METHANE – A FUEL FOR AGRICULTURE

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Abstract

The development of societies building modern economies and production was and is associated with the continuous growth of energy consumption. Nowadays the world was forced to take a different look at the problem of energy consumption and fossil fuels. Because of cost of mining and production, unstable political situation in resource-rich countries and ecological perspective, many scientists seeks renewable energy sources, in quantity sufficient to meet the demand. Because of development of technologies obtaining many types of renewable energy sources that can be adapted to the needs of energy and the environment in which it will be received. Because of rich resources of ingredients that make production possible biogas, it is the most appropriate renewable fuel for agricultural infrastructure. The paper comprehensively describes factors influencing the development of renewable energy to their nature and technology in the application of renewable fuel gas with particular reference to methane gas and biomethane. There is general agreement on the Reed for sustainable biofuel industry, there is little understanding on how to avoid social and environmental degradation with global biofuel production. Results showed a variety of government policies, the most significant of which concerns agricultural production. In analyses the impact of government's policies on promotion of affordable, alternative energy sources capable of maintaining current energy consumption standards.

Keywords: *renewable energy sources, biofuels, gaseous biofuels, methane, bio methane*

1. Introduction

For centuries, civilizations have been using various sources of energy. Constant development of technologies has led to an increase in demand for energy, which in turn posed two important problems before the modern man: growing pollution of the environment and diminishing resources of basic fossil fuels, i.e. crude oil and coal. According to the Polish Institute of Atomic Energy (IEA) estimations on the basis of the current consumption tendencies, if energy sources are still exploited in the same way, by 2030 the world's energy consumption will have grown by more than 40%. The IEA estimates that only the demand for crude oil will have increased in this period by 35%, which with the current consumption tendency will contribute to an increase in the emission of carbon dioxide, sulphur and other harmful chemical compounds.

Oil energy is produced in refinement processes, as a result of which fuels ready for combustion are produced. Oil-derived fuels are used mostly as a source of power for combustion engines, which are at present a big threat to the environment.

In order to face the growing demand for energy, it is unavoidable to undertake rational steps to limit its consumption, and to find new renewable sources which will allow people to use less fossil fuel.

2. The World's energy resources – a necessity to look for new sources

When developing, societies build modern economy and production systems, which has caused an increase in the consumption of energy. At present, however, the world has been forced to develop a new outlook on the issue of energy and fuel consumption. Electric bills are here the strongest incentive to change the attitude. A rise in prices of fuel, which was triggered by political events from 1973-74 and then deepened by the years 1978-81, put a sudden stop to the so far continuous period of development which meant an easy and cheap supply of energy resources. The public eye had to focus on the fact that crude oil and coal are extremely valuable as resources, yet limited in amount, and that the world had entered an energetic crisis.

Resources of traditional fuels are well documented; the date of their depletion is a matter of the estimated 50 years for oil and 200 years for coal. The usage of mineral energy sources emits to the atmosphere a considerable amount of gases, which leads to a slow but already visible change in its composition and consequently may lead to a global climate change.

Dynamics of the world's population increase as well as economic development in almost all countries result in a big increase in the demand for raw material and energy. In the 1970s, we witnessed an abrupt increase in oil prices and it was perhaps a turning point, which made people realize that it is dangerous to base the economy only on one main material, i.e. crude oil. An annual demand for oil is changeable and directly depends on the world's economy trends. One is yet certain: we observe a constant increase in prices of this basic energy resource used to produce engine fuels. Owners of oil fields realize that their situation may play a dominant role in politics and nowadays they follow a policy of limited extraction. Long-term prognosis says that concentration of CO_2 in the atmosphere will also grow (global warming) in line with the ceaseless increase in natural energy resources usage. It is a highly worrying phenomenon, thus new alternative energy sources are sought, among others plant fuels. Carbon dioxide limits heat emission into space (in the form of infrared radiation). The warming of water reservoirs results in plankton mass increase and as a consequence marine transgression. CO_2 emitted to the atmosphere by combustion engine is absorbed by oil plants, so a cycle is closed.

Replacing oil with substitute fuels is also caused by other factors, e.g. the need to ensure supply safety. Main oil resources are located in the politically unstable countries (the Middle East) so renewable and alternative fuels production in countries which do not have their own oil resources diminishes the political blackmail threat.

Against these facts, it is justified to undertake steps which on the one hand would limit energy resources usage (limiting the needs), and on the other hand would widen the range of renewable energy applications. The quicker the renewability cycle is, the more attractive such a resource may be.

