VOLKSWAGEN AG

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SunFuel

Volkswagen's Fuel and Powertrain Strategy

Can mobility really be sustainable? Can road transport be not only economical but also ecologically and socially compatible? One thing is for sure: if humankind is to remain mobile in the future, sustainable mobility is a must. Because firstly the most important resource in the current fuel production chain – oil – is a finite resource, and secondly the numerous impacts of growing levels of traffic are becoming an ever-increasing problem.

The response from the automobile industry will be twofold: not only new vehicle concepts but also new powertrains that will require new fuels. These fuels will no longer be based primarily on fossil resources but they will have to be compatible with the existing fuel supply infrastructure. For its part, since 2000 Volkswagen has been working on a fuel and powertrain strategy that will lead to these goals. Today our efforts are already beginning to bear fruit – not least through the Alliance for Synthetic Fuels in Europe (ASFE), in which we work hand-in-hand with partners from the European automobile and oil industries to bring about the market launch of synthetic fuels in Europe.

> "Our fuel and powertrain strategy is both level-headed and leading-edge. It relies on three principles: increasing the efficiency of the powertrain while reducing tailpipe emissions; incorporating alternative energy sources in the fuel production process; and developing fuels that are CO_2-neutral and can be used in existing engines."
>
> Dr. Bernd Pischetsrieder, Chairman of the Board of Management, Volkswagen AG

Oil is the locomotive that drives the world's economies. In 2004, the countries of the European Union (EU) alone consumed roughly one fifth of the world's oil production. As we all know, within the foreseeable future it will no longer be possible to produce oil at today's cost levels. In other words, the price of oil is sure to go on rising. Nevertheless, in the coming years and decades oil will remain an essential part of the fuel production process.

Consequently, Volkswagen's fuel strategy is based on the diversification of raw materials (feedstocks) and not of fuels. The idea is to use a range of different raw materials to produce fuels that can then be distributed via existing filling stations and used in existing vehicles.

Given the overarching aim of reducing carbon dioxide emissions from road traffic and the ongoing tightening of emissions legislation, Volkswagen is promoting the more widespread use of CO_2-neutral energy sources and in particular biomass. The aim is to use biomass alongside oil and natural gas in the production of liquid fuels.

Working for a clean future: Renate Künast, German Federal Minister of Consumer Protection, received the BtL life cycle assessment study from Prof. Herbert Kohler (DaimlerChrysler) and Volkswagen's Head of Research Matthias Rabe (right). Time for a test drive with Matthias Rabe (left) and Reinhold Kopp, Corporate Government Relations, Volkswagen AG

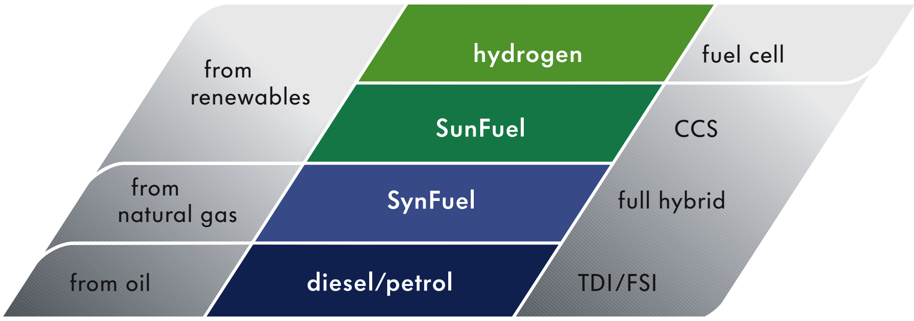
This aim of using more biomass in fuel production has also been set down in the fuel strategy of the Federal Republic of Germany, the main points of which align with those of Volkswagen's fuel strategy. Biomass will have a major part to play in realising the declared aims of the German government and the EU by 2010, when biofuels are due to account for 5.75 percent of the fuel market. In this respect, synthetic fuels, which can also be produced from biomass, have far greater economic and ecological potential than either biodiesel or ethanol, for example.

