POWER UNITS FOR FUTURE - QUO VADIS?

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1. HISTORY - A VIEW AT THE PAST

For almost four decades, from the first issue of the journal „Motor Vehicles and Motors“ (1975), which name has become the name of the scientific meeting held here, in Kragujevac, the question has been set on which power units will drive the automobiles of future, that is which will replace the piston internal combustion engine (IC engine) in the next 10 to 15 years? This question has not lost its actuality even today and the generation of engineers and scientists currently engaged in these problems has an impression that development had never been as dynamic and diverse as nowadays.

The French writer, André Malraux, had said: "If you want to read the future, then you should scroll through the past!"

For over 130 years, the piston IC engine has been without the competition as a power unit, not only for motor vehicles - automobiles, but in many other areas of human activities. During historical development, many other power machines (Figure 1) have been tested, none of which, with a sum of its features, had succeeded to establish itself in any field of application of the IC engines [1].

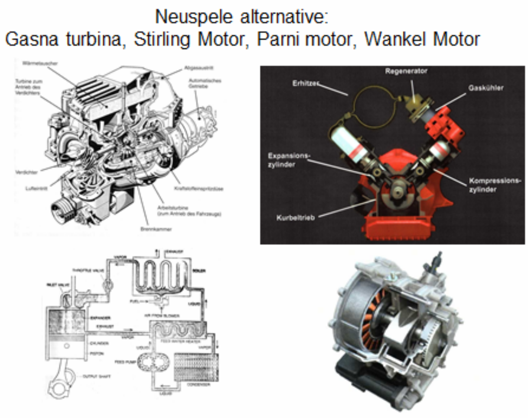

***Figure 1** Unsuccessful alternatives*

For several decades, discussions on vehicular traffic have been followed by forecasts on limited reserves of oil and other fossil fuels, by increased demands regarding the vehicle's economy and by more and more severe legal regulations regarding reduction of toxic components exhaust emission and carbon dioxide (CO_2) emission.

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2. THE STATE NOWADAYS

From year to year, the modern vehicles are safer, more reliable and their negative impact on environment is getting smaller. In spite of this, emission and consumption must be further reduced so their impact on human environment would be as small as possible.

It is very interesting that, despite huge efforts to replace the conventional piston engine with some other, better unit, and despite the forecasts that it could not fulfil more and more severe legislation set in front of the automobile, it has shown a very great development potential that has enabled it to fulfil all demands set before it so far.

Pretty picture of the achieved engine progress is painted by Porsche 911 vehicle which has been evolutionary and continually developing for 45 years. At the first test of exhaust emission performed in 1966, a former Porsche 911 vehicle with the engine volume of V_H = 2.0 dm^3 and the power of 130 HP (96 kW), has had fuel consumption of 15.4 l per 100 km. The modern Porsche 911 vehicle has engine volume of 3.6 dm^3 and the power of 295 kW (400 HP) and the fuel consumption (at the same test) amounts to 8,2 l per 100 km, that is, it is 47% smaller than its predecessor (Figure 2).

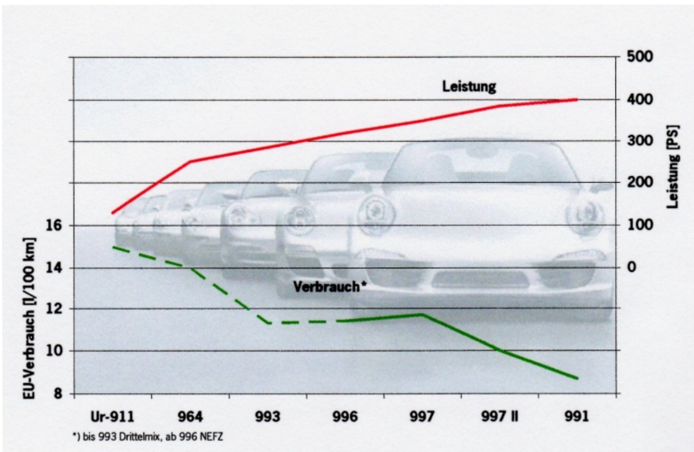

Figure 2 *Historical development of Porsche 911 fuel consumption*

Of course, the toxic components emission from the exhaust emission in modern engines is incomparably smaller than in their predecessors. The same amount of legally limited components (CO, HC, NO_x) emitted by a single automobile half a century ago is being emitted by 300 to 500 modern automobiles.

3. ECOLOGICAL DEMANDS SET BEFORE THE MOTOR VEHICLE

After the distance travelled for almost 140 years, IC engine, in its further development, must take more into account the social framework in which it is placed. The central place thereby belongs to:

- increasing anthropogenic emissions, in context with discussions on climate change,
- demographic changes in the world, with increasing number of population on Earth and with moving the age limits,

- increasing urbanization and
- limited reserves of fossil fuels that follow this development.

These social frameworks, as well as forecasts that both passenger and freight traffic will further grow in the next 20 years, explain the reason for more severe legislation set before the automobile and its power unit.

Firstly, there is reduction of energy consumption and closely related reduction of CO_2 emissions. Member countries of the European Union have adopted the so-called "20-20-20" program in 2007 or the program with the goal to reduce energy consumption by 20%, to reduce CO_2 emission by 20% and to cover 20% of energy needs with so-called green energy, *i.e.* energy from the renewable sources.

Satisfaction of the legislation on reducing CO_2 emissions is one of the greatest challenges in development of new propulsion systems for vehicles. The European Union and Japan lead today in regard to the law on the reduction of CO_2 emissions; China prepares stricter regulations, followed by the USA and the other countries (Figure 3).