These are basic factors which condition the development of renewable energies:

- mineral energy resources are diminishing,
- gas emissions, e.g. of carbon dioxide or sulphur oxides, can contribute to the global climate change,
- more food than needed is produced in highly developed countries so a growing reserve of agricultural soils can be used for non-food plantations - growing energetic plants,
- it is possible to encourage people to live in the countryside so that they can work at energy plantations,
- there is a need to ensure an appropriate and stable resource base. Technologies of utilizing biomass for energetic purposes are available and energy products made from biomass are cost-attractive.

Converging, the above factors give a chance to use biomass for energetic purposes on a larger scale. Each of the above mentioned elements can be controlled to a certain degree. E.g. as part of its environmental and fiscal policy, the state can influence the prices to a large extent and can also accelerate technological development by research programs.

The search for alternative carriers and sources of energy is stimulated by growing ecological requirements, which focus mainly on a gradual decrease in emissions of harmful components. In this way, producers are forced to make vehicles which are more environmentally friendly. A need to find other solutions than gasoline- or oil-fuelled engines is becoming more and more obvious. Although engines are becoming more and more ecologically clean and efficient, these advantages are offset by a sudden increase in the number of vehicles. According to the International Energy Agency, in 1996 there were 634 million vehicles in the world, which meant an increase by 30% within one decade. These vehicles emitted altogether 3.7 bn tons of carbon dioxide [1].

Substitutes for the I.C. engine fuelled with gasoline or oil have always been looked for since motorization developed. It sees its hope for future development in the 'forgotten' external combustion engines (the Stirling engine and the steam engine) or internal combustion micro-turbine engines, as well as traditional but modified engines powered by alternative fuels, i.e. those derived from sources other than crude oil refinement. These are both organic (hydrocarbons and their derivatives) as well as inorganic (hydrogen) fuels.

The list of most important alternative fuels features:

- mixture of liquefied propane and butane, LPG (due to the fact that propane-butane is a mixture of oil derivatives, including toxic ones, and is derived as a product in oil distillation, its share in the fuel market is not going to grow),
- compressed natural gas (CNG) or in liquefied form (LNG),
- plant fuels: alcohols (methanol, ethanol, 1-propanol, butanol and others), higher carboxylic acids (plant oils) and their derivatives (primarily esters),
- biogas derived in anaerobic decomposition of organic compounds,
- fuels derived in the process of other fuels' processing (among others synthetic fuels); synthetic gasoline, dimethyl ether, ammonia, illumination gas, water gas, generator gas and other substances,
- hydrogen.

3. Kinds and characteristics of fuels derived from methane

Renewable fuels are such fuels that come from fuel resources which do not undergo depletion. These are e.g. wood, biomass, solar energy, wind energy, water energy from water accumulation and hydrothermal vents. In spite of being exploited, they constantly renew themselves. The basic characteristic of these fuels consists in a specific path of carbon and oxygen in photosynthesis.

Fuels which can be seen as future substitutes of oil derivatives [4] should fulfil many conditions. They should:

- be available in big quantities,
- show technical and energetic properties determining their usability in I.C. engines,
- be cheap to produce and sell,
- pose smaller threat to the natural environment than traditional fuels,
- enable engines to show acceptable economical indexes and safety.

Extending energy base for motorization by introducing substitute fuels will be take place in two stages.

Research into alternative fuels focuses mainly on gaseous and liquid fuels (Fig.1). The main emphasis is put on those whose resources are considerable and renewable.

Renewable fuels can be divided into two groups: new one-component fuels and mixtures of two or more kinds of fuel. In the first case, fuel is a substance whose physical-chemical and exploitation properties enable it to power engines in traditional fuel systems. These fuels are characterized by a much wider composition of basic resources than traditional liquid fuels and by a lower toxicity, in some cases positively influencing economical parameters of the engine. Fuels from this group can be used in modern engines with no changes of their construction. Only the feed system is adapted, introducing some changes in the regulation system of mixture composition.