> "In the medium to long term, a new generation of biofuels produced synthetically from biomass exhibit the greatest potential, because in this way high quality diesel fuel can be produced from any kind of biomass – such as waste, plants or wood – by gasification and subsequent synthesis."
>
> German government progress report on "Sustainable Development"

In future, not only will fuels be endowed with specific properties, but these "designer fuels" will also become an influential factor in the engine development process. This will open the door to new engines that bring about further substantial reductions in fuel consumption and emissions. Thus our fuel strategy is set to become a fuel and powertrain strategy, within which the development and optimisation of fuels and powertrains will be closely geared to one another.

In the long term, Volkswagen sees the fuel cell as a highly promising complement to the tried and tested internal combustion engine. Before that can happen, however, there are technical, economic and logistical problems to be resolved, such as the production of hydrogen from renewable energy resources.

The Volkswagen fuel and powertrain strategy: Evolution not revolution



Source: Volkswagen AG

Our goals

Sustainability
Economic, ecological and social compatibility are the driving forces behind our fuel and powertrain strategy.

Diversification of feedstocks
The aim is to safeguard future supplies by using several different raw materials for fuel production.

Use of existing infrastructure
The market launch of new fuels only has a realistic chance of success if they can make use of the existing supply infrastructure.

Optimising oil-based fuels

Along with the development of new fuels, however, the future will also bring a worldwide improvement in conventional oil-based fuels. A reduction in the sulphur and aromatics content of these fuels will lead to a significant drop in vehicle emissions. In addition, these enhanced fuels will enable engine technologies such as the direct-injection petrol engine (FSI) and the direct-injection diesel engine (TDI) to be rolled out worldwide. These are proven technologies that bring about a substantial reduction in both fuel consumption and exhaust emissions.

Synthetic fuels

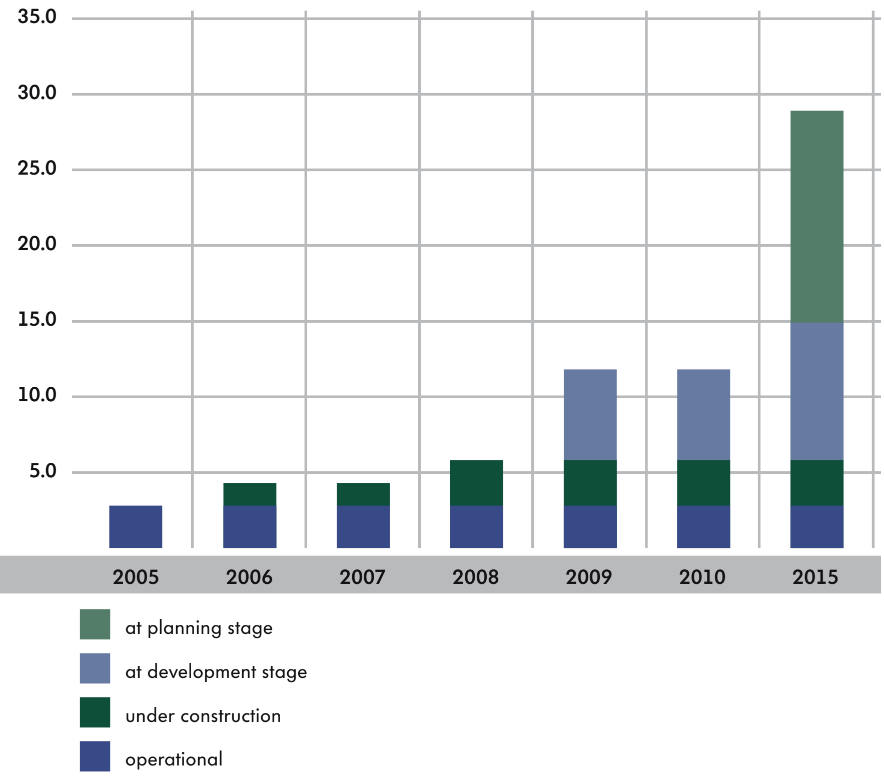
Synthetic fuels, or SynFuels for short, are produced from synthesis gas in a two-stage process. The synthesis gas, made up of hydrogen and carbon monoxide, is obtained either from fossil feedstocks such as coal or natural gas, or from biomass. It is transformed into liquid fuel in a process known as Fischer-Tropsch synthesis. If natural gas is used as the feedstock, the overall process is referred to as GtL or gas-to-liquid, as a liquid fuel is obtained from a gas. GtL fuel has been in industrial-scale production since 1993, when companies such as Shell began manufacturing it in Malaysia. Given the right background conditions, the technology involved is