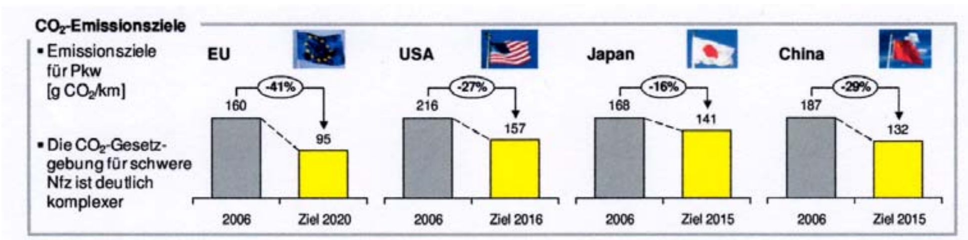

Figure 3 *CO_2 emission reduction goals*

According to current plan, the new passenger vehicles in the European Union will be allowed to emit, on average, just 95 gCO_2/km (≈ 3.8 l/100km) from 2020 and this value should be reduced to 70 gCO_2/km (≈ 2.8 l/100 km) from 2025. Currently, average value of CO_2 emission from passenger vehicles in Germany amounts to 148 gCO_2/km (≈5.9 l/100 km).

Of course, it is required that the automotive industry will continue to meet the ever harsher legislation on reduction of toxic components in the exhaust gases: carbon monoxide (CO), unburned hydrocarbons (HC), nitrogen oxides (NO_x) and particulate matter (PM). In the European Union, the strongest legal regulations for now, known as Euro 6, are predicted for the year 2014, while in the United States, with legal regulation LEV 2 (**L**ow **E**mission **V**ehicles), the California Air Resources Board (CARB) has introduced the world's sharpest legal rules defined as SULEV (**S**uper **U**ltra **L**ow **E**mission **V**ehicles), Figure 4.

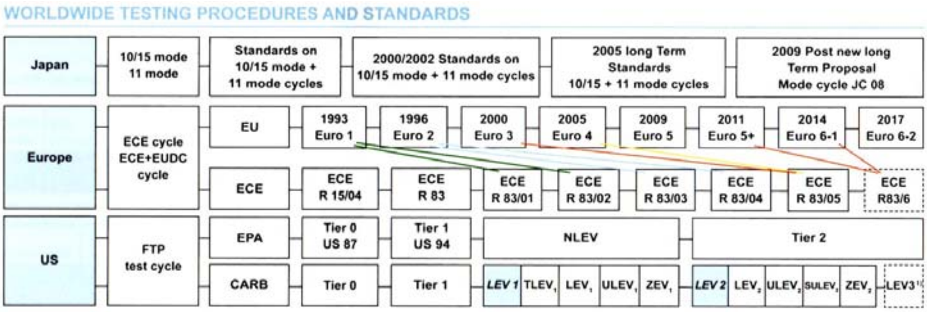

Figure 4 *Legal regulations on exhaust emission in the world*

In order to classify the vehicle as PZEV (**P**artial **Z**ero **E**mission **V**ehicle), the limit value recommended for SULEV vehicles must be guaranteed for 15 years of the vehicle operation and for the path of 150,000 miles (240,000 km) travelled. Vapour emission of the stationary vehicle must be 0 and the vehicle emissions are controlled by OBD II (**O**n **B**oard **D**iagnostic II) system.

At the end of their "life" (End of Live Vehicles, ELV), passenger vehicles must meet the legal requirements on recycling, which in the European Union say that, from 2015, only 5% of vehicle weight may go to landfills, while 95% of vehicle weight must be used, either as material or energy.

4. TOPICS IN MODERN DEVELOPMENT OF IC ENGINES

To respond to the demands that are set upon it, the IC engine is still continuously and evolutionary developing. Its future depends, above all, on the further increase of efficiency in all areas of work. Former studies show that there is still considerable potential for further reductions in fuel consumption and CO_2 emissions that is estimated as at least 15% for both Otto and Diesel engines in the short-term.

4.1. Downsizing

Under pressure from legislation, the main priority in the development of the engine is to reduce the fuel consumption. One of the attractive ways that is being increasingly used is the so-called "downsizing" or reducing the engine capacity, while maintaining the desired power with the help of engine turbocharging (Figure 5). The fact that it is more important what cylinders do and not how many of them there are in the engine is slowly being accepted by the professional world.

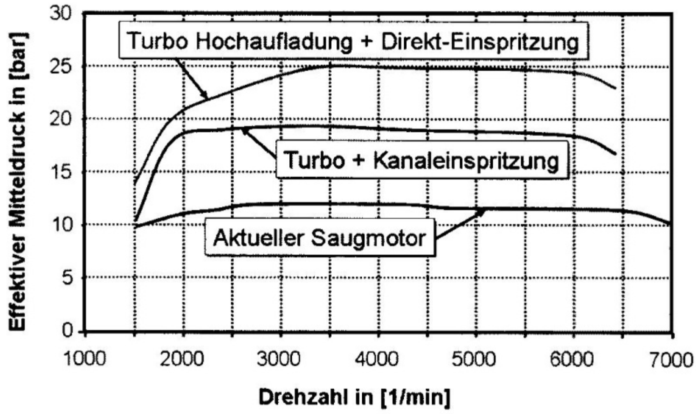

Figure 5 *Characteristic curves of engine torque with turbocharging and with free intake*

"Downsizing" process, *i.e.* a turbocharged engine with a relatively small volume, had allowed the mass use of diesel engines in passenger vehicles 20 years ago and completely had thrown out the free intake diesel engines from applications, even in the field of commercial vehicles. While this process in diesel engines have long been the standard, manufacturers of vehicles with Otto engines introduce in their programs more engines with reduced volume and charging, in order to meet CO_2 emission value of 130 gCO_2/km (≈ 5.2 l/100 km) required by the European Commission, Figure 6, Table 1.

