VOLKSWAGEN

AKTIENGESELLSCHAFT

Evolution not Revolution

The Volkswagen Fuel and Powertrain Strategy

High time for a change of direction

FOSSIL FUELS SUCH AS OIL AND NATURAL GAS ARE ONCE AGAIN HEADLINE NEWS – AND FOR A VERY GOOD REASON: DESPITE THE OCCASIONAL PRICE CUT, THE LONG-TERM REALITY IS THAT THESE FUELS ARE SET TO BECOME MORE AND MORE EXPENSIVE. TWO FACTORS ARE PRIMARILY RESPONSIBLE FOR THIS: LIMITED AVAILABILITY, AND INCREASINGLY DIFFICULT POLITICAL CIRCUMSTANCES IN MANY OF THE REGIONS IN WHICH THEY ARE PRODUCED.

In spite of the fact that ever more innovative techniques are being used to extract fossil fuels, the truth is that, for many years now, we have been consuming oil faster than we have been able to find new reserves. In any case, even such supposedly spectacular and increasingly media-hyped recent finds as those in the Gulf of Mexico have little impact on our current situation, since these new reserves are depleted within a matter of months.

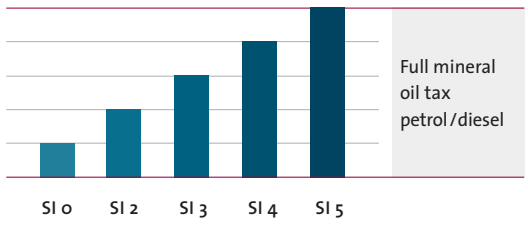
According to latest estimates published by the Federal German Institute for Geosciences and Raw Materials (BfGR), peak oil production is now not far away. Depletion mid-point – the moment when we cross the halfway mark of the planet's entire crude oil reserves – will be reached in just ten to 20 years. From this point on, worldwide production will slow, whereas consumption is likely to continue growing for the foreseeable future. This means that rising demand and stagnating or even falling supplies will push oil prices to even greater heights than those we are experiencing today. All this is only a matter of time.

That's why Volkswagen has developed a Fuel and Powertrain Strategy that opens up a route to sustainable mobility; a mobility that is economically, ecologically and socially compatible. We want to play an active part in cutting global emissions of the climatically relevant gas carbon dioxide (CO_2); to help reduce local emissions of pollutants such as nitrous oxides and soot particles; and at the same time to restrict our dependence on oil. Consequently, our strategy focuses on diversifying the feedstocks (the raw materials from which fuels are derived). The idea is to use a range of different feedstocks to produce fuels that can then be distributed via existing filling stations and used in existing vehicles. Furthermore, these fuels should have the potential to be used in even more efficient and cleaner generations of engines.

But these goals will not be achieved with some of the first-generation biofuels currently available; fuels such as ethanol, biodiesel, natural gas (CNG) or LPG Autogas. These products often have entirely different molecular structures and therefore very different characteristics. So in the majority of cases

BIOFUEL TAXATION

Volkswagen's proposal



Vehicles could be assigned to one of six sustainability categories (SI = Sustainability Index) as a basis for taxation. SI 5 corresponds to the existing mineral oil tax in Germany. Regular reviews would ensure that biofuels do not benefit from excessive tax breaks.

Source: Volkswagen AG

they require not only the development of new engine technology, but also a new production and supply infrastructure.

Modern fuel production processes are normally optimised in line with economic rather than ecological considerations. For example, bioethanol is derived from a distillation process involving the combustion of lignite, which generates almost 10 percent higher emissions of CO_2 than petrol. That is why Volkswagen supports not only the increased use of CO_2-neutral sources of energy – and biomass in particular – but also production processes that can demonstrate a very good CO_2 balance. The result is what we call second-generation biofuels.

One of the benefits of these fuels is that they only emit into the atmosphere the same volume of carbon dioxide as was taken up by the plants as they grew. That's why, as a long-term incentive for the production of these fuels, irrespective of the technology employed, Volkswagen has called for a modified taxation model in place of quotas. Any such tax model should be aligned with market economics and based on CO_2 efficiency and sustainability criteria. In other words, the lower the volume of carbon dioxide emitted, the greater the tax benefit should be.