Makes flaring natural gas a thing of the past: A GtL plant in Qatar

already economically viable, and as the demand for oil grows, driving its price ever upwards, GtL technology will become an even more attractive economic proposition. This trend is reflected in the GtL activities of the major oil companies in Qatar, for example. Shell alone is currently investing five billion dollars in what is today the world's largest commercial GtL plant, with a capacity of 6.5 million metric tons of SynFuel a year.

Worldwide GtL output*

Annual capacity in million metric tons of oil equivalent



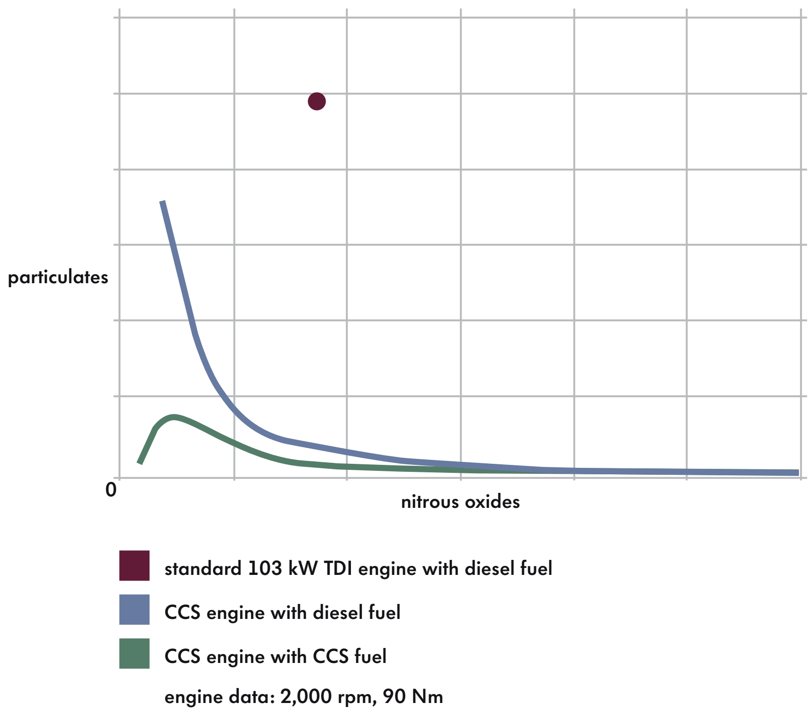
Source: Volkswagen AG

*** By way of comparison: 28 million metric tons of diesel fuel were consumed in Germany in 2003.**

SynFuels offer two decisive advantages:

Lower emissions:
Using the above production process, fuel properties can be determined more precisely than is possible at today's refineries, leading to a substantial reduction in emissions not only from modern vehicles but from older vehicles in particular. SynFuel also permits the application of enhanced engine technologies such as the Combined Combustion System (CCS), which combines the lower emissions of a petrol engine with the low fuel consumption of a diesel engine. A SynFuel tailored to CCS virtually eliminates emissions of soot and nitrous oxides.

Potential reduction of emissions with CCS



Source: Volkswagen AG

Use of the existing filling station infrastructure:
SynFuel is a high-purity liquid fuel with physical properties similar to those of petrol or diesel. As a result, the existing filling station network can continue to be used with no problems. This is not the case, for example, if natural gas is used directly as a fuel rather than as a feedstock. Moreover, no technical changes to the current vehicle fleet are required. This is a decisive advantage, because it means that lower emissions are not restricted to new vehicles but can be achieved by all vehicles.

Production of GtL represents a viable option in particular for natural gas fields in remote geographical locations, where the production of natural gas by conventional means is not economically feasible. Unlike natural gas, GtL produced where the gas is extracted does not have to be pumped to market along pipelines, involving great cost and effort. Instead it can be easily filled into road tankers. For this reason, oil companies Chevron and Sasol are building a GtL plant with an annual capacity of 1.5 million metric tons in Nigeria, where natural gas that was previously flared is to be converted into high quality fuels.