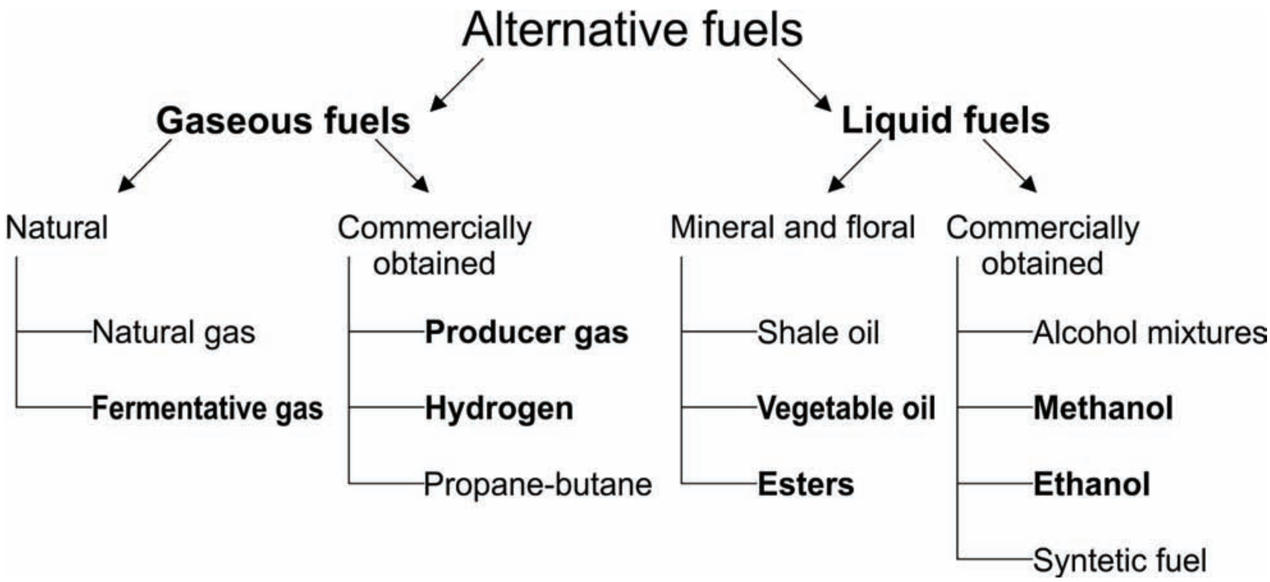

Fig.1. A typology of alternative fuels used in I.C. engines [1]

4. Gaseous fuels used in I.C. engines

Depending on their properties, gaseous fuels used in I.C. engines can be transported in two phases:

- gaseous, compressed to 20MPa (methane, hydrogen, generator gas, natural gas, and fermentation gas),
- liquid, when gas is liquefied at low pressures up to 1.5 MPa (butane, propane, ethane).

The latter have one important disadvantage in terms of safety, i.e. their density in the gaseous state is higher than air density. If the system is not tight, these gases fill repair pits, pipelines, and other rooms, posing an explosion threat.

- Methane – it is a saturated hydrocarbon, which is a basic component of natural gases.
- Hydrogen – is more and more often referred to as the future fuel for piston I.C. engines.
- Coal gas – is a by-product when coke is produced. It consists of methane, hydrogen and carbon oxide.
- Fermentation gas – is produced from agricultural waste, animal waste and in a sewage treatment plants.
- Natural gas – constitutes a mixture of methane and other combustible gases and incombustible compounds.
- Butane – can be derived from crude oil refinement or from natural gas.
- Propane – can be derived from crude oil refinement or from natural gas.
- LPG – is a mixture of propane and butane in different proportions, depending on the climate in which it is used. It is stored and transported liquefied at 1.5 MPa. Being relatively cheap and easily distributed, it s becoming a very popular car fuel.

Properties of the above fuels are presented in Tab. 1.

Gaseous fuels have different physical and chemical properties than liquid fuels. Nowadays, the following three kinds of gaseous fuels are applied in S.I. engines:

- natural gas,
- propane-butane mixture or propane,
- biogas and hydrogen.

Tab. 1. Properties characteristic for chosen fuels [4]

Gaseous fuel	Normal density [kg/m^3]	Calorific value [MJ/m^3]	Calorific value of stoichiometric mixture [MJ/m^3]	Oxygen content in stoichiometric mixture [%]	λ index for the lower flammable limit	MON (RON)
Methane	0.655	36	3.4	19	1.88	110 (140)
Propane	1.800	83	3.3	20.2	1.96	95
Butane	2.370	110	3.4	20.3	1.83	92
Natural gas	0.695	34.7	3.4	18.9	2.10	100-110
Coal gas	0.468	13	3.35	-	-	95
Generator gas	1.015	5.65	2.6	10.9	4.35	105
Illumination gas	0.614	17	3.25	16.9	2.50	90
Fermentation gas	1.200	24.2	3.2	18.2	1.94	110
Propane-butane 50%/50%	2.080	96.5	3.35	20.25	1.91	95 (100)

5. Natural gas, methane (CNG)

The idea to power I.C. engines with gaseous fuels appeared first in the 19th century and was used in the first I.C. engine, constructed by Etienne Lenoir in 1860. Illumination gas was then used. The engine had the power of 12KM. In 1878, Nikolaus A. Otto and E. Langen constructed a four-stroke engine fuelled with gas. In 1896 in Dessau and in 1897 in Jelenia Góra, there were trams fuelled with illumination gas stored in three containers at 0.6 MPa. In 1918, natural gas was used for the first time to fuel a bus engine. In the 1930s in Italy, gas engines were used in vehicles on a bigger scale.