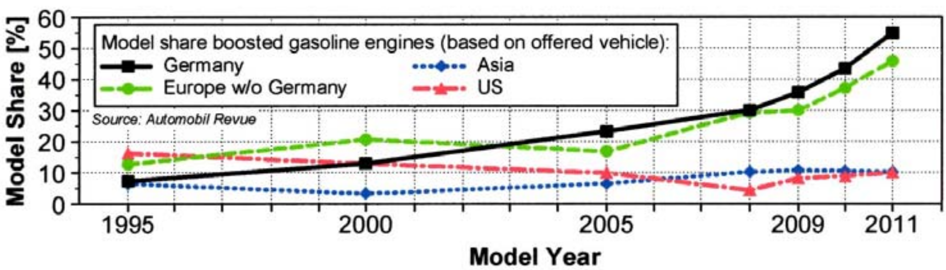

Figure 6 *Share of „downsized“ Otto engines in the world market*

For the current generation of "downsized" turbocharged engines, the displacement is reduced by about 75% compared with the displacement of the engine having the same power, but with a free intake.

Table 1 *The producers of turbocharged „downsized“ engines*

Producer	Displacement VH [dm^3]	Number of cylinders	Power [kW]	CO_2 [g/km]
Ford	1.0	3		
Kia		3		85
Fiat	0.875	2		
Nissan	1.2	3		95
Renault	0.9	3	66	

VW	0.8	2	35	

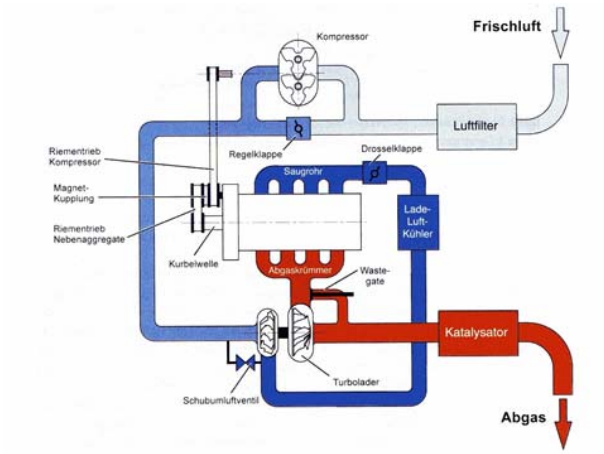

Figure 7 *Engine with double turbo charge (source: VW)*

While complex turbocharging systems with two (mostly turbo) compressors and direct injection at diesel engines have become almost standard, they begin to be more and more applied in Otto engines, more often combined with variable valve timing scheme.

4. 2 Working process

Success of internal combustion engines decisively depends on the combustion process, which takes place in the cylinder. Efforts to reduce the losses during engine operation have led to the development of valve drives with variable valve timing.

Direct fuel injection with pressures of over 2000 bars has become a standard for diesel engines, while direct fuel injection with pressures of over 100 bars is more and more applied in Otto engines as well. Otto engines with two injection systems increasingly appear on the market (Figure 8).

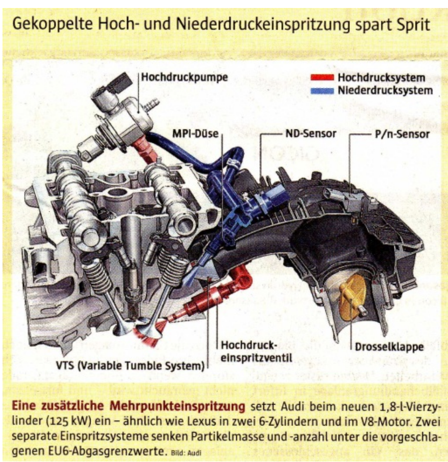

Figure 8 *Engine with two injection systems (Audi)*

The first system allows the injection of the main fuel quantity in the initial stage of realization of the mixture. It is used to achieve homogeneous, lean mixture of fuel and air. The second, smaller amount of fuel is injected just before the combustion of the mixture, in order to facilitate its safe ignition.

In a recent dispute between the automotive industry and an inventor, it has been found that modern diesel engines operate on the principle, which has been described by so-called thermodynamic cycle with isothermal expansion (Figure 9).

This thermodynamic cycle had been patented back in 1975. The goal was to achieve high efficiency with the least emissions of nitrogen oxides (NO_x) and unburned hydrocarbon (CH). In order to achieve this, it is necessary that the first, main amount of energy (fuel energy, Q_1') is introduced in the first phase of the cycle, at constant volume, in order to reduce maximum combustion temperatures, responsible for the creation of NO_x, while the second, smaller quantity of energy (Q_1'') is introduced during the expansion, which provides relatively high temperature, important for further oxidation of unburned hydrocarbons during the expansion stroke and in the exhaust system.

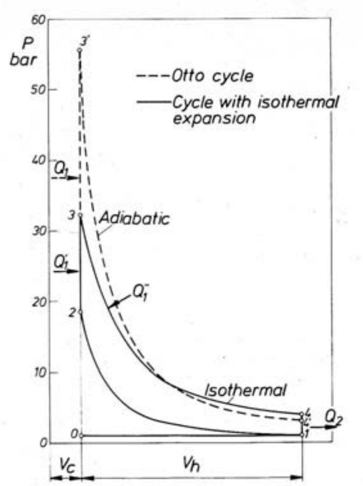

Figure 9 *Otto cycle and cycle with isothermal expansion [4,5]*

It was found that all modern Otto and Diesel engines with multiple injection operate in accordance with this thermodynamic cycle.