SunFuel derived from biomass

Synthetic fuel derived from biomass, also known as SunFuel, is just as straightforward to use as SynFuel and has the same advantages on the emissions front. It is produced by the same synthesis process, which means that the characteristics of the fuel are of the same high standard. The main difference is that biomass is used as the feedstock instead of natural gas. As a result, SunFuel presents a greenhouse gas neutrality level of up to 85 percent. This is because the carbon dioxide generated by a car powered by SunFuel was originally taken up from the atmosphere during the growth of the plants that provide the energy. The combustion of fossil fuels, by contrast, leads to higher concentrations of CO_2 in the atmosphere.

Powering up for a better climate: Measuring emissions from a SunFuel-powered New Beetle on a rolling-road test rig

The primary feedstock for SunFuel is biomass, which is why the production process is referred to as biomass-to-liquid or BtL. The biomass can be made up of a variety of fast-growing and undemanding crops, although organic waste such as straw or wood waste can also be used. The gasification process leading to synthesis gas is successfully implemented by Choren Industries in Freiberg, Saxony, for example, as well as at the Karlsruhe Research Centre, both in Germany.

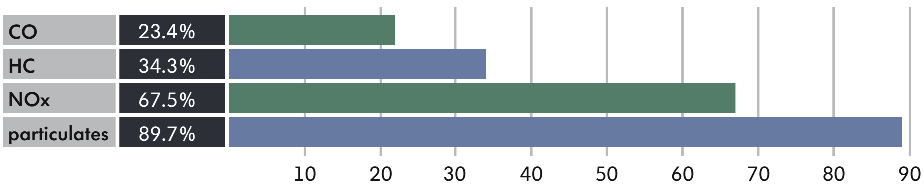
The SunFuel process is particularly suitable for the production of diesel fuel and kerosene, as well as – with additional process steps to increase the octane rating – for petrol. DaimlerChrysler and Volkswagen are currently engaged in successful

In search of green energy: Prof. Konrad Scheffer (right) with a group of engineers in test fields near Ehmen in Lower Saxony, Germany

joint tests of a BtL diesel fuel manufactured by Choren – a fuel we call SunDiesel. In a Golf TDI with a 103 kW engine, emissions of nitrous oxides (NOx) have been reduced by more than 30 percent over the New European Driving Cycle (NEDC) compared to oil-based diesel fuel. Emissions of hydrocarbons (HC) and carbon monoxide (CO) have been cut by an even greater margin.

BtL emissions*

relative to diesel



Source: Volkswagen AG

* **Engine control unit tuned for maximum reduction of NOx**

Choren puts the cost of manufacturing SunFuel at approximately 70 euro cents per litre, and can see potential for cutting that figure to 50 cents per litre as a result of further progress and greater market penetration. As the German government has granted biofuels exemption from oil tax from January 2004, such production costs mean that SunFuel can compete with conventional oil-based diesel on price.

SunDiesel or SunFuel should not be confused with biodiesel. Biodiesel is made from rapeseed oil, and has very different properties from diesel manufactured from crude oil. It can only be used in diesel engines that have been technically modified. SunFuel, by contrast, can be used to power any vehicle.