In the world, gas became more popular as engine fuel in the 1970s since there was an energetic crisis. In the recent years, the interest in gas fuels has grown since conventional fuels are getting more and more expensive and the limits for toxic fumes emission are tighter and tighter. In Europe and in the world, we can notice attempts to introduce new vehicle engines originally (in the production process) adapted to CNG, which allows for better safety of exploitation, lowers homologation costs and provides professional service, thus fulfilling more and more restrictive requirements.

An interest in CNG developed on the turn of the 1980s and 1990s, especially in those countries where gas and oil were less available. New Zealand, Argentina, Italy, India and China are among such countries. Then in the developed countries, in line with a growing environmental consciousness, CNG started to be used to power vehicles, since it diminishes toxic components emission from fumes. Vehicles running for natural gas appeared in dynamically developing European cities: Paris, Nice, and Nuremberg. In all cities which organized recent Olympic games, communal transportation systems relied for power on CNG (Atlanta, Barcelona, Sapporo, Sydney). (ATTENTION: when combusting, methane does not emit PM – carcinogenic particle matter).

Natural gas can and does fuel not only cars and tractors but also e.g. forklift trucks. Natural gas is used because:

- in comparison with LPG, it is easier to air-condition halls where natural gas is used (it has lower density than air),
- it has been decided that natural gas is the safest,
- it is cheaper than propane-butane (LPG).

According to the assumptions of the TREN Directorate-General of the European Commission, in the EU countries there should be 20% cars fuelled by alternative by 2020, half of which should be CNG powered, 5% - hydrogen powered and 5% biofuel powered. It means that in 2020 in the EU there should be 24 million vehicles fuelled by CNG. In Poland, there should be about 2 million of such cars, and thus demand for natural gas is going to rise to about 47 billion m^3. It is difficult to say if this estimation is entirely plausible, although even now some countries in the EU undertake very intense steps to make it happen. E.g. in Germany in 3-4 years there will be one thousand stations to refuel cars with CNG (now there are almost 400), and the longest distance between them will not be bigger than 25 km.

Passing the Kyoto protocols at a Climate Change Conference is one of the most important steps taken to limit pollution emitted into the atmosphere. The protocols oblige countries which ratified them to limit pollution emissions. Moreover, in 2001 the EU directive to promote 'green' energy was passed (UE 2001/77/EC) as one more important legal solution in this field.
In motorization, changes in the legislation pertain to emission standards (Euro 0 to Euro 5). These are regulations which define a maximal concentration of certain exhaust gases, as shown in Tab. 2, which can be emitted into the atmosphere by newly-registered road eligible vehicles [7].

Tab. 2. Maximal concentrations of gases in fumes for newly-registered cars [7]

Substance	**Date of first registration**			
	to 1 October 1986	**from 1 October 1986 to 1 July 1995**	**after 1 July 1995**	
	idling	**idling**	**idling**	**2000-3000 rpm**
Carbon oxide (CO)	4.5%	3.5%	0.5%	0.3%
Hydrocarbons (HC)	-	-	100 ppm	
λ excess air factor	-	-	0.97-1.03	

As it is seen in Tab. 2, current norms for emissions of harmful substances in fumes have been limited even more than by 90% in comparison with first legal regulations. This forces power units' producers to look for new construction solutions or introduce new alternative and more environmentally friendly fuels.