4. 3 Reducing mechanical losses

Many of the measures to improve IC engines have already been applied after years of effort, so that it becomes increasingly difficult to devise the ways for their further optimization. Especially for Diesel engines, options for the further improvement of the combustion process are almost exhausted, so it's harder to develop engines using conventional methods and all possible potentials where further optimization is still possible are searched for on the engine as a whole. Beside the efforts in improving the combustion process and reducing the engine losses, a great potential is still seen in reduction of mechanical losses and friction (Figure 10) [6].

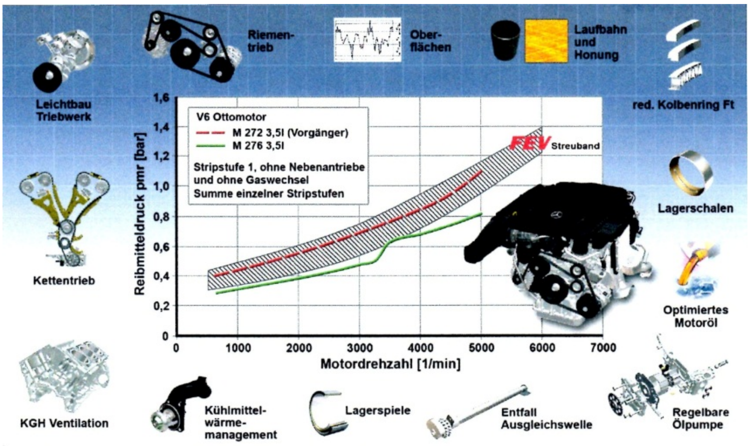

Figure 10 *Measures for reduction of engine mechanical losses*

In addition to new technological procedures in the processing of cylinder liners, piston group and bearings, this area also includes the reduction of piston mechanism weight, which significantly reduces the inertial forces at higher engine speeds, and thus also reduces the mechanical losses.

In addition to optimization of the engine, further development of all the important components that affect not only the combustion process, such as the injection system, but the entire operation of the engine, particularly the system for lubrication and cooling, is required. Significant potential for reduction of mechanical losses is also in variable drive of auxiliary units on the vehicle: oil pump and water pump, which are involved in the work according to engine needs. Neglecting these potentials will not allow further necessary development of IC engines.

4. 4 Modular design of engine

Of course, all these necessary measures to improve the engine, in addition to large investments in research and development, have resulted in the increase of production costs, including the price of the engine.

At the end of 1960-ies, before the introduction of legislation on reduction of exhaust emissions and fuel consumption, the production cost of one full 8-cylinder engine with the exhaust system in the U.S. was around 160 to 180 US $. The production cost of modern engines that meet all legal requirements, rises to several thousand dollars.

Despite the steady increase in production costs, continuous efforts are being made to reduce, as far as possible, the production price of the engine. Similarly, as many years ago, when the principle of "common platform" has been introduced in the construction of vehicle in order to reduce production costs, the modular design principle is also observed in the construction of the engine (Figure11), which represents a common base to build a family of engines with different displacements and numbers of cylinders by one producer.

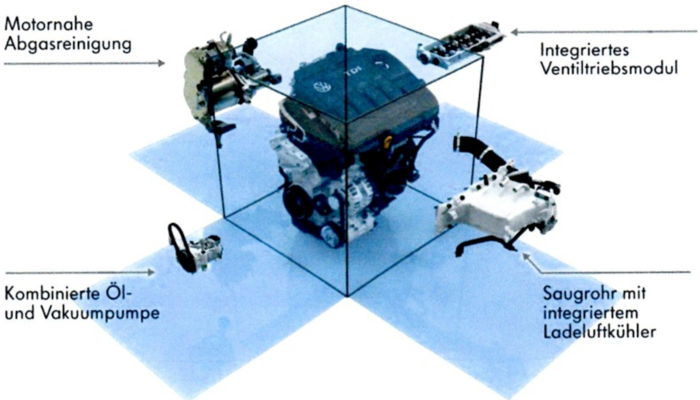

Figure 11 *Modular design system (source: VW)*

Modules - joint groups and sets - are divided into groups of the base engine (piston mechanism, cylinder head, valve mechanism) and sets that are built on the engine (elements for filtering of the exhaust emission, intake system with integrated cooler for cooling the air for turbocharging).

Even in the engine concept phase, it is taken into account to modularize the engine to the greatest extent. In addition to reducing the production cost of the engine, modular construction offers possibility to produce the engines in different places and for different markets and applications. With no major losses in time, the engines can be built according to the different requirements that are set in the world in the standardized production plants, with always optimal technical solutions.

5. HYBRID DRIVE

In the last ten years, the vehicle power units with two units: IC engine and electric motor have been recognized as the only alternative to a purely engine power unit that is produced in series.

5. 1 Micro hybrid

The initial step in this direction, the so-called “micro hybrid” or start-stop automatics (start-stop generator) has become an integral part of modern engines. In the city driving, fuel savings with this system amount to about 3% to 5%.

5. 2 Mild hybrid

A "Mild Hybrid", in addition to the start-stop generators, uses power of the electric motor at start-up and acceleration of the vehicle. The energy needed for the electric motor is taken from a relatively small battery. Starting the vehicle for a long distance is not possible for this system, because the battery is too small. Very often, braking energy recuperation is frequently used in this system during deceleration. Fuel savings during city driving and during new European driving cycle (NEUDC, **N**ew **E**uropean **U**rban **D**riving **C**ycle) are about 15% to 20%.

5. 3 Full hybrid vehicle

Unlike "mild hybrid" vehicles, "full hybrid vehicles" have a battery of sufficient size, so the electric motor can drive the vehicle on a relatively long distance. Electric motor power is between 20 kW and 60 kW. Fuel savings or CO_2 emission reduction in the new European test are between 20% and 50% (Figure 12).