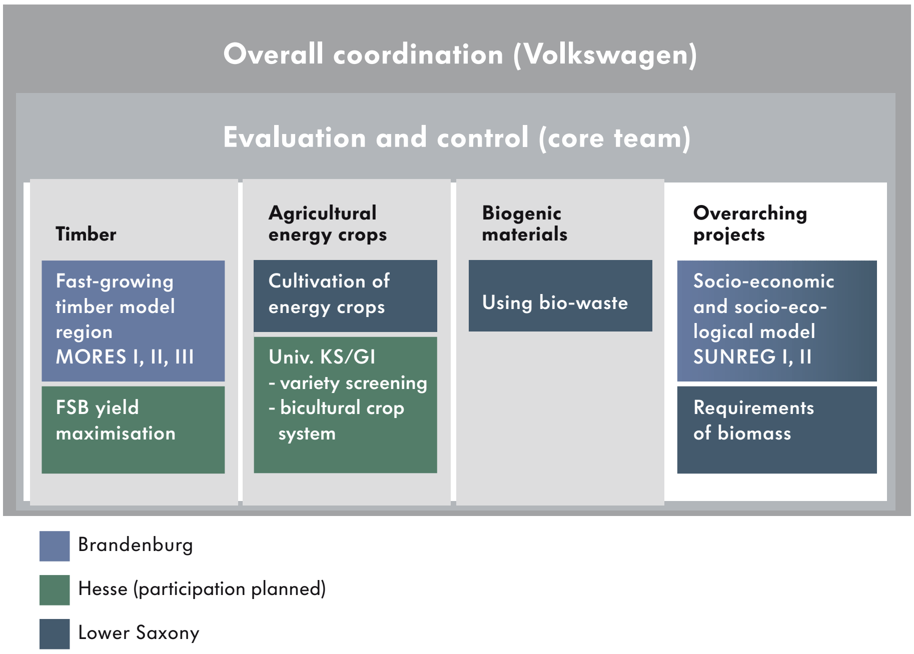
New opportunities for farmers

Using biomass as the feedstock for fuel production opens up new earnings potential for farmers. It also creates opportunities to master the problems of overproduction and the additional challenges that will face the agricultural sector in the future. According to a study** conducted by the Institute for Energy and Environment in Leipzig, Germany, Europe (defined as the EU 30 in 2020) will be capable of pro-

** **“The technical potential of liquid biofuels and biohydrogen”, Institute for Energy and Environment, 2004.**

ducing 70 million metric tons of SunFuel a year without cutting back on food crops. This would meet more than one fifth of the total demand for vehicle fuel (diesel and petrol for cars and commercial vehicles) of the 30 EU states of the year 2020.

State project: “Biomass for SunFuel”



Source: Volkswagen AG

The future introduction of such biogenic synthetic fuels on a larger scale will lead to a fundamental change in the agricultural landscape, and this calls for comprehensive preparations. To this end, the German federal states of Brandenburg and Lower Saxony have joined forces with Volkswagen in a project called “Biomass for SunFuel”. The federal state of Hesse has also expressed a strong interest in the topic and announced its intention to join this cooperation. The aim of the project is to develop a biomass supply infrastructure within a viable ecological and economic framework, as a fundamental prerequisite for the industrial-scale production of SunFuel.

Debating the fuel strategy: Renate Künast, German Federal Minister of Consumer Protection (3rd right) with experts from the Business Forum at the International Conference for Renewable Energies in Bonn

SunFuel is eco-friendly

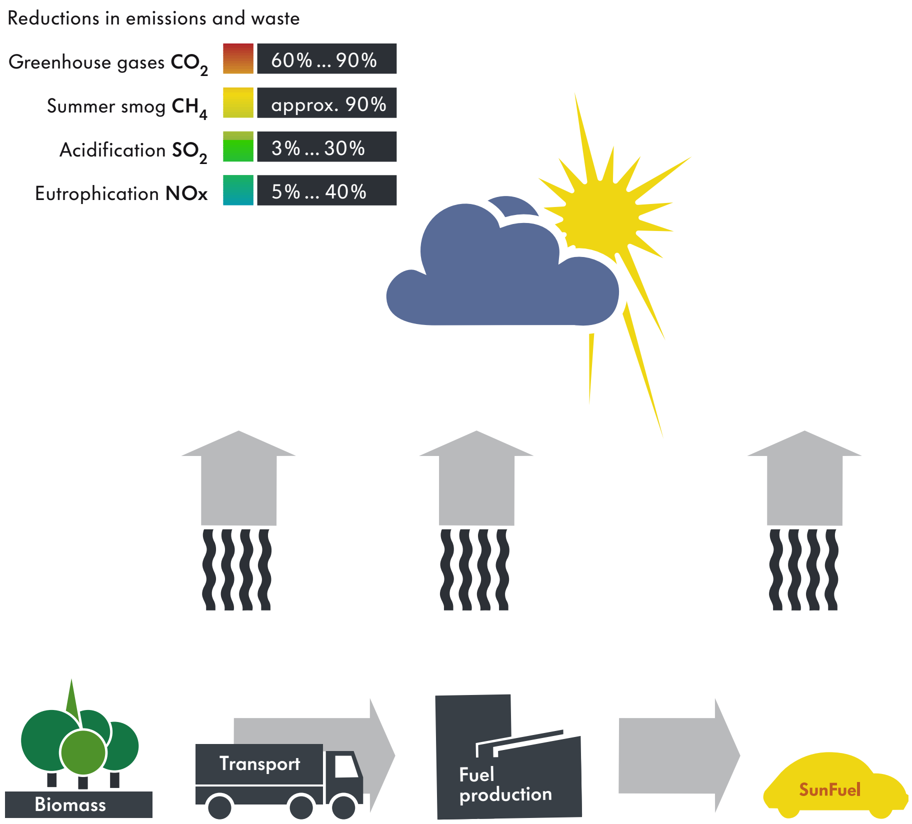
A life cycle assessment (LCA) study* commissioned by Volkswagen and DaimlerChrysler confirms the ability of SunFuel to ease the load on the environment. Like all life cycle assessments, the study took account of all processes along the value chain from the extraction of the raw materials to the actual use of the fuel. That includes not only the chemical transformation processes but also the transport of the biomass to the production plant and of the resultant fuel to the filling station. And while the production of SunFuel calls for large volumes of biomass to be transported, the LCA shows that the transport process does not cancel out the synthetic fuel's marked positive impact on the environment.