6. Technical solutions applied in gas systems with methane fuelling I.C. engines

The development of power systems enabled to use methane as fuel. It appears in the following versions:

- natural gas compressed to 200-250 (currently) bars in one-fuel S. I. engines, with modern solutions with multi-point injection. Such solutions are used primarily in buses. Gas engines for vehicles are produced by a few big companies. In Europe, the market is dominated by MAN, but there are also engines by VOLVO, FIAT, PEUGOT or MERCEDES. It is possible to adapt self-igniting engines to gaseous fuels (CNG), although it requires changes in construction. In Poland, big part of buses powered by CNG underwent such changes. One-fuel engines are the best when we consider their efficiency, but they are usually used when the vehicles are run in the vicinity of a CNG refuel station (e.g. communal transportation system buses), or where there are many such stations (Argentina, Italy, soon Germany),
- bi-fuel or bi-power, when the engine is adapted to CNG and gasoline. Such vehicles are produced by many companies but also adapted from gasoline fuelled vehicles. In the former, usually a small gasoline container (app. 15l) and a bigger container for compressed natural gas (app. 120-150l) are mounted. Apart from containers, an appropriate system is installed to power the vehicle with gas and control gasoline delivery. In some countries, there are more

adapted cars (e.g. in Argentina), while in others originally produced CNG cars are preferred (e.g. in Germany or Sweden). Bi-power enables to use natural gas also in places where there are not many CNG stations,
- dual-Fuel is one more version when the C.I. engine is powered by a mixture of oil and natural gas (stored as CNG). In every work cycle, the engine uses oil as a pilot dose; when it ignites and the temperature rises, the air-methane mixture combusts. Common Rail systems widely used in such vehicles let control the pilot dose strictly so that the results are as estimated. Fig. 2 shows a diagram of how "gas Diesel" engine works. It is an C.I. engine constructed in the Mechatronics Chair at the University of Warmia and Mazury,
- the last version discussed here is liquefied natural gas (LPG). It is different than CNG mainly in the way it is stored. Cryogenic containers are necessary and so far this solution has been quite rare.

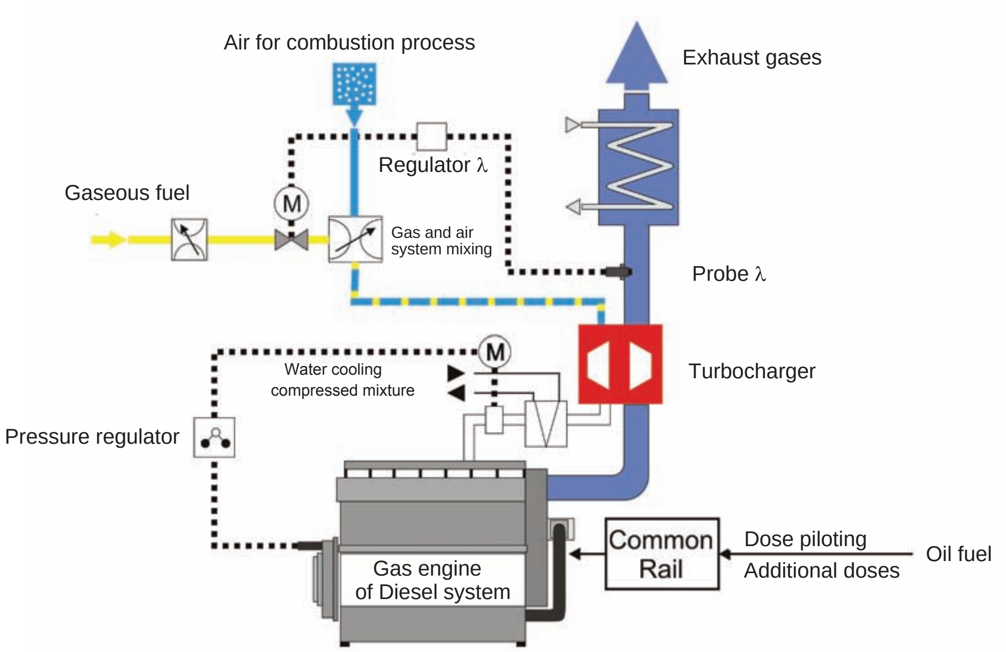

Fig. 2. C.I. engine system powered by gas with the oil pilot dose [6]

At present, all important car producers offer CNG powered vehicles. In Europe, there are over 50 models available.

It is worth summarizing all the factors that have contributed to a growing interest in this kind of fuel. These are:
- Safer delivery of fuel as a result of diversifying sources of deliveries and suppliers,
- Ecological considerations: CNG is a clean fuel (less CO_2, CO, NO_X, and especially carcinogenic PM). Among all the known fuels, only hydrogen is more ecological,
- At present, it is the cheapest fuel on the market (CNG equivalent of 1l of gasoline costs 1.46 PLN),
- Because of its properties (low density – it evaporates quickly; narrow flammability range in mixture with air; and high ignition temperature), natural gas is one of the safest fuels used in engines.

