GREENPEACE

Four steps to a three-litre Golf

Expectations for the new Golf VII

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1. Introduction: The new Golf VII - at last, a three-litre car?

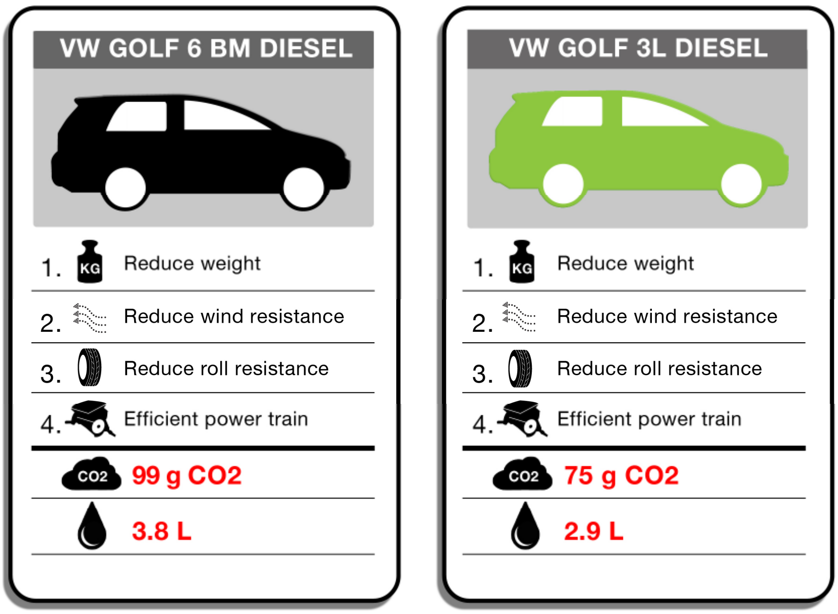
As the largest automobile manufacturer in Europe and perhaps soon the world, Volkswagen has a special responsibility for climate protection that it is not meeting. It is finally time to act.

Since 2011, Greenpeace's climate campaign has been challenging Volkswagen to make its cars more efficient and more climate friendly. The introduction of its mass-market model Golf VII in the autumn of 2012 offers VW an opportunity to live up to its climate responsibilities. In the following study Greenpeace demonstrates that the new Golf (diesel and petrol models) could achieve CO2 emissions of just 80 grams using about 3.4 litres of petrol (or three litres of diesel). And, it could do so using existing conventional technology – without partial electrification and without sacrificing safety, comfort or performance.

Diesel powered versions

Using simple technical measures and very slight additional costs the new Golf VII diesel could even achieve an efficiency level of 2.9 litres per 100 km (75 grams of CO2/kilometre). That would cause 25 % fewer CO2 emissions than the best Golf diesel (BlueMotion, 99 grams) and 37 % fewer than the current top-selling standard Golf diesel version (119 grams).

Four steps to the three-liter Golf VII



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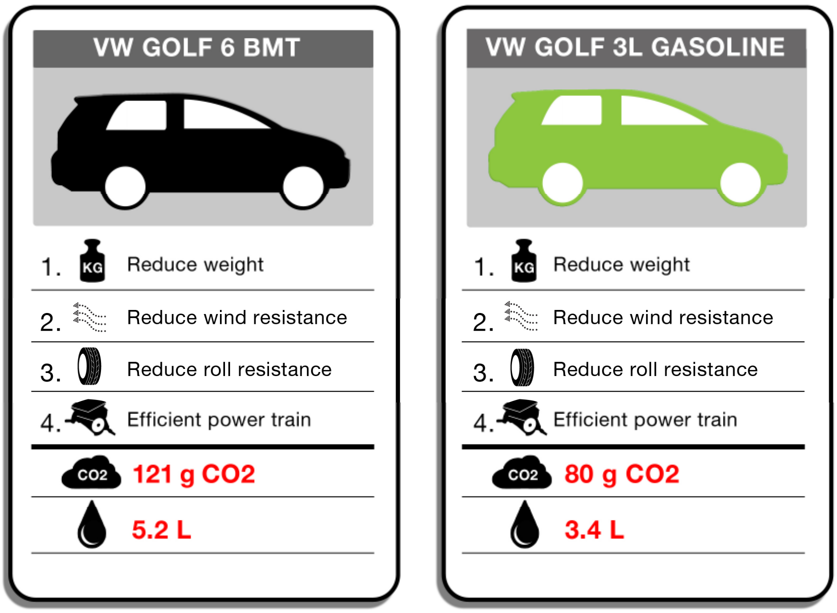
Petrol powered versions

Petrol models with a future consumption rate of 3.4 litres (80 grams CO2/kilometre) would improve CO2 emissions by 34 % over today's best model (121 grams with BlueMotion-Technology) or by 41 % compared with the current average petrol version (134 grams).

Four steps to the three-liter Golf VII



By employing a 'light hybrid' VW could even get fuel consumption down to as low as 2.6 litres of petrol (61 grams CO2/kilometre) – an improvement of almost 50 % over today's best model.

A standard model gas guzzler? No!

Greenpeace is demanding that VW turn the standard model for the next Golf (Golf VII) into a true three-litre car. 80 g CO2 emissions per kilometre using three litres (petrol: 3.4 litres) of fuel or less is already possible using conventional technology.

2. Why this study? Why now? A history

Why the Golf and why a three-litre car? The importance of fuel efficiency for climate protection and the need to cut automobile CO2 emissions in half has been clear now for more than 20 years. Climate protection is not an optional extra. The challenge/demand is that vehicles should not use more than three litres per 100 kilometres. This equates to a maximum of 80 grams/kilometre of CO2 emissions.

2.1 The SmILE

In the 1990s there were initiatives to bring a subcompact or microcar[1] on to the market with fuel efficiency of around three litres. Since then 'three' has become the magic number. As early as 1996 Greenpeace's SmILE (Small, Intelligent, Light, Efficient) project demonstrated that it was possible to cut fuel consumption in half without skimping and without higher costs. A mass-producible prototype – which to this day is still a landmark in technology and design - could cut the fuel used by a comparable standard model in half using "downsizing and supercharging" (highly compressed combustion air) together with a radical reduction in cylinder displacement size). The original Twingo (the base model for the SmILE project) used 6.6 litres; the SmILE version with a supercharged engine and less weight used only 3.3 litres. On numerous trips throughout Europe the SmILE averaged even less than 2.5 litres/100 kilometres.

However, the goal of the SmILE project was not the three-litre car. It was to cut fuel consumption in half for all types of vehicle.

[1] Translator's note: For a summary table listing the terminology used for passenger automobile size classes in Europe and the USA: http://en.wikipedia.org/wiki/Car_classification

2.2 VW and the three-litre car

Calls for a three-litre car grew louder. Volkswagen reacted and brought its '3-litre' Lupo diesel on to the market. But its exorbitantly high cost attracted few buyers to this eco demonstration model and even dealers advised against buying it.

Nevertheless, Volkswagen achieved two things with this project.

First, the company could now claim customers weren't interested in fuel-efficient cars. To this day VW Group has abused this argument to excuse its failure to offer an attractive fuel-efficient mass-market automobile.

Second, VW established the 'three-litre car = subcompact car' equation. But that still meant a drastic reduction of fuel consumption and CO2 emissions in the whole mass market.

2.3 Three litres in today's context

Greenpeace's 1996 goal – to cut average fuel use in half – is as timely today as it was then. In the meantime, SmILE technology – downsizing and supercharging – has won wide acceptance in the automobile industry. Fifteen years after SmILE, engine displacements have got smaller. But instead of lowering fuel use, cars have grown ever heavier and fuel consumption has fallen at only a snail's pace – **despite the fact that today the three-litre goal is technologically possible not just for subcompact cars but also for compacts and midsize cars.**

The future of the car will depend on its CO2 emissions. The emission limits set by the EU Commission will fall further. Greenpeace and other organisations are demanding 80 grams/kilometre for new cars by 2020. At a consumption rate of about three litres of diesel this figure is achievable using modest technical methods. By 2025 cars should no longer be emitting more than about 60 grams/kilometer CO2. This equates to fuel consumption of 2.3 litres of diesel (2.6 litres of petrol).

The new Golf will have a big influence on the car market for the next ten years. Accordingly, VW must incorporate the best fuel efficiency technology available as standard equipment. The goal: three litres.

