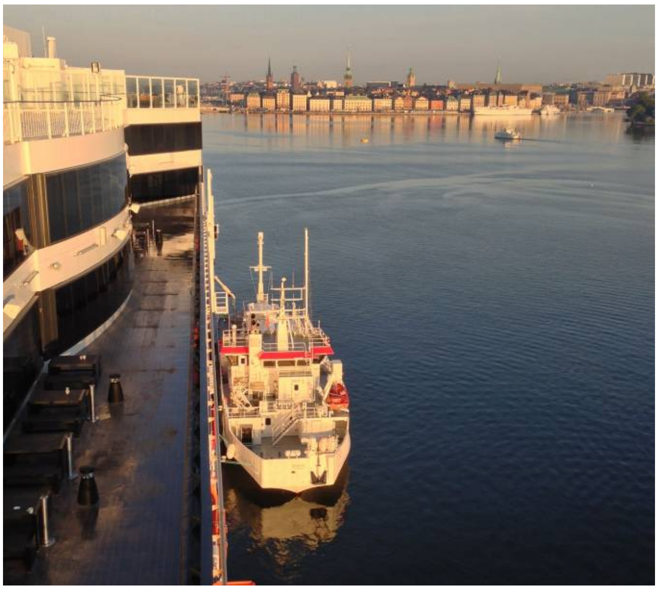

Fig. 4-13: The world first hybrid-gas powered Ro-Ro ship Viking Grace is being refuelled by the tailored bunker ship in Stockholm. The process is monitored from the bridge through computer as well via video stream [image: Author]

In 2014 DNV-GL [47] forecasted an exponentially rising curve of spread which seems to be fulfilled till now. According to the April 2017 data of LNG World Shipping the number of LNG fuelled vessel projects has come above 200 and there may be 129 marine vessels including the ones registered in 2017 which will be followed by another 43 already ordered vessels in 2018 and 28 more afterwards. All this does not include the number of LNG tankers where the gas engine would be the only natural solution and the conversion of the ones equipped with diesel engines seems to be practical in terms of operation. This is confirmed by the calculation of GE where in case of an LNG tanker vessel; $ 20 million operation costs can be saved with the COGES engine system in 20 years [62]. According to GIIGNL [53] there were 511 active LNG tanker vessels on the seas, out of which 28 as FSRU (Floating Storage Regasification Unit). The increasing international LNG trade is well illustrated by the fact that another 120 orders were placed, 72 of which will be delivered in 2018, twice as much as in 2017. 30 of the 511 vessels were out of use for reconstruction or other reasons.

Fig. 4-14: Size of recent LNG-fuelled fleet without the LNG tanker vessels and the inland water vessels, according to the DNV-GL survey [47]

Starting from division of vessel categories by IMO, the expected spread of LNG vessels can be refined by modelling. The acceleration of spread may be strongly influenced by the pace of return, which has several factors in addition to the price difference of fuels, like time spent on water or the nature of the shipment and the typical length of routes. Examining the potential spread by 2030 and by 2050 and consequently the rate of fuel consumption, it can be concluded that achieving 15 % and 30 % LNG share in row presents a significant result since it requires 7.5 thousand vessels in the fleet of 72.7 thousand by 2030 and 16 thousand by 2050. In case of constant number of vessels, utilization and fuel consumption, according to the simulation the alt-fuel modal split results in avoiding 34.76 mtpa (-4.1 %), and 70.17 mtpa (-8.3 %) CO_2 emission respectively by that two planning dates. In the event that the increase in the number of vessels and the performance of the navigation pushing the CO_2 increase by 50-250 %, as it is forecasted by the IMO report for the mid-century under the business-as-usual scenario, the result of LNG consumption and the belonging CO_2 reduction will differ in a very wide range. The energy-based total fuel consumption in this case will increase in the range between 63.6 % and 281.7 % by the middle of the century (with the previous 30 % LNG spread rate for 2050). It means that the registration of new vessels will be accelerated (amazingly in the latter case) and the hastened shipbuilding may significantly improve the share of the efficient driveline solutions, taking better care of the environment.