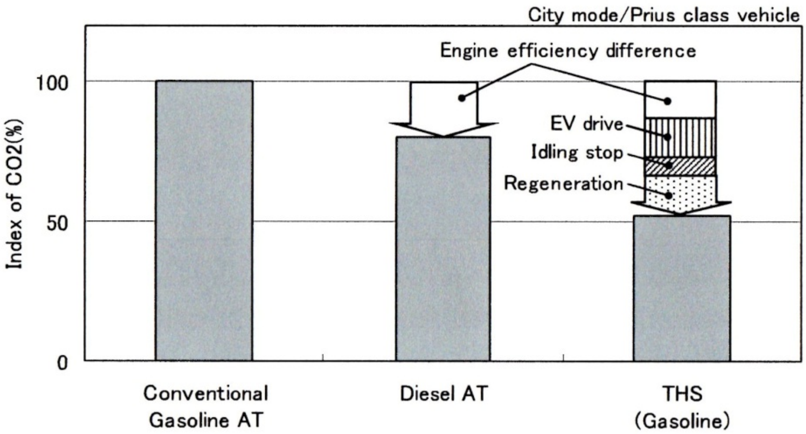

Figure 12 *Reduction of CO_2 emission in hybrid vehicle (Toyota)*

The key features of full hybrid vehicles are: pure electric driving ability at a certain distance, the exclusion of both engines operation at idle speed and braking energy recuperation.

5. 4 Range Extender, Plug in hybrid

High production costs and the price of full hybrid vehicles and their relatively small radius with pure electric drive, and the fact that most of the vehicle rides during the day do not exceed 30 to 60 km, led to hybrid vehicles solution with so-called "range extender" or "plug-in" systems.

Electric battery and electric motor power are dimensioned at these vehicles in a way that enables pure electric driving for about 50 to 60 km, for example, going to work and returning home, where the battery is charged during the night to ride the next day. If the vehicle has to take more distance or the energy consumption is increased (lights, wipers, heating, air-condition), then the additional IC engine is engaged in operation, which is so dimensioned that allows unobstructed started drive ("range extender").

"Range extender" - IC engine, as modular part of a hybrid concept, provides compensation of known deficits of purely electric drive. To support the electric motor, one relatively small and light IC engine (V_H = 0.3 to 0.8 dm3) with low production costs is used (Figure 13).

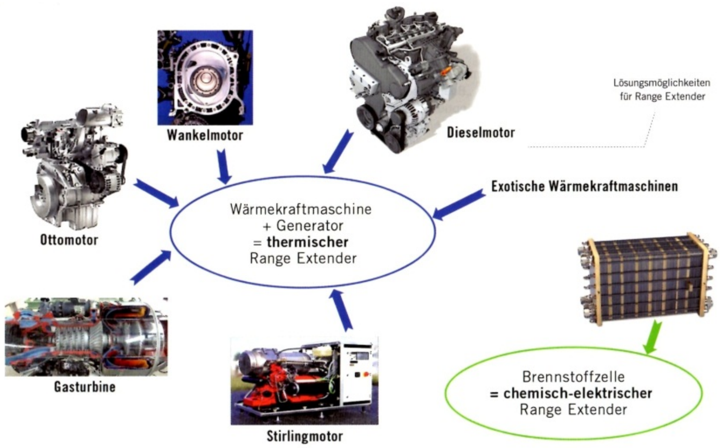

***Figure 13** Researched power units as „range extender“*

Almost all alternative power units that were once offered to drive motor vehicles now are being researched as possible variants for the position of the "range extender" engine (Vankel engine, two-stroke engine, gas turbine, etc.).

Despite all the efforts to promote the hybrid vehicles at the market as a serious alternative to a pure engine drive, their share in the total vehicle fleet is still very small: At the beginning of 2012, the number of new hybrid vehicles in traffic in Germany totalled 12.622. The share of hybrid vehicles in Germany in total number of passenger vehicles is now about 0.80%.

6. ELECTRIC VEHICLES

In its efforts to reduce CO_2 emissions, the current policy in many countries is very focused on electric drive motor vehicles. After the nuclear disasters in the USA (Three Mile Island), Ukraine (Chernobyl) and Japan (Fukushima), electro-mobility provides opportunities to reduce CO_2 emissions only if the electric energy is derived from the so-called renewable energy sources (water, wind, solar energy). Since more than half of electric energy today is generated using fossil fuels (coal, oil, natural gas), the switch to electric vehicle drive does not reduce CO_2 emissions, but, on the contrary, induces its global increase.

Electric automobiles are not the discovery of today’s techniques. The first electric drives were already built between 1835 and 1839 [9]. At the beginning of the 20th century, more vehicles were powered by electric motors than with IC engines. Advantages and disadvantages of electric vehicles at that time were similar to those that now follow the development of these automobiles.

Plans of some countries regarding the introduction of electric vehicles in the traffic sounded very seriously a few years ago. Federal Republic of Germany had a goal that 1 million vehicles in the traffic should be with pure electric drive until 2020. In 2030, that number should be increased to six million electric vehicles on German roads. China has planned that, by 2015, half a million electric vehicles should be found in traffic, and by 2020, this number should be increased by ten times - to five million vehicles [10].

The main drawbacks of electric vehicles are found, same as 150 years ago, with the battery or accumulator of electric energy or with its capacity, weight and production cost (Figure 14).