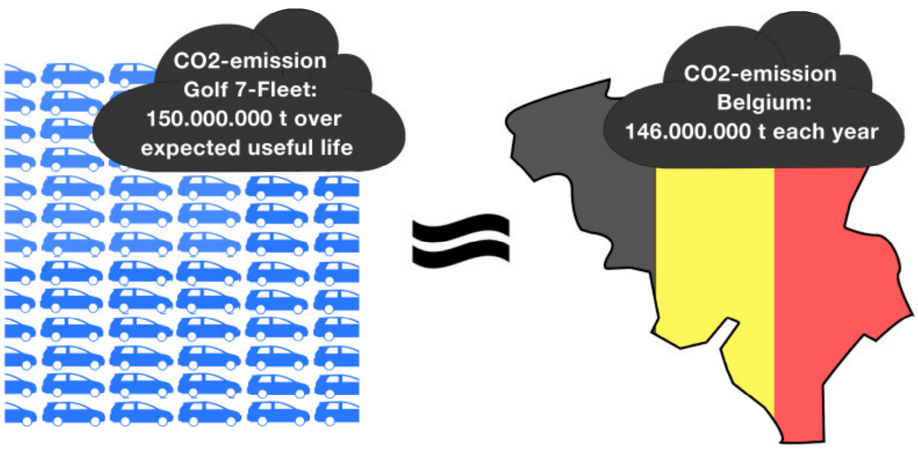
3. Why the Golf?

A three-litre Golf as a standard model? Technical advances have made it possible. The new Golf VII must be a true three litre car because political progress on climate change will be decided in the compact and/or the smaller compact class ('Golf class'). Here too, the key question is whether the fleet values permitted by the EU Commission will lead the way.

The Golf VII will come on to the market at the end of 2012. This is THE big event for VW because the Golf is the company's bread-and-butter car. Over the next ten years it is likely once again to be the bestselling automobile – and not just in Europe. The carmakers from Wolfsburg want it to lead the world market.

It is expected that 10 million will roll off the line. With an average driving distance and average fuel efficiency of five litres per 100 km (about 120 g of CO2/kilometre) they will collectively emit approximately 150 million tonnes of CO2. At first glance the difference between 120g and 80g of CO2 emissions doesn't seem particularly large. But the enormous number of cars translates into enormous effects and around 50 million tonnes of CO2 could be saved.

CO2-Emissions: Golf 7-Fleet



The three-litre Golf VII would play an exemplary role for an entire generation of cars in the compact and smaller compact class. Moreover, it will not only determine the quantity of fuel consumption and emissions until the next version appears (sometime around 2020), but its impact will last far longer in the used car market.

> Time for new cars: the new Golf generation will be THE most influential mass-produced automobile on the market for the next ten years. A reduction of fuel consumption by a few percentage points is not enough. Consumption has to drop drastically.

4. The background

No one disputes the necessity for significant reduction in fuel consumption by passenger vehicles for both economic and ecological reasons. But the German federal government, the automobile industry, automobile clubs and environmental groups have quite different views on what road to take to get there.

- For the German federal government the solution lies in ‘electro-mobility’. In other words, cars operating on batteries charged via the electrical grid. To ease the transition, more fuel should be produced from plant material.

- The automobile industry regards all-electric powered cars (plug-in cars) as merely a niche market over the long term. They may not say that quite so directly to the politicians but in the meantime they're happy to take their subsidies. And, by including E-cars as "zero emission cars" it makes it easier for them to meet CO2 goals. They expect, however, that even in the future the lion's share of vehicles will be powered by internal combustion engines.

- For the automobile clubs cheaply operated vehicles are desirable in the interests of the wallets of their members. In their view it would be even better, of course, if the state would ensure cheap fuel and lower crude oil taxes. Otherwise, these groups tend to welcome anything that the automobile industry offers by way of novelty.

- Environmental groups tend not to share the enthusiasm for electric vehicles. Combustion engines in their view may be obsolete but because of their dominance they offer the largest potential for pollution reduction. Moreover, there are increasing ecological concerns about plant-based fuels.

Other fundamental issues include:

How much more might a fuel-efficient car cost? Must cars in the future always be larger, faster, safer and more comfortable? Will fuel savings become so important in the future that speed limits will have to be imposed? What conditions can and will politicians set to ensure fuel savings are made?

A vehicle's efficiency depends on the demands placed on it and the behaviour of its driver. Critical for fuel consumption are the vehicle's weight and dimensions, the size of the engine (displacement and power output) and its gear reduction ratios. These factors in turn are influenced primarily by the desires of the purchaser and by legal requirements (the Traffic and Vehicle Registration Ordinance - StVZO, for example) with respect to vehicular safety and emissions.

Vehicular technical and individual factors influence each other. Drivers will drive faster with certain cars and vehicle manufacturers will design new models according to what they think buyers want. Volkswagen's successor models will be larger, stronger and more comfortable and their fuel consumption might also drop slightly. (See appendix: ‘A short history of the Golf models’). However, up to now these improvements in efficiency are considerably less impressive than in other consumption sectors, e.g. industry and households. On the other hand, the growing size of automobile fleets have cancelled out these specific improvements. A significant step towards more efficiency is overdue.

This study will highlight the technical modifications that can transform a Golf into a true three litre car with less than 80 grams/kilometre of CO_2 emissions.

5. Point of departure: the best Golf models

We start with the most fuel-efficient models – both petrol and diesel – existing today.

The idea is to show the efficiencies that can be achieved through sensible improvements. In so doing, we need to examine the diesel and petrol-powered models separately because the energy content of a litre of diesel is known to be about 13% more than that of petrol. Thus, in terms of energy and CO_2 emissions, a three-litre diesel car corresponds to a 3.4-litre petrol-powered one. The computations are derived from the current Golf VI. We will first discuss the possible steps that can turn the next Golf VII into a three litre car.

With respect to **diesel engines** we start with the most fuel-efficient model:

- Golf BlueMotion, 1.6 l displacement, TDI 77 kW (105 Hp), five-speed, DPF, avg. consumption: 3.8 litre/100km (city: 4.7, highway: 3.4) CO_2 emissions: 99 g/km curb weight 1,314 kg, max. gross weight 1,750 kg, with closed grill, tinted glass tail lights, 15 millimetre lower sport suspension as well as distinctive spoilers and rocker panels. With special undercarriage and rear axle coverings, friction-optimised drive shaft assemblies, longer gear ratios, lower idle speeds, reduced roll resistance tyres, shift prompts and a stop-start system.

With respect to **petrol-powered** versions we start with the most fuel-efficient model:

- Golf BlueMotion Technology, 1.2 l displacement TSI, 77 kW (105 Hp), six-speed, avg. consumption: 5.2 l/100 km (city 6.5, highway: 4.5), CO_2 emissions: 121 g/km, curb weight 1,234 kg, max. gross weight 1,750 kg.

Diesel	Gasoline
1.6 l displacement, TDI, BlueMotion	1.2 TSI BlueMotion Technology
77 kW (105 Hp) five-speed, DPF	77 kW (105 PS) six-speed
Fuel consumption combined 3.8 l/100 km	Fuel consumption combined 5.2 l/100 km

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Curb weight 1,314 kg	Curb weight 1,234 kg
Top speed 190 km/h	Top speed 190 km/h
Acceleration 0-100 km/h 11.5 sec.	Acceleration 0-100 km/h 10.5 sec.
CO_2 emissions combined 99 g/km	CO_2 emissions combined 121 g/km
Exterior dimensions: length x width x height: 4199 mm x 1786 mm (with mirrors 2,048mm) x 1512mm	Exterior dimensions: length x width x height: 4199 mm x 1786mm (with mirrors 2048 mm) x 1512 mm

