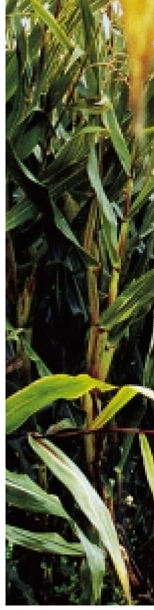
VOLKSWAGEN AG

The Basis for Sustainable Mobility

www.sunfuel.de

SunFuel



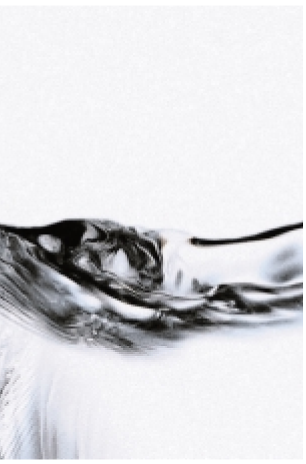
Volkswagen is banking on synthetic fuel

Volkswagen is facing up to the challenges of sustainable mobility. In practical terms that means we have to help reduce local emissions of, for example, nitrous oxides or soot particles, bring down the global output of the climatically relevant gas carbon dioxide (CO_2) and, last but not least, cut our dependency on oil imports.

The Volkswagen Fuel Strategy provides one answer to these challenges. The strategy represents a roadmap to sustainable mobility; a roadmap which already applies and can be taken forward step by step.

> "The topic of sustainable mobility extends well beyond the debate over motor vehicles and fuels. It is related to the far greater goal of sustainable development, which for us is the greatest challenge of the 21st century."
>
> Dr. Bernd Pischetsrieder, Chairman of the Board of Management, Volkswagen AG

Bringing a variety of alternative fuels such as methanol, ethanol, natural gas and hydrogen to market is not an economically viable option. That would call for too many different new production technologies, distribution infrastructures and engine designs. In sum, it would mean substantial cost and effort, and a virtually unpredictable level of risk – factors which could well prevent a new fuel making a successful breakthrough. For biodiesel and bio-alcohols such as ethanol, blending with conventional fuels in line with existing fuel standards offers a more productive approach.



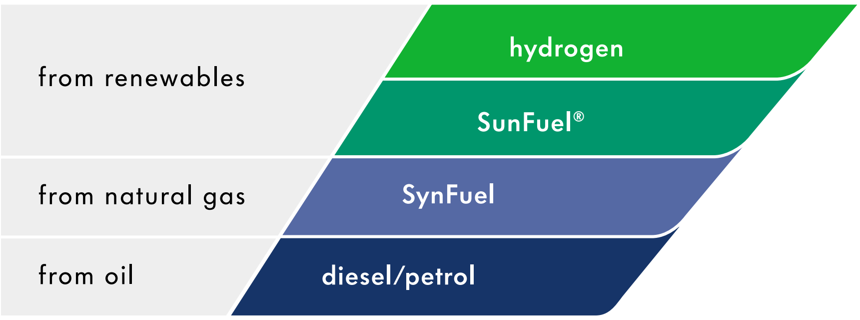
The core of our Fuel Strategy lies in the diversification of feedstocks (energy resources) not of fuels. The idea is to use a range of different raw materials to produce fuels which can be used in existing vehicles and distributed via existing filling stations.

Power plants: Dr. Wolfgang Steiger, Director of Powertrain at the Volkswagen Group Research division, with plants that could provide fuel crops.

Volkswagen is aiming to ensure a more widespread use of CO_2-neutral biomass alongside crude oil and natural gas in the production of liquid fuels. At the first stage, these fuels are similar to conventional petrol and diesel. The advantage of such fuels is that they are not only fully compatible with the existing filling station infrastructure, as well as with vehicles currently on the roads; they also represent a means of substantially reducing emissions and the output of greenhouse gases, as well as cutting dependency on oil.

The second stage is to use these new production processes to endow the resultant fuels with very specific properties, transforming them into what we call designer fuels. In future, such designer fuels will influence the engine development process, opening the door to new combustion processes with the potential to bring about further tangible reductions in fuel consumption and emissions. And since the development and optimisation of fuels and powertrain concepts go hand in hand, our Fuel Strategy is set to become a Fuel and Powertrain Strategy.

Evolution not revolution: The Volkswagen Fuel Strategy



Source: Volkswagen AG

Volkswagen is advocating a four-stage fuel strategy: In future, SynFuel, SunFuel® and hydrogen will complement the existing range of fuels.

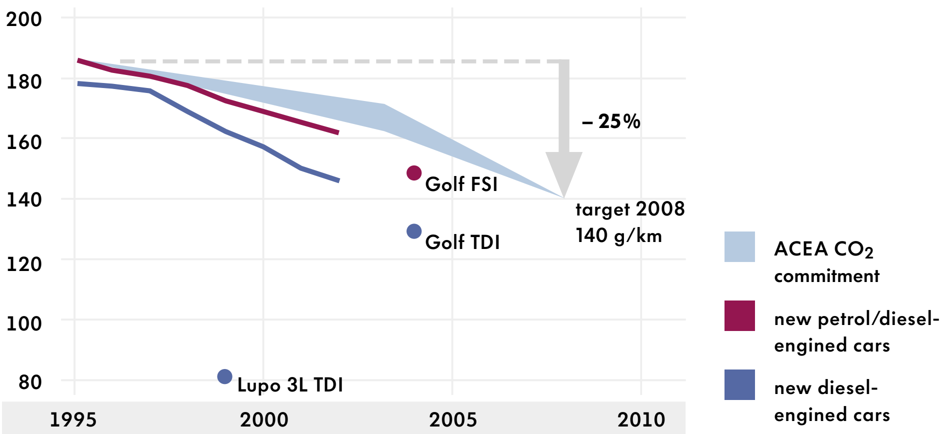
Looking to the longer term, once the current technical and economic challenges have been mastered, we can expect to see vehicles with conventional internal combustion engines side-by-side with fuel cell powered vehicles running on hydrogen from renewable resources.