For Volkswagen, there is no doubt that a major part in solving these problems can be played by second-generation biofuels – that is to say, those that not only reduce CO_2 emissions by over 80 percent, but do so by exploiting biomass cultivated without impacting foodstuffs production. Second-generation biofuels include bioethanol derived from straw and the now familiar SunFuel®. We are therefore also supporting research into advanced development of fuels derived from biomass, and in this context, Volkswagen is represented on the management committee of the European Biofuels Technology Platform, a research initiative responsible for establishing framework conditions to successfully bring biofuels to market in the European Union (EU).

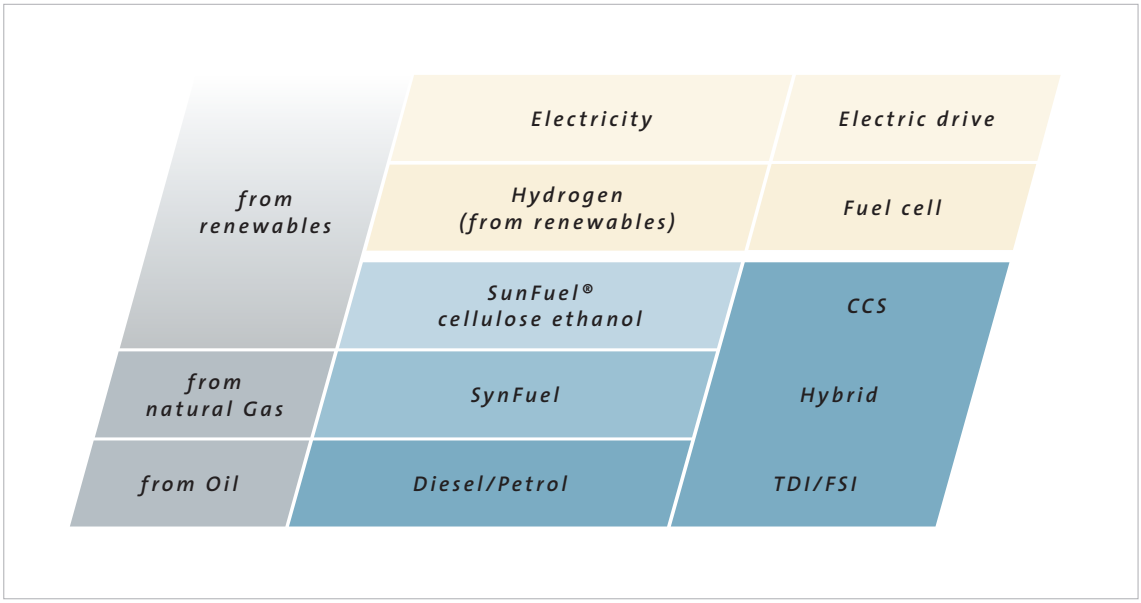
In September 2006, the President of the Technical University of Braunschweig, Prof. Dr. Jürgen Hesselbach, and the Head of Group Research at Volkswagen, Prof. Dr. Jürgen Leohold, signed an agreement to endow a five-year university chair with the aim of directing research into sustainable raw materials for use in fuel production. Volkswagen has donated one million euros to help fund this teaching post. Other partners include the Federal Agriculture Research Centre of Germany (FAL) and the Association of the German Biofuel Industry (VDB), which has contributed 250,000 euros. In the short term, however, our focus will be on TSI and TDI engines with direct fuel injection and supercharging as effective technology for fuel-efficient, low-emission vehicles.

"Volkswagen is ready to back a drive towards manufacturing second-generation biofuels in Germany with considerable investment. To achieve this, however, we need clear European-wide framework conditions in the form of a CO_2-specific taxation model that offers long-term planning security."