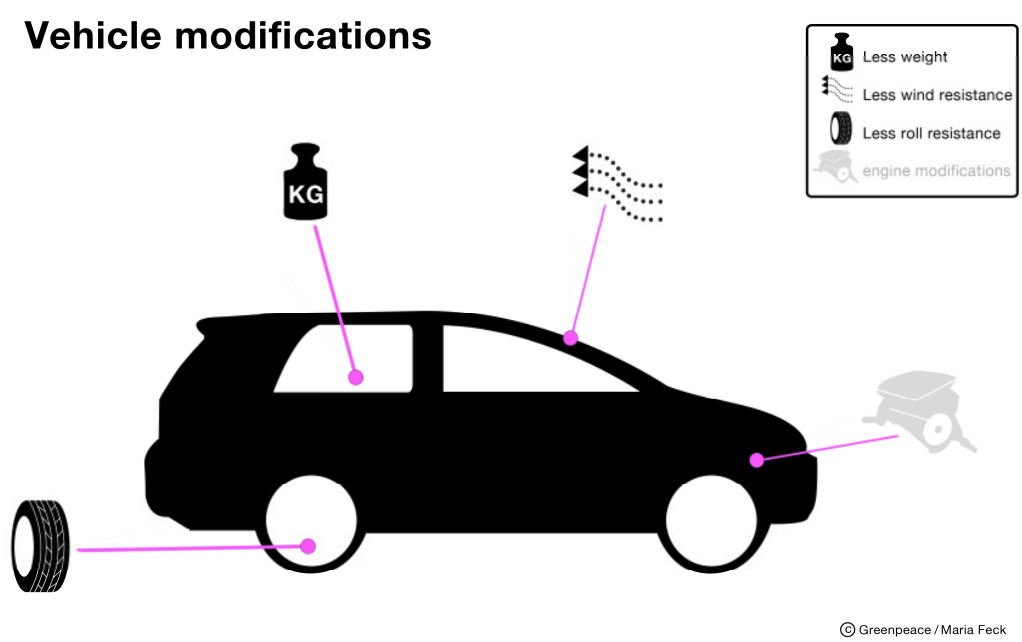
For the new Golf VII we assume – besides the goal of improved fuel efficiency – that the handling qualities for the driver will remain unchanged.

6. Four steps to a three-litre Golf

All the components of a passenger car model must be optimised to reduce its specific energy consumption. Systemically, we divide these into two areas:

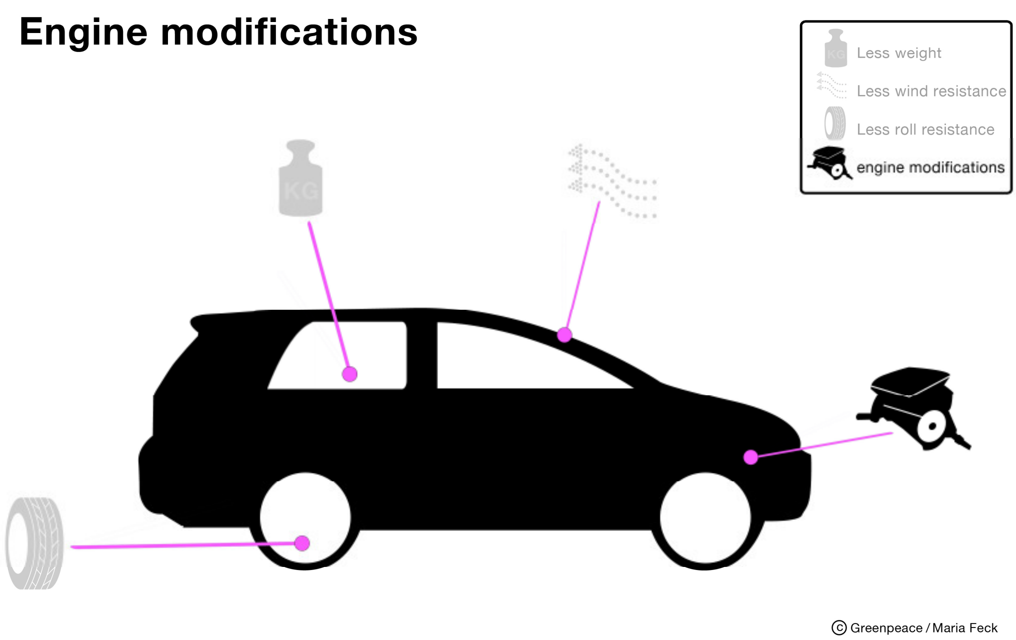
1. Area: energy requirements – vehicle modifications

The energy needed to move the vehicle: how much power must the power train provide and for how long to keep the car in motion?



2. System: efficiency – (changes to the power train)

Power train efficiency: how much fuel must be burned to produce the required mechanical energy for propulsion?



To compute the consumption reduction potential of the Golf VII we must first (step 1) express the energy required to move the vehicle in a simulations formula. Step 2 involves changes to the motor to increase the efficiency of the power plant. In step one the changes for both diesel and petrol-powered engines are practically identical. In step two, however, we must proceed differently.

6.1 Energy required to propel the vehicle

For what kind of vehicular motion must mechanical energy be provided within the prescribed New European Driving Cycle (NEDC)?

The cycle contains the following phases:

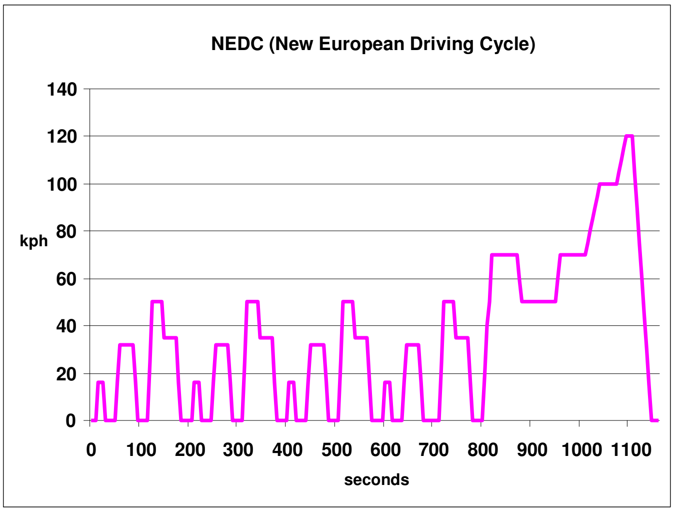
- Stationary vehicle (the engine is off or idling)
- Acceleration
- constant speed
- deceleration (e.g. with brakes)

In modern designs the engine of a vehicle at rest shuts itself off and saves idling fuel. Given the start-stop system used by both reference models (diesel BlueMotion and gasoline BluMotionTechnology) and their reduced idle speeds we can ignore this portion of the consumption. (For the record, the NEFZ figures calculate about 0.35 litres/100 kilometres).

The mechanical energy needed to accelerate and maintain a constant speed differs depending upon the range of speeds within the cyclic phase. The elements of acceleration vary. They include e.g. accelerations from zero to 20, from zero to 50 or from 70 to 120 kph. Maintaining constant speed, for example, is computed for short intervals at 30, 50, 70, 90 and 120 kph. The necessary propulsion energy for each segment or interval is computed separately and then totalled.

During deceleration phases no energy is added. (On the contrary: in deceleration phases energy can be generated; we will discuss this recapture later on.)

6.2 Excursus: the European driving cycle – basis for consumption data



The registration requirements of Germany's Traffic and Vehicular Registration Ordinance are identical to the EU guidelines. With respect to fuel consumption and pollution emissions they are based on driver behaviour described in the NEDC – New European Driving Cycle. Most of the consumption figures measured in the NEDC lie considerably below the values for average consumption in real life situations. The test cycle does not describe actual traffic behaviour. For example, in normal life, people brake more strongly and drive faster. The cyclical values overall provide deceptively low consumption figures. The discrepancy is especially large in the case of new test conditions for hybrid vehicles with driving intervals using electric motors.

Despite the difficulties in using the NEFZ, our study must also use these testing parameters when discussing savings potentials. The individual elements of the driving cycle must be viewed separately for fuel consumption and savings potentials. One must first differentiate between the inner-city traffic intervals (about 4 km in city traffic lasting a total of 780 seconds at a range of speeds up to 50 kph interrupted by several simulated waits at traffic signals), and the subsequent phase involving about 7 km of driving outside built-up areas lasting about 400 seconds at (sequential) speeds of 70, *50, 100 and finally 120 kph. The consumption figures measured for the inner-city traffic segment (a) and the segment outside urban areas (b) are added together to come up with a total consumption figure.*

Source : Greenpeace presentation of data illustrating Rule No. 101 of the UN/ECE published in the official gazette of the European Union dated 19.6.2007

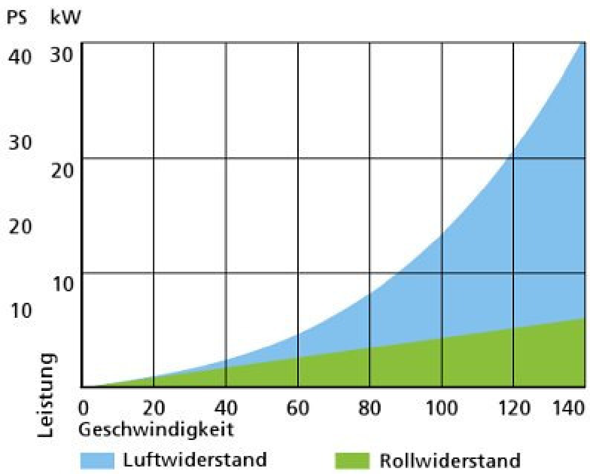
Some comments concerning the phases:

- **Vehicular mass** directly determines energy consumption in the **acceleration phases**: the heavier the car, the more energy must be used for acceleration. The 1,500 kg weight used marks the upper end of the Golf VI weight spectrum. For models with intermediate equipment and engines, one can assume weights of 1,300 to 1,350 Kg. A reduction of energy requirements by about 23 % would require a reduction in curb weight to between 850 and 900 kilograms.