*** "A comparative life cycle assessment of SunDiesel (Choren process) and conventional diesel fuel", 2004.**

A comparative life cycle assessment with three scenarios**

SunFuel / conventional diesel fuel (life cycle assessment)

**** The three scenarios are set out on the Internet at www.sunfuel.de**



Source: Volkswagen AG

But the benefits do not stop there. Along with substantial potential for optimisation in the synthesis process itself, the logistics of the operation also offer scope for improvement. For example, small decentralised plants can be set up to convert biomass to pyrolysis oil – as an intermediate product – in a relatively simple fast-pyrolysis process. This greatly facilitates the use of biomass for the production of SunFuel, as different kinds of biomass can be used and the pyrolysis oil has good storage properties and a high energy density. As a result, it can be transported efficiently to the large central synthesis plants, thereby further enhancing the economic and ecological benefits of the SunFuel production process.

Dreaming of the future: A fuel cell Touran HyMotion on the Challenge Bibendum 2004 in Shanghai

Hydrogen from renewable resources for the fuel cell

Hydrogen is a fuel, i.e. it is derived from a feedstock. If it is obtained from natural gas or other fossil fuels, it loses its ecological advantages. It is like a zero-emission electric car, in that the power it needs has to be generated by a power station. And the global pro-rata CO_2 emissions of a power station can be greater than those of an efficient conventional powertrain.

So in fact, only hydrogen obtained from renewable energy resources (renewables) represents a sensible step forward. But before hydrogen from renewables can become available as a fuel for mobile applications, several technical and economic problems still have to be resolved in terms of:

- production from renewables
- on-board storage for an adequate operating range
- the very costly establishment of a hydrogen infrastructure which, given the cross-border nature of traffic, would not be restricted to a single country.

In Volkswagen's opinion, using hydrogen as a fuel makes sense only in fuel cells – on account of their high efficiency. The benefits of using hydrogen in internal combustion engines cannot offset the expense and complexity of storing the fuel and creating the required infrastructure. A more meaningful approach in terms of easing the burden on the environment is to use hydrogen in oil refineries or in the production of SunFuel. The use of hydrogen produced externally from renewables can more than double the amount of SunFuel generated per unit of biomass. The advantage here is that while the hydrogen supply infrastructure is being put in place, the time can be used to set up production of hydrogen from renewables. So effectively SunFuel helps to make the transition to the hydrogen economy a closer and more realistic prospect.

Volkswagen can only see hydrogen becoming a serious contender as a fuel for mobility applications in 20 years' time at the earliest. But we also need a solution that we can implement faster – a solution that will help us make a timely contribution to sustainable mobility in the near future. For us, that solution is SunFuel.

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