As a result of the simulation we have 31.4 mt LNG used by 2030. The calculation indicates 63.4 mt use by 2050 with unchanged activity while the 50-250 % CO_2 increase scenario for the sector by IMO, indicates between 103.7 and 242 mt LNG use. Calculating with “only” 15-25 % increase in the sector by 2030 due to the exponential spread curve, 36.1 - 39.3 mt use of gas is forecasted, resulting 37.7 - 41 mt CO_2 emission avoidance.

4.4. Natural gas consumption potential in the transport sector

Summarising the above results it can be concluded that transport may be converted into a significant gas consumer without hindering the feasibility of apparently overheated expectations of e-mobility. The road transport sector may provide 644.6 mt gas consumption by 2030 along the expected spread scenario of which at least 272.6 mt will be filled into the vehicles in the form of LNG. This results in avoiding 545.7 mt CO_2 tail-pipe emission.

5.72 mt LNG consumption is expected in the railways by 2030, resulting in 4.8 mt CO_2 emission decrease compare to the diesel traction.

The vision for marine and inland water shipping forecasts between 36.1 and 39.3 mt (med. 37.8 mt) LNG use, resulting in 37.7 – 41 mt (med. 39.3 mt) better CO_2 balance than without the alternative fuel.

To sum up the entire transport sector may become able to use 682 mt of gas by 2030 which means 0.59 Gt less tail-pipe greenhouse gas emission than in case of the scenario without the alternative fuel. (See Annexes III Table D/20)

By the technological development of the energy system the possibility of avoiding the loss of 122.2 mt methane in an economically sustainable way is mapped up. This results an emission avoidance of 47 mt methane and 194 mt CO_2 i.e. 1.59 Gt carbon-dioxide equivalent greenhouse gas potential decrease.

It is worth stopping for a moment here. The amount of CO_2 deficit described in the introduction has been 2.2 Gt for years which can be reduced to zero by 2030 (1,59 Gt CO_{2e} + 0,59 Gt CO_2) by converting transport to natural gas fuel. In this way the transport will provide a consumer market for the losses or if you like it otherwise: for the elimination of the defects of the energy sector.

5. SUPPLY OF THE NATURAL GAS CONSUMPTION DEMAND IN THE TRANSPORT SECTOR

The previous figures pointed out that in addition to the methane losses collected, the transport sector may become the user of another 559.5 mt methane (total 681.7 mt) by 2030. The least frequently asked question is what sources can cover the increasing demand of transport for methane, considering that according to the uniform opinion in the energy industry the resources can provide natural gas supply for hundreds of years with the currently available and tested production technology. The natural gas production of the world achieved 3551.6 billion cubic metres (~2.63 Gt, using the conversion factor of the publication) [56] in 2016 with 2.4 % average growth in the past 10 years. The 560 mt extra demand for transport by 2030 equals 21 percent of the production in 2016. In the forecast of ExxonMobil [6] 7.9 % annual increase of gas consumption is predicted between 2015 and 2025 for the transport sector and somewhat lower growth (+5.1 %/a) is calculated after that. An exponentially growing consumption is more probable than this scenario, which can be described as follows: the exponential growth starting in 2020 will boost to 30 percent. (See Annexes IV Table E/1) As a result of this the consumption demand seems to modify the 2.4 % average extraction growth upwards which will rise above 3 % from 2025 and will exceed 6 percent annually by 2030. The result of the study shows 5.66 trillion cubic metres annual production, compare to the 4.95 trillion forecast of ExxonMobil. The different is to be reduced by the possible renewable methane sources, how it is following next.