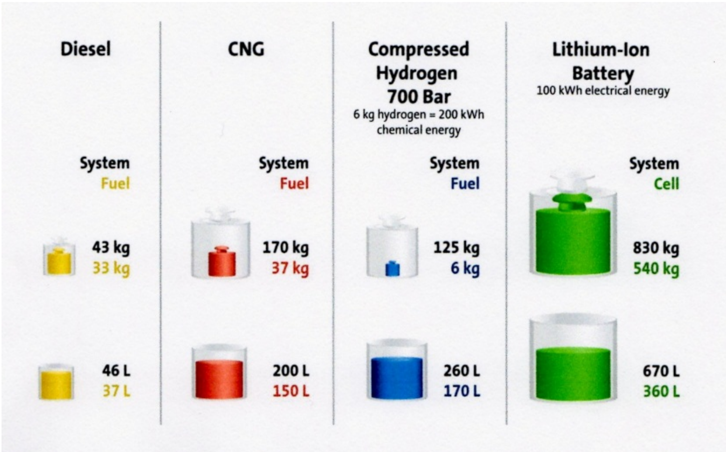

Figure 14 *Weight and volume of energy sources (source: GM)*

The capacity of the today's best batteries, Lithium-ion batteries, amounts to 0.5 kWh/l, which is 20 times less than that of gasoline and diesel fuel (9-10 kWh / l). Low capacity means great battery weight for any longer distances, which vehicle shall travel. Today, they amount to a maximum of 120 to 150 km at a flat, dry road, on a sunny, not too hot day. Turning on the lights, wipers, heating or air conditioning of the vehicle, reduces the potential radius of the vehicle by half.

The second major handicap of electric vehicles is the high production cost of battery that has been moving between 600 and 800 €/kWh for years, which is 20 to 25 times greater than for IC engines. The goal of battery price reduction is set between 200 and 300 €/kWh, which is expected to happen in about 10 years.

Electric vehicles producers are trying to reduce production costs for both electric and hybrid vehicles with using electric modules, which can be integrated into existing vehicle platforms. Thus, the modular building system is one of more important paths of development for electric automobiles.

Listed shortcomings of electric drive, along with a lack of necessary infrastructure and standards for supply stations, cables, sockets (Figure 15) and still great amount of time of several hours for charging the battery, have led to slow correction of ambitious plans on the share of electric vehicles in traffic.

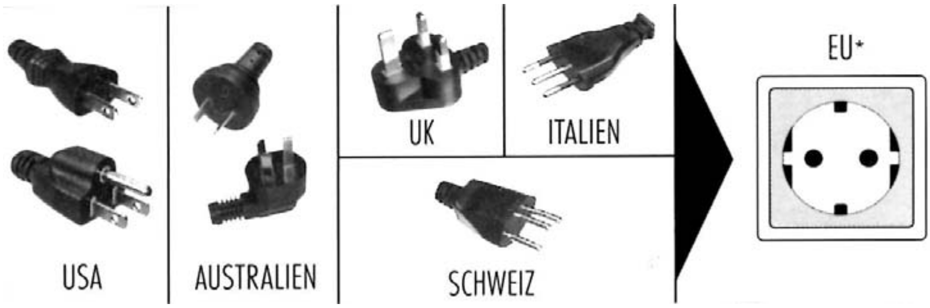

Figure 15 *After 150 years: different sockets for electrical devices in the world*

In early 2012, there were only 4541 electric vehicles in traffic in Federal Republic of Germany or 0.01% of the total number of vehicles in traffic. In China, until this year, 7.000 electric vehicles were sold, representing 0.02% of the vehicles in traffic.

Most experts agree that, in the next 15 to 20 years, electric vehicles will not make a greater breakthrough in the market, but they will be used only for small, local fleets. According to Professor Lenz (Technical University of Vienna), electric vehicle will not at all contribute to improving the state of human environment, while, for vehicle buyers, it means a considerable increase of the price of vehicle that is significantly inferior in terms of all properties compared to IC engine drive [7].

7. FUEL CELLS

At the beginning of the 1990s, especially under the influence of development in Daimler Corporation, the electric vehicle drive with so-called “fuel cell” as a source of electrical energy, which was supposed to be the solution to drive the vehicle in the near future, had been euphorically presented. Electrical energy that serves to start the vehicle is produced by joining the fuel (hydrogen H_2) and oxygen from the air (O_2). The other product of this chemical reaction is water (H_2O), which has no harmful effect on the human environment.

Almost all vehicle producers have invested heavily in research and development of fuel cells. Predictions about the introduction of fuel cells in mass production were very optimistic (Figure16).

Predicted introduction of vehicles with fuel cells in serial production

Firm	Star of serial production	Prediction from year
Honda	2003	(2000)
Daimler	2004	(2000)
GM	2004	(1998)
Ford	2004	(2001)
Chrysler	2007	(1997)

Figure 16 *Predictions on introduction of fuel cells in serial production*

Most producers claimed that they will start the serial production in 2003 or 2004 [8, 9, 10]. To date, however, the basic weaknesses of the system have not been solved. High production rate (100 to 150 times higher than that of IC engines of the same power), lack of fuel (hydrogen has proved to be the only possible solution) and a complete lack of the necessary infrastructure for the production, distribution and storage of hydrogen have meant that the chances for application of fuel cells in road traffic are considered much smaller than the chances for battery-powered electric vehicles.

8. VIEW AT THE FUTURE

Accepting the advice from Andre Marlowe that "If you want to read the future, then you should scroll through the past", the past development shows that, so far, no alternative power unit has managed to threaten the primacy of IC engines. Today's parameters also show that the IC engine remains unchallenged power unit for motor vehicles.

Experts around the world mutually agree that the piston IC engine will maintain its dominant status for several decades as the main power unit for vehicles

8. 2 Fuels

They also agreed that fuels based on oil and other fossil sources will not be able to meet the growing global demands for energy alone, so the answer to the question which sources of energy will be available will also carry the answer to the question of which power units will drive the future vehicles. Apparently, in the future, several fuels with similar characteristics, originating from the different sources will simultaneously exist at the market.