Prof. Dr. Jürgen Leohold, Head of Volkswagen Group Research

One strategy – many steps

VOLKSWAGEN FUEL AND POWERTRAIN STRATEGY



Source: Volkswagen AG

In the long term, Volkswagen sees the electric motor as the ideal prime mover for sustainable mobility. From the present perspective, however, it is impossible to say whether this will be in vehicles with more advanced battery technology or a fuel cell energy-conversion system that runs on hydrogen. Whichever system achieves the breakthrough, it will have the undisputed benefit of using electricity or hydrogen produced from renewable energy resources such as wind, water or sun. Another benefit is the fact that electric powertrains cause none of the local emissions generated by conventional combustion engines.

For Volkswagen, one of the keys to further development of powertrain technologies lies in advances in energy storage systems. That is why we are currently involved in research in the field of battery technology. In cooperation with chemical companies Degussa and Chemetall, we are setting up a Chair of Applied Material Sciences for Energy Storage and Conversion at the University of Münster in Germany. The aim of this endowment is to develop innovative materials in order to further increase the efficiency and cut the cost of lithium ion batteries.

In the battery sector, hybrid drive systems already represent a first step forward. Here, Volkswagen has been testing various demonstration vehicles with diesel and petrol hybrid drive systems since the 1980s. But we have also been playing an active role in the field of fuel cells since 1999, and have now successfully developed a totally unique kind of high-temperature fuel cell (HTFC). This concept eliminates many of the drawbacks associated with the now familiar low-temperature fuel cell (LTFC) that is used worldwide in virtually all fuel cell vehicles. In particular, considerable attention has been paid to the development of membranes and electrodes.

Moreover, the HTFC makes for a lighter, more compact, more resilient and cheaper fuel cell system overall – key factors when it comes to setting the fuel cell on the road to volume production.

But before a drive technology based on hydrogen and the fuel cell can really be developed to series production standard, we must first find answers to three technological problems:

1. the sustainable production of hydrogen from renewables
2. the establishment of a hydrogen infrastructure
3. practical and affordable fuel cell and hydrogen storage technology.

We are working on the assumption that finding answers to these challenges will take at least another 20 years. And in all probability a further decade will pass before these new technologies will have achieved a market share big enough to make a tangible difference. That is why it is imperative that – in parallel to the long-term goal of an electric drive system – we develop a second strategy for the near future that will take us closer to sustainable mobility in successive steps, each of which makes sense.

Further improvements to petrol and diesel

Any view we take of the future must be rooted in the present. Oil-based fuels such as petrol and diesel will continue to dominate mobility for many years to come. So it is imperative for them to undergo continual development. More specifically, there must be a worldwide reduction in the sulphur and aromatics content of these fuels. In addition, we are banking on reducing CO_2 emissions by a method that has been widely available for some years now: the blending of first-generation biofuels with conventional fuels – biodiesel with diesel, and bioethanol with petrol. Today's Volkswagen petrol engines, for example, are designed to work with admixture of up to ten volume percent of ethanol.

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 real chance of success if they can make use of the existing supply infrastructure.