- In the **constant speed phases roll resistance** (at lower speeds) and air resistance (from about 50 km/h on up) are the most important factors. Roll resistance is computed as the product of the specific roll resistance of the tyres (cr) and vehicular mass. Generally speaking, resistance figures for tyres in the past were always getting lower but, on the other hand, the trend to wider tyres is unfavourable. In general, narrower tyres offer less roll resistance. They also help reduce air resistance. In today's tyre market, roll resistance can vary between 0.008 and 0.012. Choosing the best (easy running) tyres instead of the worst identified in this study (there are still worse examples out there) would produce a 12 % drop in needed energy. However, because manufacturers post their official measurements based on relatively good tyres, the potential for savings here would be lower (from about 0.011 to 0.008).

- The **air resistance** of the vehicle is derived from the specific ‘air resistance coefficient’ that describes how well a body is designed to ‘cut through’ the air and the frontal surface area (width x height) of the passenger car. Thus, a very good cW alone will not be enough if the frontal surface area gets larger.

- The length of the vehicle does not directly affect air resistance but it does do so indirectly: the air resistance coefficient cW drops for longer vehicles (‘length runs’). That shortness produces unfavourable automobile cW values which can also be seen in the poor cW values for the Smart car. A reduction of the cW value from, for example, 0.35 to 0.29 could reduce driving cycle requirements by about 10 %; and if, for example, you were to reduce the front surface area (vehicle width times height) from 2.6 to 2.2 m^2 the energy needed would drop by about 7 %. If you assume the improvements described above in air resistance (0.35 to 0.29), in frontal surface area (2.2 instead of 2.6 m^2) and roll resistance (from 0.011 to 0.008) then the energy required drops by about 35 % (from about 13.5 kWh per 100 kilometres to 8.8 kWh per 100 kilometres).



This german graph dramatically illustrates the effects of air resistance (blue) in particular as speed increases. (green: roll resistance)

In the deceleration phases, i.e. when braking, the energy produced for the acceleration phases is lost. If it were possible to store all that energy and use it for driving, the energy required for the driving cycle could be computed solely from the amount of propulsion energy consumed to maintain constant speed. However, recapturing 100% is not possible; at most around 50 or 60% is feasible. But even then one would get below 2 litres per 100 km. What might braking energy recapture look like? Hybrid vehicles provide some practical examples. What is needed is a "light" hybrid with somewhat larger (and unfortunately heavier) batteries and the capacity to switch on an electric motor during acceleration phases in order to tap the energy stored from braking.

Thus there are three ‘adjusting screws’ for reducing the energy needed for propulsion:

a. vehicular mass,

b. roll resistance, and

c. air resistance.

6.3 The first step: less weight

Here, matters have been going in the wrong direction for decades: the Golf has grown heavier and heavier. What are the possibilities for making the golf VI models lighter? The technical literature provides the following weight allocations/distributions:

- 35 % to the chassis (of which 58 % raw body shell, 25 % add-on parts, 19 % glasswork, etc.)
- 22 % to the drive train (of which 50 % for the engine, 17 % for the transmission)
- 20 % to the suspension (of which 36 % horizontal and vertical moving parts, 32 % wheels/tyres, 20 % brakes)
- 16 % to the interior (of which 36 % seats, 30 % interior trim)
- 7 % to miscellaneous items

We will concentrate on the primary massive parts: the raw body shell, drive train and suspension. In the case of the Golf VI the raw body shell weighs about 440 kg and without moving parts like doors and the hood: about 300 kg. According to the results of the EU's 2008 SuperLIGHT Car project, which used a Golf class car as its subject matter and in which the VW headquarters participated, the static raw body shell – while maintaining its safety levels in crash tests (head-on collision, side and rear end collisions) – could be made 115 kg lighter. It was estimated that doing so would add approximately 10€ per kg to the cost.

Another 65 kg could be saved by using lighter add-on parts (engine and trunk lids, doors and light sheet glass). (This is implied by the savings achieved on the modified VW Lupo 3-litre with 52 kg less weight for parts added on to the chassis including, e.g. aluminum doors, aluminum magnesium trunk lid, add-on parts, thinner plate glass, weight-optimised undercarriage protection.) At that time the raw body shell was not modified for cost and safety reasons. Translating the findings from the Lupo to the larger Golf VI leads to a savings potential of 65 kg. This reduces the weight of the whole raw body shell to 180 kg.

A study done by RWTH Aachen in 2011 calculated that this reduction in mass makes a "secondary weight reduction" possible that allows a further 45 kg less weight in other important components for every 100 kg of lower vehicular weight.

This is possible because, for example, the lighter vehicle requires somewhat less braking surface, wheel suspensions do not have to be so strongly dimensioned, the same acceleration values can be achieved with less cylinder displacement. The engine and suspension, the tyres and petrol tank, battery etc. of lighter cars have to transfer less power and withstand less torque. This allows a weight reduction spiral to be set in motion.

Secondary weight reduction for engines, suspensions etc. based on the assumed 180 kg lower weight could add up to another 50 to 70 kg. Another area of reduction would affect the interior trim (seats etc.). Both these reductions should not be separately quantified here. They can increase the economically available reduction potential to – an estimated – 220 kg. We will continue to use a weight reduction of 180 kg as a conservative value for the new Golf VII compared with the corresponding versions of the Golf VI. (Comment: that would bring the curb weight of the Golf VII to the level of the earlier Golf IV. In interviews given in recent months, VW representatives have identified that as a goal).

Applying this to both golf VI reference models (diesel 1.6 TDI Blue Motion (BM) and petrol-powered 1.2 TSI Blue Motion Technology (BMT) results in the following improvements:

- Golf VII diesel BM: curb weight lowered from 1,314 kg to 1,134 kg, which reduces needed propulsion energy (and thus both consumption and CO2 emissions) by about 9 % compared with the Golf VI.
- Golf VII gasoline version BMT: curb weigh lowered from 1,234 kg to 1,054 kg, which reduces needed energy (and thus both consumption and CO2 emissions) by about 9 % compared with the Golf VI.

6.4 The second step: less roll resistance

In the second set of computations we assumed a curb weight reduced by 180 kg each. The propulsion power needed for motion is computed as the product of vehicular mass and the roll resistance coefficient or cr. For a given vehicular weight this will be determined by the qualities of the tyres. These tyre qualities are influenced in particular by tyre pressure, tyre diameter, tyre width, tyre construction and tyre tread. The higher the air pressure – as will be familiar to cyclists – the easier the wheel rolls. For its BlueMotion models VW prescribes air pressure at about 0.3 bar higher.

The dimensionless [-] coefficient cr is defined as the quotient from roll resistance force (N) and tyre load. In the published data for modern tyres (http://www.recodrive.eu/docs/35/03pkw-reifenliste.pdf) the specific resistance is given as a percentage – a normal value of 1% therefore corresponds to cr = 0.01. The EU's tyre identification ordinance 1222/2009 prescribes the classification of the cr values between <6.5 (Category A) and >12.1 kg/t (Category G); according to the other factors given, this corresponds to cr values between 0.65 % and 1.21 % or 0.0065 and 0,0121 [-]. (Comment: Additional improvement potential can be found in the higher and narrower tyres designed to date for electric autos with diameters larger than 60 cm).

After the 2012 identification guidelines went into effect, renowned tyre manufacturers announced that they had already designed models that qualified for roll resistance Category A. It is noteworthy that in so doing they also achieved the ‘A’ identification status applicable to brakes.

For the energy-efficient Golf VII we cautiously assume an improved tyre cr value ranging from 0.01 (for the Golf VI reference models) to 0.007. The following improvements result:

- Golf VII diesel BM: propulsion energy needed (and thus consumption and CO2 emissions) about 17 % lower than for the Golf VI.
- Petrol-powered BMT: propulsion energy needed (and thus consumption and CO2 emissions) about 17 % lower than for the Golf VI.