7. Biogas, marsh gas

Biogas is derived in the process of anaerobic fermentation of organic waste, during which organic substances are decomposed by bacteria into simple compounds. In the process of anaerobic fermentation, up to 60% of organic substances are transformed into biogas. In line with

the EU regulations, storing organic waste is possible only if it is protected against uncontrolled emissions of methane. Landfill gas has to be combusted in an external combustion torch or in energetic systems, and animal excrements have to undergo fermentation [2, 8].
Biogas used for energetic purposes is produced in the process of fermentation of:

- organic waste in landfills,
- sewage sediments in sewage treatment plants,
- animal waste in farms.

Biogas derived in anaerobic fermentation consists mainly of methane (from 40 to 70%) and carbon dioxide (app 40-50%), but it contains also other gases, among others nitrogen, hydrogen sulphide, carbon oxide, ammonia and oxygen (Tab. 3). In order to produce heat or electric energy, biogas should contain 40% of methane.

Having been appropriately refined, biogas can be used in many different ways. Landfill gas can be supplied to communal gas systems, used as vehicle fuel or in technological processes. Biogas can be combusted in especially adapted boilers, instead of natural gas. Heat derived in this way can be delivered to central heating systems. Electric energy produced in S. I. engines or turbines can be sold to communal energetic systems. Biogas is also used in co-generation systems to produce electric energy and heat.

Tab. 3. Chemical composition of biogas [4]

Component	**Fraction [%]**
Methane - CH_4	52-85
Carbon dioxide - CO_2	14-18
Hydrogen sulphide - H_2S	0.08-5.5
Hydrogen - H_2	0-5
Carbon oxide - CO	0-2.1
Nitrogen - N_2	0.6-7.5
Oxygen - O_2	0-1

The amount and quality of biogas derived from anaerobic fermentation depend on the kind of substrates used and a degree of their fermentation, temperature of the process, mechanical activity (stirring) and time. Biogas is produced from such components as farm animal's excrements (of cattle, swine, and poultry), optionally adding straw or plant waste. Post-fermentation mass left after gasification constitutes a valuable high quality fertilizer.

Biogas contributes to the global warming effect 27 times more than carbon dioxide and thus its uncontrolled emission from landfills, sewage treatment plants, sewage pipes, pigsties, barns and chicken coops has a highly detrimental influence on the natural environment – locally as unwanted smell, globally as a factor in climate change.

Thanks to biogas combustion in the engine powering the generator, electricity and heat can be produced in the so called co-generation (CHP) system. One ton of waste gives app. 110 m^3 of biogas, and 1m^3 of biogas gives 1,9 kWh of electric energy and 3 – 4 kWh of thermal energy in the form of 90°C hot water.

In Poland, app. 13 million tons (app. 45 gigam^3) of solid communal waste are produced every year. During 20 years, 1 ton of such waste can give about 230 m^3 of biogas. In this respect, energetic potential of landfills in Poland amounts to approximately 595 million m3 of landfill gas a year (4850 TWh).

In Poland, there are 1759 industrial and 1471 communal sewage treatment plants. On average, 1m^3 of sediments (4-5% of dry mass) can give 10-20 m^3 of biogas (about 60% CH_4). Biogas production for energetic purposes is profitable only if the treatment plant achieves the efficiency higher than 8 000-10 000 m^3 of waste per 24h. 3 kg of dry mass of sediments in sewage is equivalent to 1 litter of gasoline and more than 1 kilogram of coke. 2 kg of dry sediments in fermentation chambers give about 1 m^3 of biogas, which can produce about 6.25 kWh of energy [3]. Calorific value of pure methane is 35.7MJ/m^3. Apart from recycled dung and liquid manure, also agricultural waste and excess crop can become substrates in such a biogasification plant. Producing too much crop or when the profitability of food production drops, a farmer can gain profit selling electricity produced in a generator powered by an engine fuelled by biogas.

8. Cogeneration CHP biogas plants

In these plants, I.C. engines attached to an electricity generator are used. Engines work at constant rotational speed, which facilitates generating electricity with a quasi-stable frequency of the circuit. Optionally (instead of S.I. or C.I. engines), we can use Stirling engines, gas micro-turbines or fuel cells as power systems for the generator. The latter constructions are now being developed (even Stirling engines). A CHP module consists of a gas engine fuelled by biogas, an electricity generator and heat exchangers. The latter ones enable to utilize the heat of exhaust fumes and the heat of the liquid, oil and air cooling system.