Attracting attention: The unique high-temperature fuel cell from Volkswagen

Natural gas instead of oil

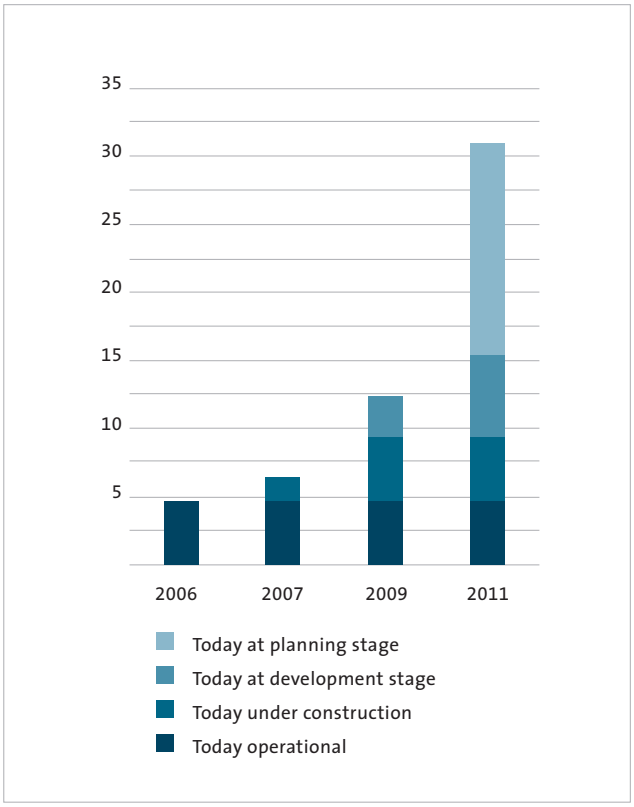
A decisive milestone along the road to next-generation biogenic fuels takes the form of liquid synthetic fuels, or SynFuels. These are manufactured in a two-stage process from synthesis gas derived either from fossil feedstocks such as natural gas (gas-to-liquid – GtL), coal (coal-to-liquid – CtL) or renewable biomass (biomass-to-liquid – BtL). The synthesis gas, made up of hydrogen and carbon monoxide, can be transformed into liquid fuel by a process known as Fischer-Tropsch synthesis. In order to hasten the market launch and advanced development of these fuels, Volkswagen has joined forces with oil companies and other leading automobile manufacturers to set up the Alliance for Synthetic Fuels in Europe (ASFE). ASFE's goals include the advancement of synthetic fuels and supporting a whole range of activities in the field of sustainable mobility to demonstrate the benefits of SynFuels and help drive forward their market launch in cooperation with public authorities.

Foundation of ASFE: Edit Herczog (European Parliament), Jos Delbeke (European Commission), Franz-Josef Paefgen (Volkswagen), George Couvaras (Sasol Chevron) and Jan Thijssen (Thijssen LLC)

SynFuel derived from natural gas burns much more cleanly than conventional diesel and opens the way for the development of entirely new engines that are both more economical and generate lower emissions. Ideal for the production of GtL are the natural gas reserves found in the "stranded" gas fields in more isolated areas, which cannot be exploited either economically or ecologically using conventional methods. To this end, oil companies Qatar Petroleum and Shell, for example, have together drawn up plans to build the world's largest gas-to-liquid plant in Qatar. By the end of the decade, the Pearl Project, as it is known, is scheduled to be manufacturing as much as 22.5 million litres of liquid hydrocarbons per day –

WORLDWIDE GTL OUTPUT

Annual capacity in million metric tons of oil equivalent



Source: Volkswagen AG

including naphtha, GtL fuels, paraffin, kerosene and lubricating oils. In another joint venture, called Oryx after the desert antelope, Qatar Petroleum has joined forces with the South African-American oil company Sasol Chevron. Now in its initial phase, their plant is already producing almost 5.5 million litres per day and the two partners are planning to expand capacity to over 10.5 million litres per day.

Combating climate change with SunFuel®

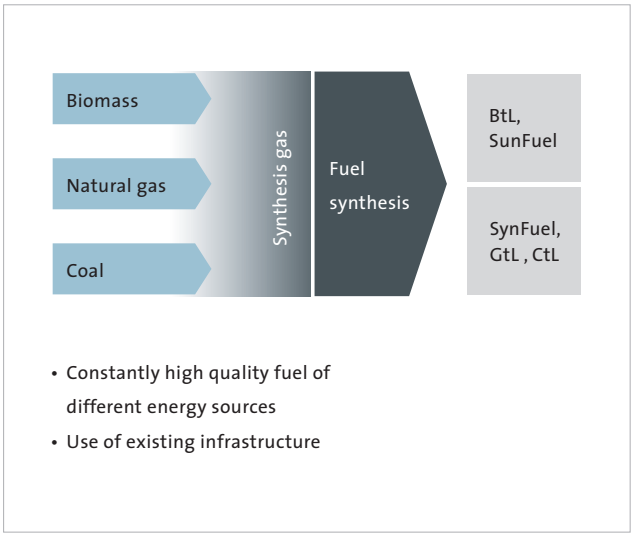
In the longer term, however, only CO_2-neutral raw materials – and biomass in particular – can help the environment when it comes to fuel production. BtL, which we call SunFuel®, refers to sulphur- and aromatics-free diesel and petrol that emit far fewer pollutants on combustion and only release the same volume of carbon dioxide into the atmosphere as was previously taken up by the energy crops through photosynthesis. The raw materials that can be used here cover a whole range of fast-growing energy crops, as well as bio waste such as straw and waste wood. A process to convert biomass to synthesis gas is already being successfully tested at the Research Centre in Karlsruhe, Germany.