6.5 The third step: less air resistance

For the step from the Golf VI to the Golf VII we assume that the front end or cross-section surface area remains unchanged at 2.2 m^2. As the Golf has developed, its front-end area has grown steadily larger, primarily through greater width. Improved air resistance resulted from the fact that – with the exception of developments from the Golf V to the Golf VI – the cars got ever longer. For cars, like boats, the rule that 'length runs' also applies to air streamlining.

But what potential lies in the specific air resistance coefficient cw? The cw value of the Golf VI BlueMotion compared with the other models was improved from 0.3 to 0.29 by modifications to things like the radiator grill and undercarriage. Aerodynamic improvements are generally cost-efficient but on the other hand the European Test Cycle with its average speed of 32 km/h gives air resistance values for fuel consumption that are considerably lower than in actual driving where a mid-range speed of 80 km/h ought to be assumed.

The professional literature cites improvements ranging up to about 0.2 while maintaining the front-end surface area / length ratio; for slimmer cars like one-litre vehicles, less than 0.16 is achieved. For the coming Golf generation we conservatively assume an air resistance coefficient cw of 0.25 for the diesel (now 0.29) and 0.26 for the petrol-powered version (now 0.31). The somewhat lower value for the diesel is because lower levels of heat wasted in the diesel combustion process requires less cooling air in-flow.

This results in the following improvements in propulsion energy requirements:

- **Golf VII diesel BM: propulsion energy needed (and thus consumption and CO2 emissions) about 22 % lower than for the Golf VI diesel BM.**
- **Petrol-powered BMT: propulsion energy needed (and thus consumption and CO2 emissions) about 22 % lower than for the Golf VI gasoline powered BMT.**

Despite the somewhat different initial assumptions and improvements with respect to parameters for weight, roll and air resistance, both reference models produce a 22% reduction in the energy required for motion during the driving cycle.

Without any further modifications to the drive train (in particular the engine and transmission) improvements in the particular weight, roll resistance and air resistance can achieve the following reduction in fuel consumption and CO2 emissions:

- **Golf VII diesel BM: fuel consumption reduced from 3.8 to about 3.0 l/100 km and CO2 emissions lowered from 99 to about 78 g/km.**
- **Petrol-powered BMT: fuel consumption reduced from 5.2 to about 4.0 l/100 km and CO2 emissions lowered from 121 to about 94 g/km.**

6.6 Efficiency improvements in the area of drive train effectiveness

As is the case for the entire car the premise applies that, in estimating the possibilities for reducing fuel consumption and CO2 emissions in the drive train, no reductions in functional utility may be demanded. Like the discussion above on weight, we may use the model figures computed by VW from its participation in publicly subsidised projects for the following discussion of the drive train.

The European driving cycle demands only a small part of available power and torque be used for measurements of consumption and exhaust values. To sell a Golf VI with at least 77 kW of engine power VW purports to guarantee that less than 11.5 seconds is needed to accelerate from zero to 100 Kph. If one were satisfied with 15 seconds, a maximum engine power of about 58 kW (instead of 77 kW) would suffice.

Energy requirements and engine power needed for acceleration vary in direct proportion to the vehicular mass. By reducing weight by about 180 kg, an engine with a maximum power of about 65 kW would suffice for the 11.5 second acceleration performance previously achieved with 77 kW.

The 77 kW maximum power is also important for the acceleration capacity and top speed of the Golf's six reference models. With the weight reduction described above a comparable acceleration performance can be achieved with about 10 kW less power (68 kW a set of 77 kW) with a correspondingly smaller engine cylinder displacement. If one takes into consideration the improvements in cr values and cw values, then less than 65 kW will suffice. (Governors would have to be used to prevent exceeding today's maximum 190 kph speed for the Golf six).

Analogous motorization would suggest a 1.4 litre engine for the Golf VII diesel and a 1.0 litre engine for the gasoline-powered version; both with 65 kW.

What modifications to improve efficiency can we now undertake for both engines?

The following in particular suggest themselves:

(A) reduction in friction and other energy loss within the engine-transmission system,

(B) increase in combustion efficiency in the cylinders, and

(C) hybridisation, i.e. adding an auxiliary electric motor.

6.7 The fourth step: more efficient engines

Concerning item (A): friction and other energy loss

Low-viscosity oils for engines and transmissions are most effective during the first minutes of operation after starting the driving cycle. According to Ifeu et al. (http://www.ifeu.de/energie/pdf/NKI_Endbericht_2011.pdf), 3 % savings can be achieved over conventional engine oils. It is unclear how high the cyclic savings might be for, say, a 0W-40 class oil over the 5W-30 class oil now recommended and/or used by VW. No data on thrifty transmission oils are not available.

Other improvements might be achievable using better materials and optimised adjustment to the friction contact surfaces; see the slogan: “friction-optimised drive shaft assembly” for diesel BlueMotion and gasoline BMT models. This could logically include in the engine and in the power plant (from piston friction over all stages to the drive shaft) and in all assemblies connected to it. Their savings potential lies to a greater extent in mechanically decoupling them from the combustion engine and shifting them to the electrical power plant. Examples of this are radiator cooling fans, the shift of all circulation pumps on the motor and transmission to electrical operation, the steering column (not included the NEFZ measurement cycle), brakes and many others. The hydraulic and some intake vacuum pressure-powered auxiliary systems can be powered by the battery. Which naturally makes sense if these are charged (a) either by ‘free energy’ from recuperation during deceleration or (b) by ‘consumption-friendly’ optimally efficient operating conditions.

BlueMotion already partially uses recuperation and decoupling of auxiliary systems from the combustion motor under certain conditions. The remaining potential for the two types of engine can be assumed at 3 % (diesel) to 5 % (gasoline).

This produces the following improvements:

- **Golf VII diesel BM: further lowering of fuel consumption from 3.0 l/100km to 2.9 l/100km and a drop in CO_2 emissions from 77 to about 75 g/km.**
- **Petrol-powered BMT: lowering of fuel consumption from 4.0 l/100km to about 3.8 l/100km and a drop in CO_2 emissions from 94 to right about 90 g/km.**

Concerning item (B): combustion efficiency

To operate the petrol-powered engine over the largest possible segments of the NEFZ at a high efficiency level, it must be operated under a heavier load, i.e. at a high compression ratio. Because the power requirements in particular during the first segment of the cycle intended to reflect inner-city driving are low, only small displacement engines with a heavy load can be operated – otherwise one has too much mechanical energy. (Another possibility for saving excess energy is dealt with under item (C) hybrid motors).

The hypothetical expense is particularly justified for modifications to petrol-powered cars since combustion using the Otto carburetion principle is particularly inefficient at low engine power output levels.

The following technical modifications are to be applied to the petrol-powered version of the Golf VII:

a. Variable valve control (VVS): this permits reduction of the amount of air in the cylinder, which in turn allows for less fuel per combustion cycle. Unlike the usual petrol engine's use of intake throttling to tune partial loads, the loss of flow is much lower. In any event, the corresponding partial load-combustion cycle evidences a lower compression ratio than the full load cycles. Using VVS, 2 to 3 % fuel consumption (i.e. for example, 0.15 litres/100 km) could be saved over the NEFZ.

b. Cylinder shut-down: this turns a 1.2 litre motor with four cylinders into a 600 cc motor by shutting down (usually) the middle two cylinders. The remaining two can then operate at nearly full load over many of the cycle segments. During those phases the efficiency rate increases from about 20 to more than 30 %. However, one must take into consideration that this assumes an engine that already has a small cylinder displacement (1.0). According to the professional literature, cylinder shut-down achieves a 10 to 15 % improvement; according to VW: 0.4 litres/100 kilometres less over the cycle.

Modifications a. and b. can be combined with each other but the savings effects cannot be simply added together. We estimate the improvement potential at a conservative 0.4 litres/ 100 kilometres (petrol-powered vehicles only!).

The running totals then look like this:

- Golf VII diesel BM: not used. Fuel consumption remains at 2.9 l/100km and reduced CO_2 emissions at 75 g/km.
- Petrol-powered BMT: fuel consumption drops to about 3.4 l/100km and CO_2 emissions fall to about 81 g/km.