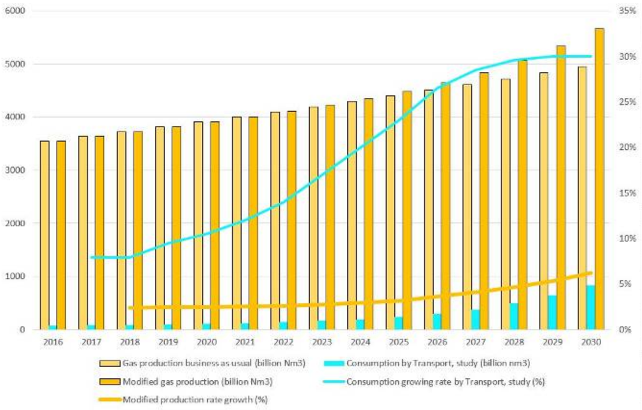

Fig. 5-1: Vision for the increase of global natural gas production due to demands of transport, according to BA model and the expected spreading tendency model of gas-fuelled transport

The source for the increase of gas consumption in transport is supplied by the existing and building capacities of the global gas market as well as partially by bio methane and even Power-to-Gas technology producing synthetic methane from completely carbon-free primary energy sources. The renewable and carbon-free methane source routes can multiply the possibility of CO_2 reduction so that they provide nearly zero CO_2 balance for the fuel on WtW basis.

5.1. Utilize of renewable methane sources

Although the amount of available bio and synthetic methane fuel is far below the almost endless resources of fossil methane, it is worth focusing on this opportunity in order to develop low carbon and carbon-free transport and it is necessary to calculate with additional costs in order to implement the more expensive technologies.

According to the figures from the introduction, the major part of anthropogenic emission sources in the Global Methane Budget [1] - in addition to the fossil energies - is the annual 188 mt methane (which is 80 percent above that of emission from energy sources), released to the atmosphere from agricultural, animal husbandry and waste sources. The greenhouse potential of this is no less than 5.26 Gt CO_{2e}. Naturally, reducing or at least partially avoiding this emission has an extremely important impact on climate protection. 59 million tons (+/- 20 % inaccuracy) of methane emission is found in relation with wastes among the more detailed survey results. The methane emission of food production and animal husbandry is as large as 136 mtpa.

It would be determined for the next decade as a clear task to reduce the global level of waste-based methane emission by one third (-19.7 mt) as well the methane emission of agriculture and animal husbandry by at least one quarter (-26.5 mt, calculating without the emission connected to the rice cultivation). In total the anthropogenic methane emission of agriculture, animal husbandry and wastes should reduce by over 50 mt (the upper limit is 160 mt) annually, i.e. the CO_{2e} value by 1.4 Gt (where the upper limit is 4.5 Gt) per the end of the next decade. The technology has long been available for any organic material to install bio methane plants also equipped with biogas and gas separator units; moreover this renewable fuel can be made completely usable for transport.

According to the latest statistical almanac of the European Biogas Association [50] 17,662 biogas plants were established in Europe by the end of 2016 from which 503 are biomethane plants. 71 % of the plants are based on agricultural base material, 16 % on sewage water treatment plants and 9 percent on landfills. The annual energy production of these plants was close to the amount of 20 billion cubic metres of natural gas in 2015 (based on Eurostat data but the figures published by IEA World Energy Statistics indicates 29.7 billion cubic metres for European biogas production in 2014) from which electric energy was produced in case of the biogas plants. Meanwhile the biomethane plants produced renewable methane are close to one tenth of the total amount produced by the biogas plants.

When we are looking for the answer to the question, how much biomethane production capacity may be built in Europe or globally, we can use Germany as a reference where the number of biogas plants is 10,849 constituting 61 percent of the European facilities and has 196 biomethane plants, i.e. 39 percent of the European plants. If the number per capita of biogas plants at the other 27 member states of the EU were increased to the German level (82.18 million residents from the 510.28 million residents, [57]) then approx. 50 thousand more biogas plants would be established with the capacity of additional 40 billion cubic metres of gas.