Also in Germany, Choren Industries based in Freiberg, Saxony, have taken this process a stage further. After converting the biomass into synthesis gas, they then apply Fischer-Tropsch synthesis to turn this gas into the biofuel SunFuel®. A pilot plant is currently being set up in Freiberg with financial backing from Shell and an annual production target of 15,000 metric tons. If the trial phase proves successful, the plan is to build five full-size facilities with an annual output of one million metric tons. Under the name MtSynfuels® (methanol-to-Synfuels) plant and equipment manufacturer Lurgi is also developing a process that extracts both high-grade diesel (SunDiesel) and normal-grade petroleum (SunBenzin) from synthesis gas, with methanol as the intermediate phase. The cost of SunFuel® is currently estimated at about 70 (euro) cents per litre, although it is hoped in future to achieve a cost target of 50 cents per litre, given the potential for reducing manufacturing costs through further progress and greater market penetration.

One important factor is that the quality of synthetic fuels is largely independent of the type of feedstock used. SunFuel® derived from biomass and SynFuel derived from natural gas or coal have exactly the same high fuel quality. And SynFuel and SunFuel® form the perfect complement to current oil-based fuels, since they can be blended with these conventional fuels in any proportions. Moreover, it is easier to fine tune the chemical and physical properties of synthetic fuels than is currently the case with conventional fuels. That's why we refer to them as designer fuels – and consider them an influential factor in the engine development process. With SynFuel and SunFuel® it is possible to improve both fuel and engine at the same time. A prime example of this is Volkswagen's Combined Combustion System engine (CCS).