Concerning Item (C): hybrid engines

One can view the electrification of auxiliary systems and the use of 'excess' electricity (either obtained from braking energy or by a good level of efficiency from the combustion motor) as an introduction to hybridisation. The storage potential of the battery in such cases can remain relatively small – that is the current state of today's technology.

To get to a hybrid drive with which one can, for example, negotiate more than 50 km of inner-city streets at speeds up to 50 km/h, the battery must be significantly larger than it is with now familiar Japanese hybrid car models. We assume a 'light' hybridisation that allows some of the acceleration energy to be recovered and for the combustion motor to be switched off under very unfavourable operating conditions.

The concept is attractive for two reasons. First, the combustion motor is used only at higher power demands on the engine when its efficiency is relatively high. In substantial parts of the NEFZ one could assume, for example, a 28 % efficiency rate from a gasoline engine instead of the – usual – less than 20 %. Second, part of the braking energy can be recaptured. This, however, comes at the cost of an added 150 kg or more of vehicle weight and about € 2,000 in higher manufacturing costs. Because of the – relatively – high efficiency rating of diesel motors the hybrid concept really only makes sense if the main power plant is a gasoline engine.

How high would achievable savings now be for the corresponding Golf VII reference model? For simplicity's sake we assume a car weighing 180 kg more (analogous to the Golf VI, 1.2 litre TSI BMT). That increases the propulsion energy required by about 11 %. (The consumption values of 3.8 litres/100 kilometre achieved through Item A. above would increase to about 4.2 litres/100 km.) If, with hybrid drive, the mid-range engine efficiency, for example, increases from 20 % to 25 % (due to the concentration on higher loads and charging the battery for electrical drive at lower energy requirements) this could bring the gasoline-hybrid combination to 3.3 litres/100 km.

With respect to recuperation (recapture of braking energy) the specifications of the NEFZ offer ideal conditions because the changes in motion are much gentler than in real life driving. As a result one could recover about 50 % of acceleration energy. A rough calculation shows that 39 % of propulsion energy is used for acceleration. In the hybrid concept all the deceleration phases are now used for generating electricity (recuperation) for the battery, from which propulsion energy is then drawn.

The theoretical maximum amount of energy that can be recovered from the decelerations in the NEFZ equates to that used for acceleration. If one assumes the inclusion of all losses in the system path from a moderate efficiency rate of 50 % for recuperation, then 19.5 % of the propulsion energy in the NEFZ (50 % of 39 %) could be saved. This does not mean, however, that recuperation can reduce fuel consumption to that extent because when using the electrical drive under battery power as described above, combustion engine operation takes place only at higher efficiency levels anyway. Thus, the following quantitative estimate is fraught with considerable uncertainties and is extremely hypothetical.

Running total with hybridisation (only for petrol models):

- Petrol-powered BMT: reduction of fuel consumption from 4.2 l/100 km to – theoretically – about 2.6 l/100km and CO_2 emissions reduced from 121 g/km to about 60 g/km. That would cut the fuel consumption and CO_2 emissions of the Golf VI reference model in half.

6.8 Summary: effects of reduction steps for diesel powered versions

Using a simplified computation model the effects of the aforementioned three modifications on the diesel BlueMotion were simulated step by step: 1. weight reduced from 1,314 kg to 1,134 kg; 2. roll resistance improved from 0.01 to 0.007 and; 3. cw values improved from 0.29 to 0.26.

For propulsion energy requirements this means:

1. **reduced weight:** achieves about **9 %** less than the initial value, plus:
2. **improved roll resistances:** achieves about **17 %** less than the initial value, plus:
3. **improved air resistance** (cw value): achieves a total of about **22 %** less than the initial value.

There is a reduction of 22 % for propulsion energy requirements; from 3.8 l of diesel/100 km or 99 g/km CO2 to 2.94 l/100km (rounded up to 3) or 77 to 78 g/km CO2.

Because of improvements in its mass/R/cw ratio, its reduced energy needs allow for a slight downsizing from 77 kW to 65 kW (displacement reduction from 1.6 to 1.4 l) – without sacrificing acceleration and top speed.

Modifications to the Golf diesel in relation to vehicular mass, roll and air resistance

Today's most thrifty Golf VI diesel (1.6 TDI BM 77 kW) Today's parameters:	**Modifications**	**Improved Golf VII (1.4 TDI BM 65 kW)** reduction %, total of all modifications	**Effect** Consumption/ CO2
weight 1,314 kg	Modification 1: weight 1.134 kg	Modification 1: about 9 % better than Golf VI	3.5 l/100km 90 g/km
roll resistance 0.01	Modification 2: roll resistance 0.007	Modification 2: about 17% better than Golf VI	3.2 l/100km 82 g/km
Cw value 0.29	Modification 3: Cw-Wert 0.25	Modification 3: about 22% better than Golf	3 l/100km about 78 g/km

		VI	
Consumption/ CO2 3.8 l/100 km. 99 g/km			Consumption/ CO2 of the new Golf VII diesel (only by modifications to the vehicle): 3 l/100km. 78 g/km

Efficiency increases with the diesel model solely by modifications made to the vehicle result in:

Overall vehicle improvement: about 22%

Consumption: 3 l/100 km

CO2 emissions: 78 g/km

Additional modifications to the Golf diesel in relation to power plant.

Golf VI diesel	Modification	Reduction by %	Effect: consumption and CO2
		Starting point without additional modifications: 22 % better than Golf VI	Starting point without additional modifications: 3 l/100 km, 78 g CO2/km
With BM partial recuperation over some segments and decoupling of auxiliary systems	Further decoupling of auxiliary systems from the combustion motor	Additional reduction of about 3 %, total effect including additional engine modifications about 25%	Conclusion: 2.9 l/ 100 km 75 g CO2/ km

Overall results for diesels:

Overall improvement: about 25 %

Fuel consumption: 2.9 litres/100 km

CO2 emissions: 75 g/km

6.9 Summary: effects of reduction steps for petrol powered versions

We start with what is currently the best Golf petrol-powered model, the 1.2 TSI with BlueMotion Technology, 77 kW (105 Hp), six-speed, with driving cycle consumption of 5.2 l/100 kilometres (city 6.5, highway: 4.5), CO2 emissions: 121 grams/kilometre, initially we make the same modifications affecting required energy that we made above for the diesel:

weight reduced by 180 kg, less roll resistance, air resistance improved to 0.26. The reference weight of 1,234 is less than the diesel. We nevertheless assume the same 180 kg weight reduction.

1. **weight reduction:** achieves about **9 %** less compared to the initial figure, plus

2. **roll resistance reduction**: achieves about **17%** less compared to the initial figure, plus

3. **air resistance reduction**: achieves a total of about **22 %** less compared to the initial figure.

As we explained with the diesel, the improvements permit a reduction in engine power from 77 to 65 kW a - with no efficiency improvements in the combustion motor itself - a 15 % reduction in cylinder displacement, i.e. from 1,200 to about 1,000 to 1,050 cc.

Modification to the Golf petrol-powered model in relation to vehicular mass, roll and air resistance

Today's most thrifty Golf VI petrol-powered model (1.2 TSI BMT 77 kW) Today's parameters:	**Modifications**	**Improved Golf VII petrol-powered version (1.0 TSI 65 kW)** reduction %, total of all modifications	**Effect** Consumption and CO2
curb weight 1,234 kg	Modification 1: Curb weight 1,054 kg	Modification 1 : about 9 % better than today's Golf VI	4.8 l/100km 110 g/km
roll resistance 0.01	Modification 2: roll resistance 0.007	Modification 1+2: about 17 % better	4.3 l/100km 100 g/km
Cw value 0.31	Modification 3: Cw value 0.26	Modification 1+2+3: 22 % better	4.0 l /100km 94 g/km

Greenpeace: Four steps to a three-litre Golf - Expectations for the new Golf VII

Consumption/ CO2 5.2l/ 100km. 121 g/km			Consumption/ CO2 of the new Golf VII (only by modifications to the vehicle): 4.0 l/100km 94 g/km

Efficiency increases for the petrol-powered version achieved solely through modifications to the vehicle:

Overall improvement: about 22 %

Consumption: 4.0 l/ 100 km

CO2 emissions: 94 g/km

Additional modifications to the Golf petrol-powered version in relation to power plant

Golf VI Gasoline version	Modifications	Reduction in %, total of all modifications	Effect: Consumption and CO2
		Starting point without additional modifications to the power plant: 22 % better than Golf VI	Starting point without additional modifications to the power plant: 4.0 7l/100km, 94 g/km
	Modification 1: Reduction in lost energy (decoupling auxiliary systems)	Additional reduction to a total of about 26%	3.8 l/ 100 km 90 g/ km
	Modification 2: Increase motor efficiency rate with VVS and cylinder shut down	Total about 34 % better than today's Golf VI	3. l/100km 80 g/km