Conventional fuels derived from crude oil globally remain, according to today's forecasts, as the main source of energy in the next 30 years (Figure 17) - the prognosis that has been repeated for over 50 years.

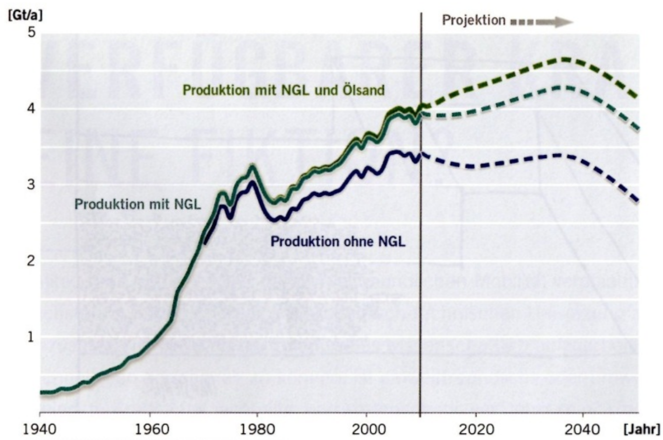

Figure 17 *Trends in exploitation of oil sources and natural gas sources*

Maximum exploitation of oil wells is expected in the next 15 to 20 years, after which there should be the reduction of oil supply, although the demands for energy continue to grow steadily. This fact means that the time of cheap oil is over. With the increase in prices of oil or fuel, many alternative fuels which could not, because of their high cost, be promoted at the market until now, become economically interesting.

Relying on the European Directive on fuel quality (2003/30/EG) and direction on the use of renewable energy sources (2009/28/EG), the European Commission, in its ambitious plan to support the use of renewable energy sources in traffic, follows a specific goal that, by year 2020, at least 10% of conventional fuels in the European Union is replaced by fuels from regenerative sources [14, 15].

In the first place, there are fuels from bio-mass as fuels from renewable sources. The goal of the efforts to introduce these fuels is to enable the traffic neutral in terms of CO_2 emissions. Since the gaining of the first generation of biofuels is potentially in competition with food production and is therefore subject to harsh criticism, experts are working intensively on the next generation of biofuels, where fruit of the plant will not be used to produce fuels, but only as plant waste material. Obtaining the biofuels from algae seems especially attractive looks and it has been intensively investigated.

Beside fuels from biomass, synthetic fuels, which are likely to have greater importance in the future than it is considered now, gain more and more importance. These include:

- ETBE - Ethyl-tertiary-butyl-ester,
- Synthetic fuel obtained from natural gas (GTL, **G**as **t**o **L**iquid) and
- Synthetic fuel obtained from coal (CTL, **C**oal **t**o **L**iquid).

Efforts to obtain synthetic or gaseous fuels from CO_2 emission, emitted by power plants and large industrial plants, by using excess electricity from regenerative sources or to conduct the "recycling" of CO_2, seem to be attractive (Figure 18).

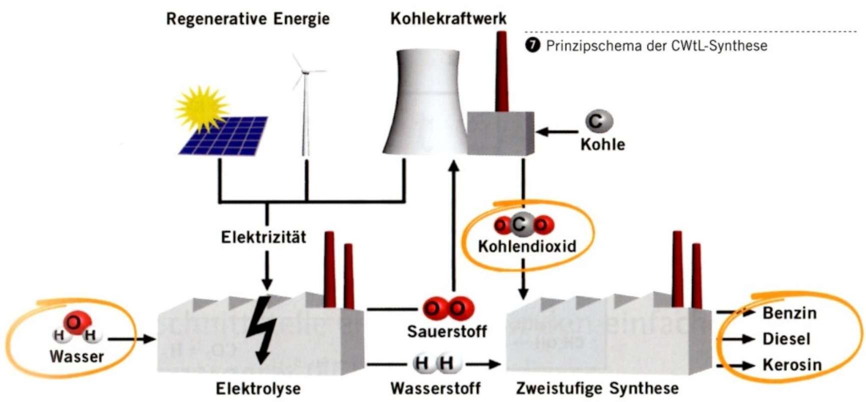

***Figure 18** Fuels from CO_2 and water*

9. CONCLUSIONS - MOTOR VEHICLE DRIVES IN THE NEXT 15 TO 20 YEARS

Since the liquid fuels from fossil and biogenic sources will be the main energy sources for road transport in the coming decades, the IC engine will keep its dominant position as a power unit for motor vehicles during that time. Of course, it will continue to be optimized in all phases of the operating cycles and in every detail of its construction (Figure 19).

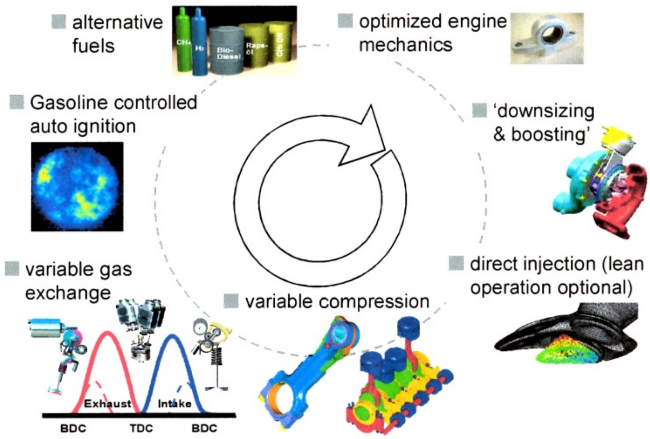

Figure 19 *Further optimization of IC engines*

The potential for further reduction of fuel consumption and CO_2 emissions is still large (Figure 20).