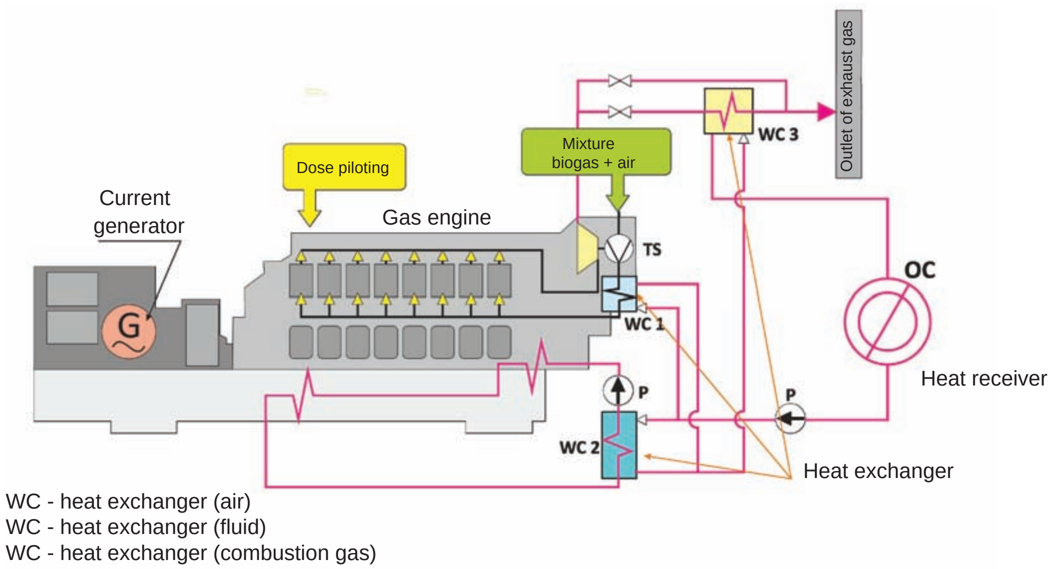

Fig. 3. A diagram of high power CHP unit

Looking at CHP units' engine power from an ecological perspective, it can be said that full utilization of renewable energy brings additional benefits from using agricultural grounds. In case of failure of such a unit, biological decomposition of oil (which lasts 15 days) is definitely much shorter than that of mineral oil. Using C.I. engines enables the CHP unit to work also when the fermentation system breaks down (the engine can then work using only oil) as well as when the fermentation system is only just being prepared to anaerobic fermentation (‘heating’ the system). CHP systems powered with biofuel reach up to 30-40% of electrical ampere-hour efficiency and 80-90% of net efficiency.

9. Biogas – a fuel for agriculture

For a long time, biogas has been used, e.g. in Switzerland and Sweden, as a fuel for lorries. If it is to be used as fuel for cars, tractors and machines for agriculture, it has to be processed so that its quality is acceptable. Remainders of sulphur dioxide, carbon dioxide and steam should be removed from biogas. It is recommended to treat biogas so it achieves the quality of natural gas. Then the power system and other devices used are identical with those for CNG systems. Fig. 6 presents an example of a machine fuelled with biogas stored in a container between axles of the tractor. A similar dual-fuel solution (with a pilot dose of oil) is offered by leading companies in the USA, Canada and the European Union.

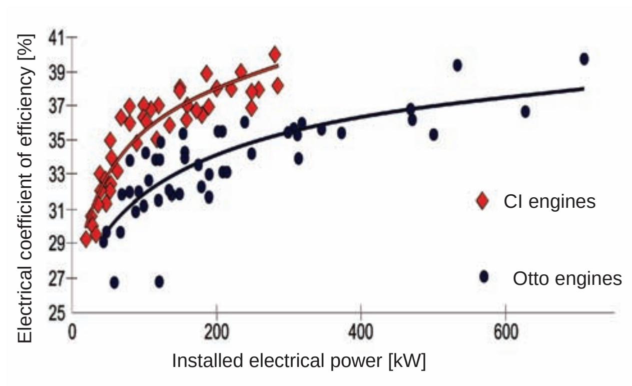

Fig. 4. A review of I. C. engines and S. I. engines applicability

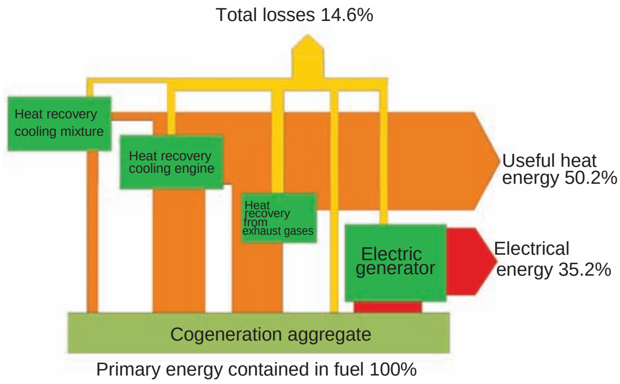

Fig. 5. A graph of heat losses of the I.C. engine

Fig. 6. Valtra N101 AGCO tractor, fuelled with biogas

Fig. 7. Volvo 7700A CNG bus service fuelled with biogas, in Ostermundigen (near Bern, Switzerland)