Overall results for petrol-powered version	
	Overall improvement: about 34%
	Fuel consumption: 3.4 l/100 km
	CO2 emissions: 80 g/km

Alternative			
Motor without electric drive	Modification: Combine with light hybrid, some segment under electric power, recuperation	This would make the Golf VII better by a total of almost 50 %	Using the light hybrid solution: 2.6 l/100km 61 g/km

Using a light hybrid:	
	Overall improvement: about 50%
	Fuel consumption: 2.6 l/100 km
	CO2 emissions: 61 g/km

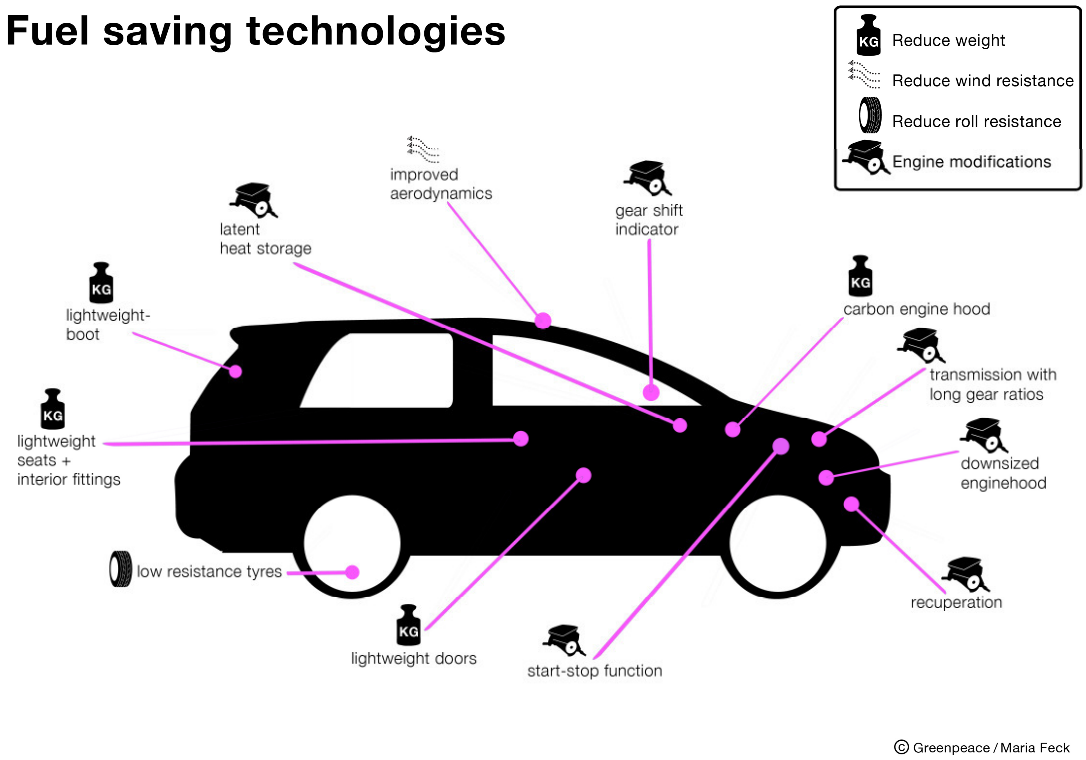
7. Outlook

One out of every five cars sold in Europe carries the VW brand. But only a fraction of the cars delivered meet the standards of its own fuel savings technology. One thing is clear – the car of the future will be small, thrifty, intelligent and efficient.

Will VW make the modifications identified above? The group is well acquainted with them, they are technically feasible, require no technological breakthroughs and, without exception, are cheap. The most expensive single modification is the ‘light hybrid’ solution but that is not even necessary for achieving the three-litre goal.

If VW doesn't achieve the magic ‘three’, it will jeopardise the sustainability of future generations of automobiles. It will be a black day not only for climate protection but for VW as well – fuel prices are going to rise further and in the long term it is the company offering the most thrifty and technically reliable cars that is going to be the market leader.

Climate protection is not an optional extra: VW must build its best fuel saving technology into every one of its passenger cars as standard equipment without additional cost. If Europe's largest car maker cannot do that, then at least marketing and pricing will have to do the work of ensuring that the thriftiest models are comparable to the others.



These are all highly conservative assumptions that need to be met at the very minimum in the Golf VII. For future developments the modifications identified here are a simple matter of course and will not suffice for very long. **The coming Golf VIII – through drastically reduced weight and still more efficient engines – will have to move in the direction of a one-litre car.**

8. Appendix

8.1 A short history of the Golf

For more than 35 years the Golf has defined Germans' images of the car. The first Golf – later called the Golf I – came on to the market in 1974. It was followed by five more. The Golf VI has been around since 2008. The countdown to the Golf VII is in process.

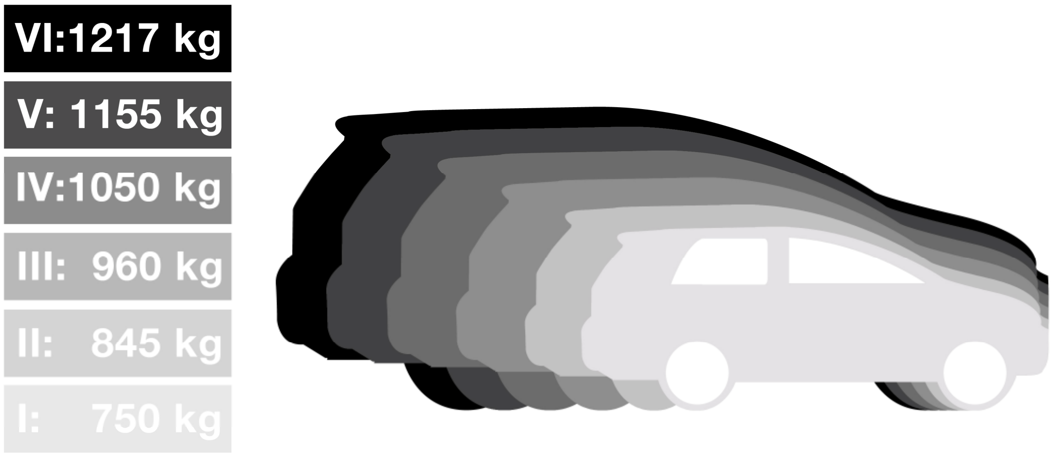
For Volkswagen the Golf is its most important source of revenue in the lower compact class. Before the Golf there was the VW Beetle, which with brief exceptions, was the world's top selling car. The engine of the first Golf had 1.1 litres displacement (50 hp) up to 1.5 litres (70 hp). Its top speed of around 150 km/h was regarded as high. Test magazines praised its acceleration figures of between 15 and 17 seconds for the sprint from zero to 100 km/h. The Beetle, by contrast, was not that dynamic: buyers of its last model in 1973 had to be satisfied with a top speed of 135 km/h and a sprint speed of 21 seconds.

The 1974 model, which represented the transition from the Beetle to the Golf years, introduced a trend for 'sporty' driving. Although the later Beetle models had had a little more horsepower than their predecessors, the new generation of Golfs deliberately aimed at boosting cylinder displacements, engine power and top speeds. VW quickly discovered that engine power could be pushed higher at relatively low cost and that the willingness of the buyer to pay was worth many times more than the additional production costs. Special models like the GTI and ever larger engines followed. Today you can buy a Golf VI with up to 270 hp with speed and acceleration numbers that in the past were reserved for the Ferraris of this world. The 'people's' car was transformed into a mid-size vehicle with racing features – right down to the wide tyres.

In order to provide ever more hp for higher speeds and faster acceleration, cylinder displacements had to get steadily bigger. In the first model the standard engine displaced 1.1 litres and the more powerful version 1.5 litres. Then in 2003 the Golf V upped the ante to 1.4 to 3.2 litres displacement. In other words, a top of the line car motor was working in the Golf. With the Golf VI this development was partially reversed. The mottos were: consumption limits and downsizing with supercharging.