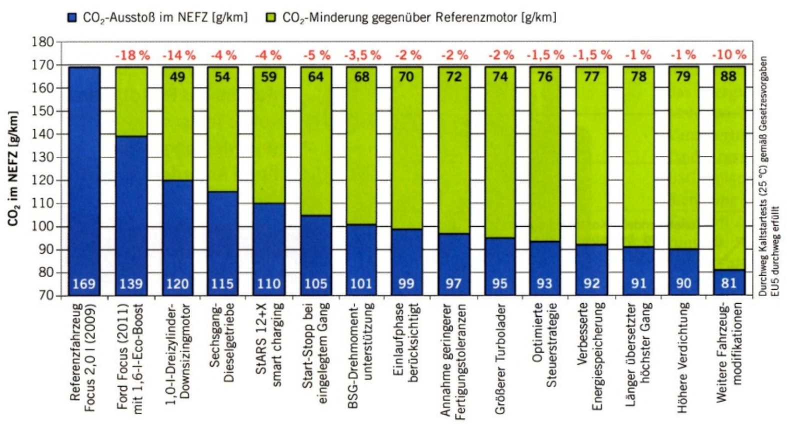

Figure 20 *Measures for further reduction of CO_2 emission and fuel consumption*

The start of power unit electrification, a hybrid drive, will probably remain a definitive solution for the foreseeable future.

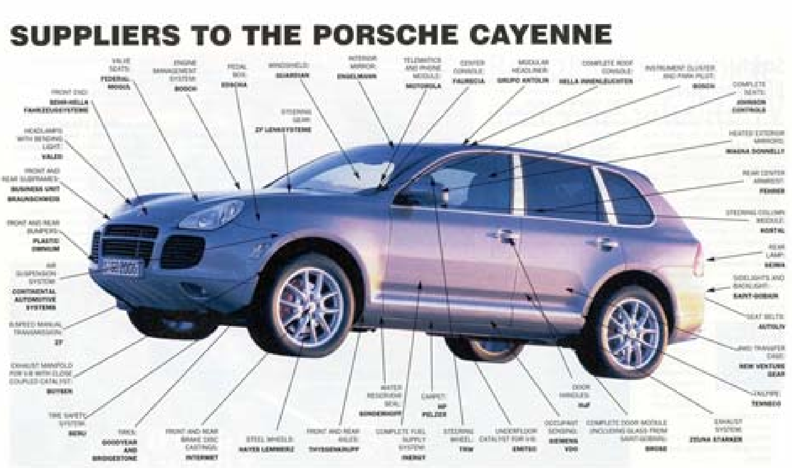

Figure 21 *Porsche and its suppliers (example of Cayenne)*

Shorter and shorter intervals available for product development and introduction of innovations in engine construction, along with the growing demands regarding the conservation of natural reserves of the planet, have led to the fact that collaboration between a producer and several partners from automobile industry has become an important factor in achieving success. Thereby, the cooperation with the so-called attached industry or the suppliers has the most important role. Over 70% of the value of an automobile is created today in the attached industry (Figure 21).

This picture will not be changed in the future.

Today, about 70 million of road vehicles are made annually in the world. In the meantime, China has become the largest producer, with annual production of over 16 million vehicles. In the next 5 years, the number of vehicles is projected to increase for more than 30% (Figure 22).

Reihung der Fahrzeugproduktion nach Ländern:

2001			2011			2016		
Nr.	Produktions Land[1]	Fahrzeuge p.a.	Nr.	Produktions Land[1]	Fahrzeuge p.a.	Nr.	Produktions Land[1]	Fahrzeuge p.a.
1	Japan	8.100.000	1	China	15.800.000	1	China	25.000.000
2	Deutschland	5.300.000	2	USA	8.400.000	2	USA	11.000.000
3	USA	4.800.000	3	Japan	7.500.000	3	Japan	8.800.000
4	Frankreich	3.100.000	4	Deutschland	5.800.000	4	Indien	6.200.000
5	Süd Korea	2.400.000	5	Süd Korea	4.400.000	5	Deutschland	6.200.000
6	Spanien	2.200.000	6	Indien	3.600.000	6	Süd Korea	4.600.000
7	Brasilien	1.500.000	7	Brasilien	3.200.000	7	Brasilien	4.400.000
8	UK	1.500.000	8	Mexiko	2.400.000	8	Mexiko	3.200.000
9	Kanada	1.200.000	9	Spanien	2.300.000	9	Thailand	2.800.000
10	Italien	1.200.000	10	Frankreich	2.200.000	10	Spanien	2.600.000
11	Belgien	1.000.000	11	Kanada	2.100.000	11	Frankreich	2.400.000
12	Russland	1.000.000	12	Thailand	1.700.000	12	Russland	2.400.000
13	Mexiko	1.000.000	13	Russland	1.700.000	13	Kanada	1.900.000
14	China	700.000	14	Iran	1.600.000	14	UK	1.700.000
15	Indien	650.000	15	UK	1.500.000	15	Iran	1.600.000

[1] (CBU & CKD)

Quelle: CSM Q2 /11

Figure 22*: Ranking-list of world vehicle producers*

More than 99% of the produced vehicles will be driven by further developed IC engines. This provides the engineers in the automotive industry with safe, interesting and intensive work in the coming time.

At the end, let's repeat the conclusions, which have been repeated for decades, since the first scientific meeting "Motor Vehicles and Motors":

- Four-stroke piston engine stays as main power unit for motor vehicles in the next 10 to 15 years.
- World oil reserves are secured for the next 30 to 40 years.

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