10. Hydrogen

Hydrogen can be widely used as a fuel in the future due to the fact that its resources are practically unlimited and it is almost pure ecologically. When hydrogen combusts, steam and some amount of nitrogen oxides are produced (NOX).

If hydrogen is to be used for energetic purposes, cheaper technologies of deriving it should be developed. Although it is the most common element in the universe (its resources are estimated at 10^{13} tons), it is quite rare on Earth as a free element because of its high reactivity with other elements, when it gives water, biomass, organic fuels and other compounds. In order to derive pure hydrogen, it should be separated from the above enumerated substances, yet this process requires high energy supplies. A few ways of producing hydrogen have been developed, yet only two methods appeared to be practical on an industrial scale: electrolysis of water and reforming methane and other hydrocarbon fuels. Water electrolysis, i.e. its decomposition into hydrogen and oxygen due to an electric current being passed through water, was performed for the first time in 1839 by a British physicist W. Grove, who invented a fuel cell. Since then, the process has been the simplest industrial method used to produce gases of very high purity. Yet, this method has one basic disadvantage, namely its efficiency is low (24-35%), thus a lot of energy, reaching even 50 kWh, is needed to produce one kilogram of hydrogen.

Hydrogen fuel has a lot of advantages, although it shows some negative features as well. The advantages include [4]:
- high diffusion coefficient of hydrogen in air, thus it is easy to produce a homogenous mixture
- virtually no toxic components in the fuel, apart from NOx, which still appears in a smaller fraction than in gasoline,
- low energy needed to ignite the mixture,
- high velocity of combustion,
- wide range of flammability $0.14 < \lambda < 9.5$, which allows to regulate engine load by changing the composition of the mixture, the so called quality governing.

Disadvantages of hydrogen are as follows:
- low octane number (tendency to knocking),
- strong chemical reactions with metals, especially in high temperatures,
- ability to decompose smear oils, which leads to origination of aggressive compounds negatively reacting with elements of the engine,
- low volumetric energy density even when hydrogen is liquefied,
- difficulties storing it.
- Hydrogen can be stored in containers of agricultural machines in three states [4]:
- as gas, at high pressure reaching 20 MPa, which requires steel bottles,
- as liquid, at pressure approaching the atmospheric pressure, but in very low temperatures (-253°C); containers require special installation systems,
- chemically bound, in compounds with metals (hydrides), filling containers which are at the same time heat exchangers.

So far, all attempts to store hydrogen in the above ways have not given promising results. Air to hydrogen stoichiometric ratio is 34:1, in comparison with 15:1 in the case of gasoline. Hydrogen as gas is distinguished by strong diffusion properties, i.e. enters into the metallic phase and builds into the crystal net of metals, introducing negative changes into mechanical properties of metals, known as brittleness of metals. The depth of such building into metals does not exceed 4-6 mm, and after the material hardens 1.5-2.0 mm – hydrogen diffusion does not appear when alloy additives, such as chromium, molybdenum, wolfram and others are introduced.

In order to produce hydrogen fuel in amounts sufficient for transportation purposes and energy supplies, at the same time seeing it as a renewable fuel which will never deplete, it is to be derived from sea water by electrolysis. According to German data, the cost of producing hydrogen in this way is higher than in the case of natural gas (by 90%), brown coal (by 90%), kerosene (by 40%) and hard coal (by 50%). It can be concluded that deriving energy with traditional methods from non-renewable resources is definitely much cheaper than deriving hydrogen from sea water by electrolysis, thus making it unprofitable. The only hope in this respect lies in cheap solar energy (produced with the use of direct and indirect methods) and atomic power plants based on hydrogen synthesis. So far, no methods have been developed to regulate this synthesis [4].

There are also additional problems when hydrogen is to be used in I.C. engines, namely creating the hydrogen-air mixture and refuelling cars with hydrogen and transporting it in cars. A number of car concerns have been proposing various solutions which still require further research.

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