Another remarkable development was its developing size: over the decades the Golf got ever wider, longer, heavier. At 750 kg the Golf I had a significantly smaller curb weight than the VW Beetle and at 3.7 metres it was also significantly shorter. But those dimensions grew with every model. The Golf VI weighs in at 1,200 kg in its lightest version and grew in length by a good half-metre. The Golf I had a surface area of 5.9 m^2 but the Golf VI has already reached 7.5 m^2 – a 25% increase. Even in its lightest version, its weight has increased by 60 %.

Golf I-VI: heavier and heavier



How wide and how high a car is determines its cross-section (or frontal area), which is important for air resistance. The combination of more weight and more air resistance means greater energy need. Air resistance increases along with driving speed and it becomes the most significant factor in energy need at around 60 kph.

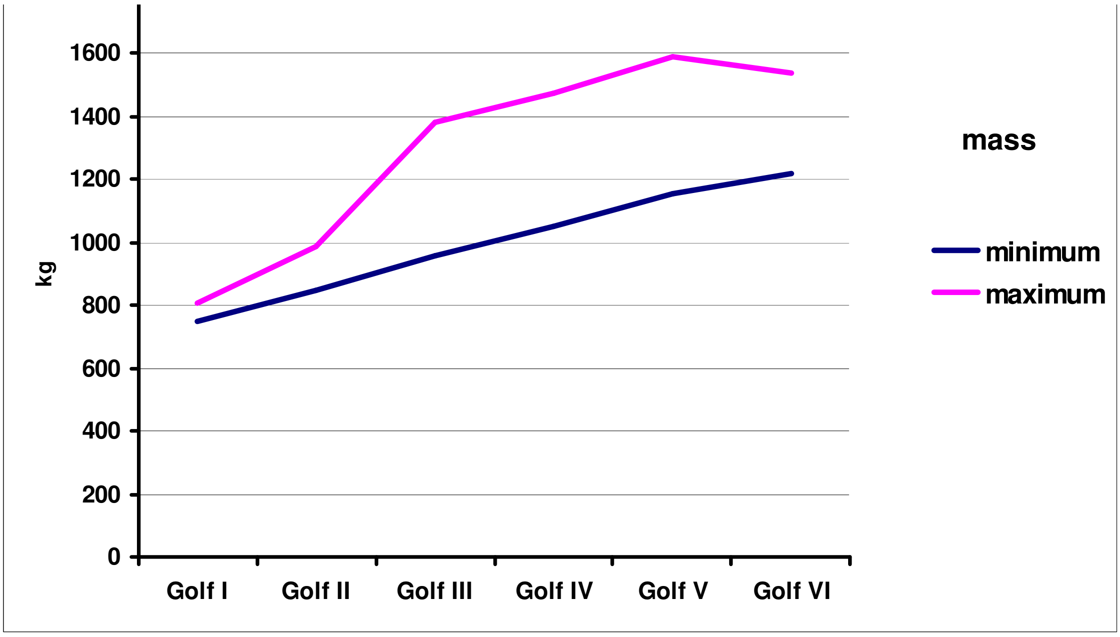
The air resistance of the latest Golf fell. But lowering the cw value of the sixth model to 0.3 , or 25 % less than the initial value (cw = 0.4), is only a superficial solution to the problem. Although according to the formula, frontal surface area times cw value the energy needed at 100 kph, for example, is more favourable by 10 percent, in reality several other factors lead to higher consumption:

- There are ever wider tyres (the cw values, however, are given only for standard tyres) and speeds driven have steadily increased.
- Cars have gotten ever faster. A Beetle was just about shot at 100 kph. Today's median passenger car autobahn speeds are around 130 kph. and the total share of driving done on the autobahn has grown.
- The improved cw values are accompanied by increasingly flat and ever larger windshields. As a result the sun's rays make interiors hotter. Air conditioning is installed. This can lead to far more than 1 litre of added fuel consumption for every 100 kilometres.

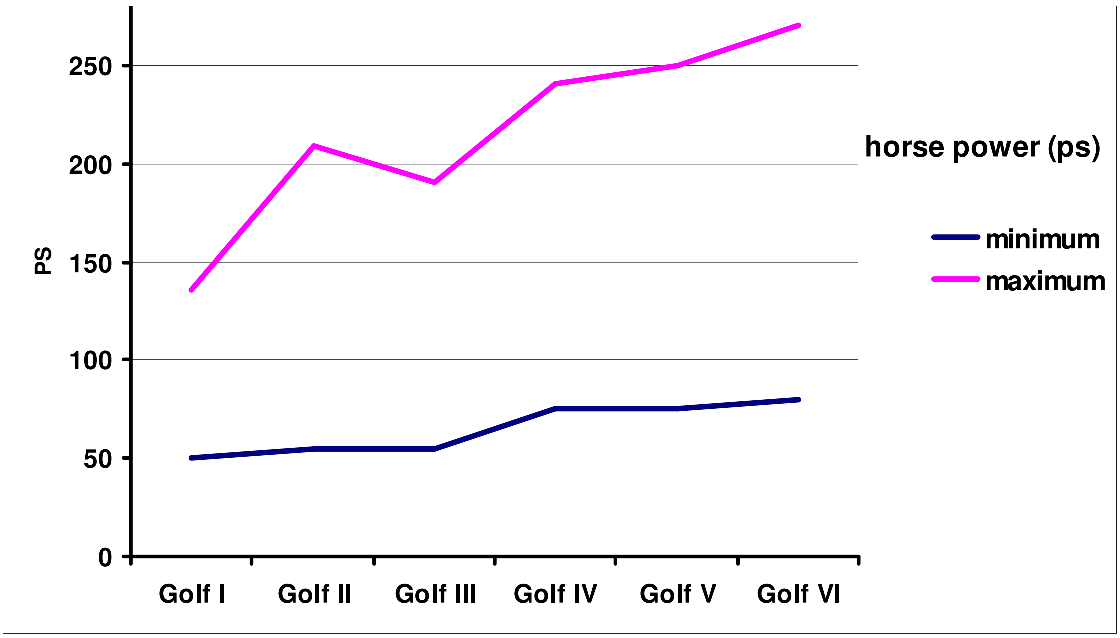
From the Golf I to the Golf VI

	Golf I 1974 – 1983	Golf II 1983 - 1992	Golf III 1991 – 1997	Golf IV 1997 – 2003	Golf V 2003 – 2008	Golf VI 2008 – 2012
petrol engines	1.1–1.6 litres (37–100 kW)	1.3–1.8 litres (40–154 kW)	1.4–2.9 litres (40–140 kW)	1.4–3.2 litres (55–177 kW)	1.4–3.2 litres (55–184 kW)	1.2–2.0 litres (59–199 kW)
diesel engines	1.5–1.6 litres (37–51 kW)	1.6 litres (40–59 kW)	1.9 litres (47–81 kW)	1.9 litres (50–110 kW)	1.9–2.0 litres (55–125 kW)	1.6–2.0 litres (77–125 kW)
length mm	3705	3985–4040	4020	4149–4397	4204–4206	4199
width mm	1610	1665–1680	1695–1710	1735	1759	1786
height mm	1390–1410	1415	1405–1425	1439–1485	1470–1483	1479
wheel base	2400	2475	2471–2474	2512 R32: 2517	2578	2578
curb weight kg	750–805	845–985	960–1380	1050–1477	1155–1590	1217–1541

Heavier and heavier: the Golf's average minimum weight has steadily increased over the years. In the case of maximum weights there has been a slight drop with the Golf VI.



Average engine sizes have grown steadily bigger; particularly in the case of the most powerful Golf models.



8.2 What is BlueMotion and BlueMotion Technology?

The modifications employed and offered by VW for the two Golf VI reference models are:

for the diesel model, BlueMotion (1.6 l, 77 kW):

- Start-stop system
- Recuperation (recapture braking energy)
- Lower idle speed
- Multifunction display with recommended gear
- Longer gear ratios
- Roll resistance optimised tyres
- Vehicle-specific undercarriage and rear axle housings
- Aerodynamically optimised bumpers and chassis suspended 15 mm lower
- Closed radiator grill for lower air resistance
- Friction optimised drive shaft assemblies
- Special seat covers.

For the BlueMotion Technology models:

(1.2 TSI, 77 kW, BlueMotion Technology)
(1.6 TDI, 77 kW, BlueMotion Technology)

in contrast to the ‘normal’ Golf 1.2 TSI or 1.6 TDI:

- Start-stop system
- Recuperation (braking energy recapture)
- Multifunction display with recommended gear
- Roll resistance optimised tyres
- Vehicle-specific undercarriage and rear axle housings
- Friction optimised drive shaft assemblies

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