The global biogas market is led by Europe despite that the stable technological bases are already present on every continent. Referring to the data of IEA, the World Bioenergy Association (WBA) [58] claims that half of the biogas production is given by Europe (2014) while the 28 member states of the EU use 11.9 % of the energy consumption of the world [57]. The rate is very similar if we examine the total biomass-based renewable energy production, since Europe produced 6.71 EJ energy in 2014 from the global 59.2 EJ, i.e. 11.3 %

Based on the extrapolating German figures – and on clear statistical basis – we can arrive to the result that along with 60 billion cubic metres of European production another 440 billion cubic metres of renewable gas production can be achieved worldwide (total approx. 360 mt.). In order to achieve this however, comprehensive economic encouragement is needed like in the German example where the government pays minimum 58 and maximum 238 €/MWh premium depending on the size of the plant [50]. Converted, it means rather high 880-3,600 €/t support but the British and the French biogas industry has also gathered momentum in development with at least the same amounts of support. In order to ensure spread, it is worth calculating with the already working minimum incentive, which means that in order to maintain the 360 mt annual excess production to be achieved worldwide mostly for climate protection, approx. € 320 billion non-returning subvention is needed in the budget-plans.

The reality of the amount for biogas-biomethane technology subvention in a high of € 320 billion annually, grounded by the knowledge that in 2017 alone in Europe € 51.2 billion was invested on constructing wind turbine capacities to increase the existing wind turbine capacities by only 11.5 GW [59]. The 141.5 GW capacity in Europe uploaded 301.9 TWh electric power into the system in 2015 [57]. Using the rate of this we can claim: 16 % of the amount of the requested € 320 billion (for biogas-biomethane technology subvention) was spent in Europe to develop 11.5 GW wind turbine capacity. The wind turbine capacity installed from this amount ensures altogether 0.46 % energy of the 500 billion cubic metres of renewable methane. Therefore the financial index of the wind power industry shows only 2.9 percent efficiency to the efficiency achievable by the support of renewable gas production.

In other words thirty-five times (35x!) more green energy can be produced from the same amount for biomethane than that which goes for wind turbine developments. This statement can be argued that the wind turbine needs investment only once and the biogas subvention is continuous. However, the comparison of the different survey methods only served to underline: the huge value of the support demand of the biogas industry is in fact lower than the capital demand of other popular technologies. Discussing which technology must have how many years' life cycle and how much supplementary infrastructural background would require another new chapter.

How is 500 billion cubic metres, i.e. 360 mt biomethane production is related to the objective of avoiding 50 mt but no more than 160 mt anthropogenic gas emission arising from agriculture and waste? Considering that 39 % of the basis of present biogas production in Europe is provided by energy plantations equally to the collected agricultural wastes, the theoretical limit and the biomass potential nearly correspond with each other.

Adding it: on WtW approach the 200 mt renewable methane fuel above the 160 mt (as the theoretical maximum of elimination, which equal to 4.5 Gt CO_{2e}) will result in 275 mt CO_2 WtW emission reduction compared with the traditional fuel (calculating with 50 % CO_2 reduction on WtW for simplicity). The global price of this pathway of climate protection is embodied in the subventions in the level of 67 €/t CO_2 specific cost of avoiding (the price of 4.775 Gt CO_{2e} annual emission reduction at € 320 billion annual subvention cost).

Compared with the cost spectrums of CO_2 eliminations published by ExxonMobil [6] the 67 €/t is a definitely more expensive option than converting coal based power plants to natural gas and roughly corresponds to the CO_2 elimination costs of applying nuclear power plants, but it shows more favourable results than most other energy technologies.

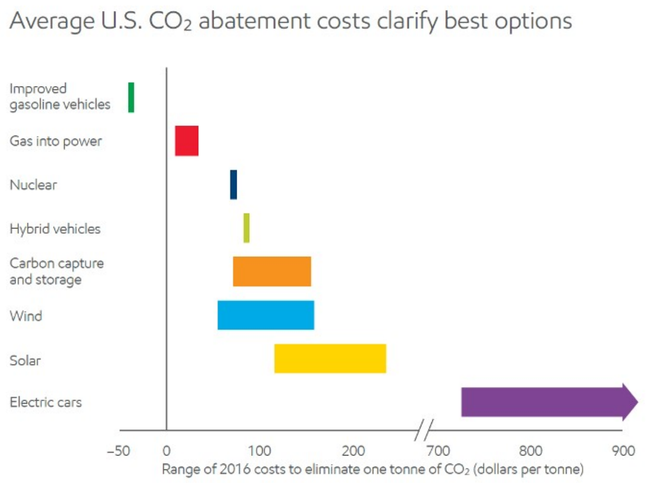

Fig. 5-2: The specific expenditure spectrums of CO_2 emission reduction technologies in USD unit with cost calculation characteristic based on the United States [6]