SYNTHETIC FUELS

Diversification of feedstocks



Source: Volkswagen AG

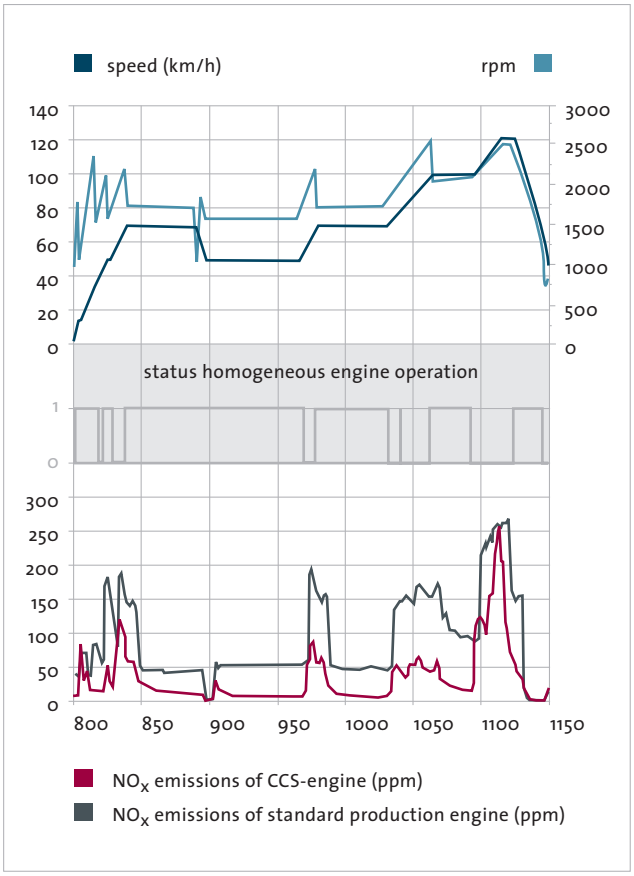
New engine model about to be launched

The CCS engine from Volkswagen is an innovative internal combustion engine that combines the low emissions of a petrol engine with the low fuel consumption of a diesel engine. This is made possible by a self-igniting and homogenous combustion process achieved through the targeted optimisation of both engine and fuel. The crucial step towards making homogenisation in diesel engines and self-ignition in petrol engines far more controllable – and therefore ultimately achievable – was the integration of advanced fuel characteristics into the engine development process.

VW Touran prototype with CCS engine

DYNAMIC ENGINE TEST BENCH

Non urban part of MVEG



Comparison of NO_x emissions: CCS engine with CCS fuel and EU IV standard production engine with diesel fuel (CCS engine operating conditions: 0=heterogeneous combustion, 1=homogeneous combustion)

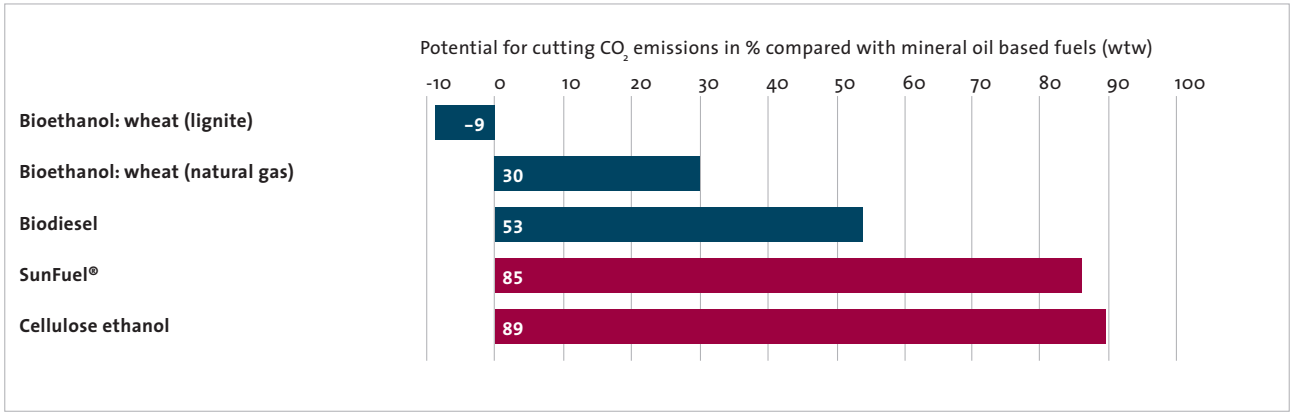
Ethanol improves petrol-engine emissions

Another second-generation biofuel with the potential to reduce climatically relevant gas emissions is cellulose ethanol, produced from the biogenic material waste straw. In partnership with Shell and the Canadian biotech company Iogen, Volkswagen plans to test the feasibility of producing ethanol from cellulose in Germany. The ethanol will be derived from agricultural waste products such as straw from cereals and maize and thus make a very inexpensive contribution to the reduction of greenhouse gas emissions, in particular CO_2,

Golf GT with TSI-technology: Equipped to run with 10% bioethanol

Peter Harry Carstensen, leader of the Federal German state Schleswig-Holstein (r.), with Horst Seehofer, the Federal Minister for Consumer Protection, and Dr. Wolfgang Steiger, Head of Drive Systems Research at Volkswagen (l.)

POTENTIAL FOR CUTTING CO_2 EMISSIONS



There are big differences in biofuels: Second-generation biofuels display an almost completely closed CO_2 cycle. Depending on the process energy used, first-generation biofuels may generate more CO_2 over their full life cycle (wtw) than fossil fuels

from road traffic. The Iogen process is also much more sustainable than the conventional method in which ethanol is produced from foodstuffs such as wheat or sugar beet. With over 25 years of development experience in this field, in Canada Iogen operates the world's only demonstration plant manufacturing cellulose ethanol. The company first brought the fuel to market in 2004.