5.2. Opportunities of synthetic methane

The opportunities hidden in synthetic methane cannot be omitted from this line of thoughts as a proven available solution of absolutely CO_2-free transport. If you like, this is the e-gas fuel system for the entire transport energy value chain demonstrated and called by AUDI. AUDI g-tron owners can fill CO_2-free CNG fuel virtually anywhere in Germany by the gas which is produced at the AUDI Power-to-Gas (PtG) plant and fed into the gas pipe network, with molecule accounts records.

The PtG technology already proven in a size above demonstration level, provides a real solution for the problem which seriously hindering the power-sector. The electric power storing capacities are practically insufficient and therefore the need of keeping the power network (production-consumption) balanced stands as an obstacle in front of the further spread of carbon-free renewable power generation technologies in most markets. Nevertheless the more the thermal power plants ensuring only the balancing of the system, the higher their specific capital cost is, therefore no matter if the power generated by solar cells became theoretically cheaper and cheaper the hybrid system would still become significantly more expensive and this equation is further worsened by the costly ideas on solving the power storing battery.

Instead of storing electric power, PtG technology converts the power into hydrogen and then to methane in the next step which can be stored in almost unlimited amounts (and reversible) in the gas network and gas storages. The technology of PtG plants allows for actually stabilising the network by turning off and on and that it only loads the network when the costs thereof are low (there's excess power production). And the synthetic methane produced (as well as the hydrogen produced in the intermediary stage) ensures zero CO_2 emission on WtW basis for the vehicle since the vehicle emits exactly as much CO_2 as the PtG power plant used for converting the hydrogen to methane, typically absorb CO_2 from industrial emission.

The technology has almost unlimited potential for the production of synthetic fuel (called e-gas by Audi) in the future and to make gas-fuelled vehicles CO_2 neutral, but it has a price. We need to calculate with the total investment cost of the renewable power source and the PtG power plant where the PtG certainly works part time only, to fulfil its balancing role in the power grid. The operating time strongly determines the specific cost of CO_2 elimination. In the ExxonMobil study [6] the CO_2 neutralisation cost spectrum for the wind turbine calculated at 50-150 \$/t is multiplied yet in combination with the PtG system. Real cost however will be seen with the large-scale technology level, considering that the examples were built as experimental or demonstration plants and started operation, are evaluated at sky-high specific prices.

5.3. Climate protection overview of energy system improvements ensuring g-mobility

Transport used 19 %, i.e. 109 EJ of the global primary energy consumption of 573 EJ in 2014. However, it is one of the most difficult and most costly sector to decarbonise. Nevertheless, the study highlights that the systematic, transport user-centred development of energy systems and turning systematically the transport into a gas-based consumer, implements a synergy, which can result economically viable, sustainable pathway without significant subvention. The renewable pathway shows only little deviation from this and the synthetic methane fuel road is only somewhat larger. However these pathways may allow, that out of the at least 11 Gt CO_{2e} reduction to be presented by 2030 for the 2°C climate protection goals, the synergies of the transport and energy sectors may deliver a savings not only 2.2 Gt on the fossil route, but additionally 4.77 Gt reduction based on the renewables can archive. Top of that if using the synthetic path, the results only limited by the financial capabilities. It is obvious, that G-mobility can serve the two thirds required to achieve 2°C goal, by an ambitious global methane fuel plan, but even the decarbonisation process requiring the total 11 Gt CO_{2e} may take place, if we accelerate the utilization of synthetic technology.

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7. ANNEXES

See enclosed document.