Greater yield from the field

Production of fuels derived from biomass brings with it major challenges – but also a great opportunity for the agricultural sector. Not only the crops themselves, but also the cultivation methods will play a crucial role, since monocultures – as seen in the cultivation of rapeseed for biodiesel – are not sustainable. In addition the same land area could produce three times the yield for BtL compared to biodiesel. According to a study* published by the Institute for Energy and Environment in Leipzig, Germany, by 2020 Europe (EU 30) will be capable of producing 70 million metric tons of SunFuel® without cutting back on food crops. This would meet one fifth of the total demand for vehicle fuel (diesel and petrol for cars and commercial vehicles) of the 30 EU states in 2020.

Volkswagen is currently engaged in a research project into energy crops at Ehmen near Wolfsburg. The aim of this de-

Dr. Wolfgang Steiger, Prof. Dr. Jürgen Leohold and Eckhart Zipse, Head of Test Plant in Ehmen (r.)

A popular Volkswagen Research model: The yello New Beetle powered by SunFuel

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

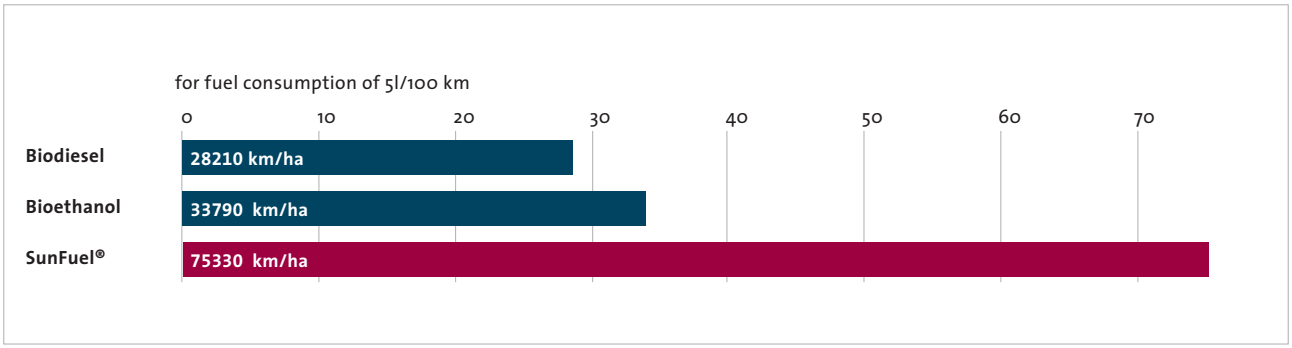
monstration is to increase the diversity of species that can be used as energy crops. At the same time, in order to underpin the demonstrational nature of the exercise, individual test crops are being grown on areas of land approaching to those that would be used in actual farming. Biomass derived from the crops will then be tested at Choren for its suitability for synthesis into BtL.

There's so much to do – so let's get started

The current situation leaves us in no doubt that there is an urgent need for alternatives to oil. In the long term we must safeguard mobility by reducing our dependence on fossil fuels and ultimately finding a replacement for them. Second-generation biogenic fuels lend themselves ideally to this strategy since they offer the best platform for economic and low-emission engines of the future; they can be used in existing vehicles; and they require no new supply infrastructure. But since only a fraction of the world's transport energy needs can be met with fuel derived from biomass, it is also vital to enlist the support of other renewable feedstocks for fuel production – although these will be used to produce electricity and hydrogen. The Volkswagen Fuel and Powertrain Strategy is a roadmap that responds to the many challenges we face as we strive to end our dependence on oil. The road to a post-fossil fuel age will follow not a revolutionary but an evolutionary course – and the journey will still take many decades.

Further information is available on the Internet at www.vw-sunfuel.com

AREA YIELD



Vehicle range per hectare of cultivated area, for a fuel consumption of 5 litres per 100 kilometres. Only second-generation biofuels can make a substantial contribution to climate protection

www.vw-sunfuel.com

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