The future starts here: Optimising fuels derived from oil

Visions of the future are important, but we must not neglect the present. The fuels that dominate the mobility landscape today are derived from oil and these fuels will continue to play an important part over the next few decades. Further improvements such as a global reduction in the sulphur and aromatics content of these fuels will lead to a significant reduction in vehicle emissions. In addition, new engine technologies such as the direct-injection petrol engine (FSI®) and the direct-injection diesel (TDI®) will be rolled out worldwide. These are proven technologies which bring about a substantial reduction in both fuel consumption and exhaust emissions.

The European Automobile Manufacturers' (ACEA) voluntary commitment to reduce CO_2 emissions

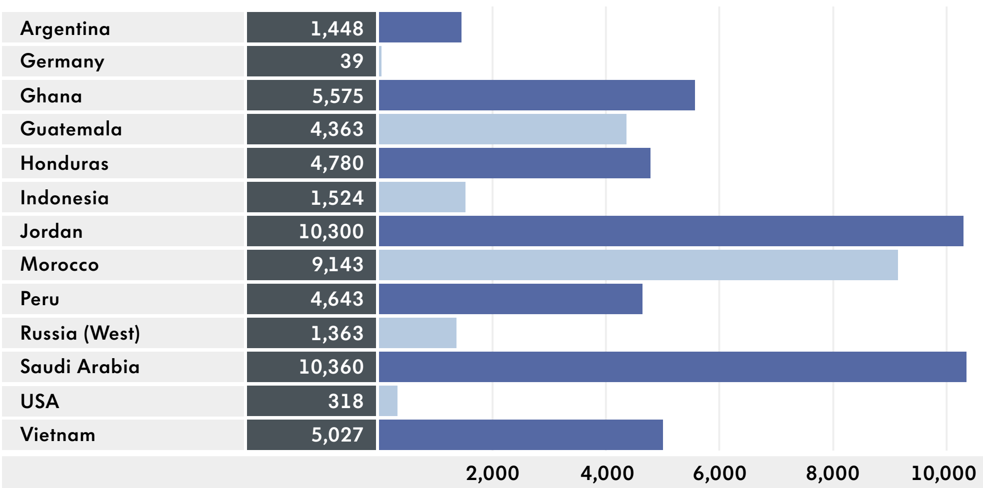
CO_2 in g/km



Source: Volkswagen AG

Average sulphur content of diesel fuel 2001/2002

parts per million (ppm)



Source: Volkswagen AG

A designer fuel called SynFuel: Natural gas forms the feedstock

SynFuel is a synthetic liquid fuel derived from natural gas. There are two stages to the SynFuel production process: First natural gas is reformed into a synthesis gas comprising hydrogen and carbon monoxide. Then, in a process called Fischer-Tropsch synthesis, the synthesis gas is transformed into a liquid fuel. The entire process also goes by the name of gas-to-liquid or GtL. GtL fuel has been in industrial-scale production (600,000 metric tons a year) since 1993, when companies such as Shell began producing it in Malaysia. Given the right background conditions[1], the technology is already economically viable.

[1] Favourable background conditions are given, for example, in the case of what are called "stranded" gas fields. These are natural gas fields where transporting the gas is not economically viable on account of the geographical location. Another increasingly important raw material is "flare" gas. This natural gas is a by-product from the process of extracting and processing oil that is currently burnt off ("flared").

SynFuel offers many advantages:

Lower emissions: With 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 from modern vehicles – and from older vehicles in particular. SynFuel also permits the application of further optimised 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.

SynFuel can use 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 will be necessary. This is a decisive advantage, because it means that lower emissions will not be restricted to the latest generation of vehicles. All vehicles can benefit.

SynFuel is already suitable for everyday use: In 2003, a five-month test was staged in Berlin involving a fleet of 25 standard production Golf TDIs and using Shell GtL. The fleet covered a total of 220,000 kilometres and the test proved a success. Particulate emissions, for example, were down by 26 percent.

Fuel properties

A comparison of conventional diesel fuel and sulphur-free SynFuel in the Berlin fleet test

Properties	Diesel	SynFuel (Shell GtL)
Density [kg/m³]	830	780
Net heat of combustion [MJ/kg]	42.5	43.99
Aromatics content [%–w]	20.6	0
Carbon content [%–w]	86.3	84.9
Sulphur content [ppm]	< 10	0
Initial boiling point [°C]	220	197
Final boiling point [°C]	360	358
Cetane number	53	80

Source: Volkswagen AG

But what about the CO_2 balance?

Using natural gas instead of oil as the primary feedstock may only lead to a small overall reduction in greenhouse gas emissions, but it represents an important step along the road to expanding the range of feedstocks. GtL technology opens up the possibility of exploiting new reserves of natural gas which were previously considered uneconomical. As these are found in different locations from oil, SynFuel may also lead to a reduction in dependency on oil imports.

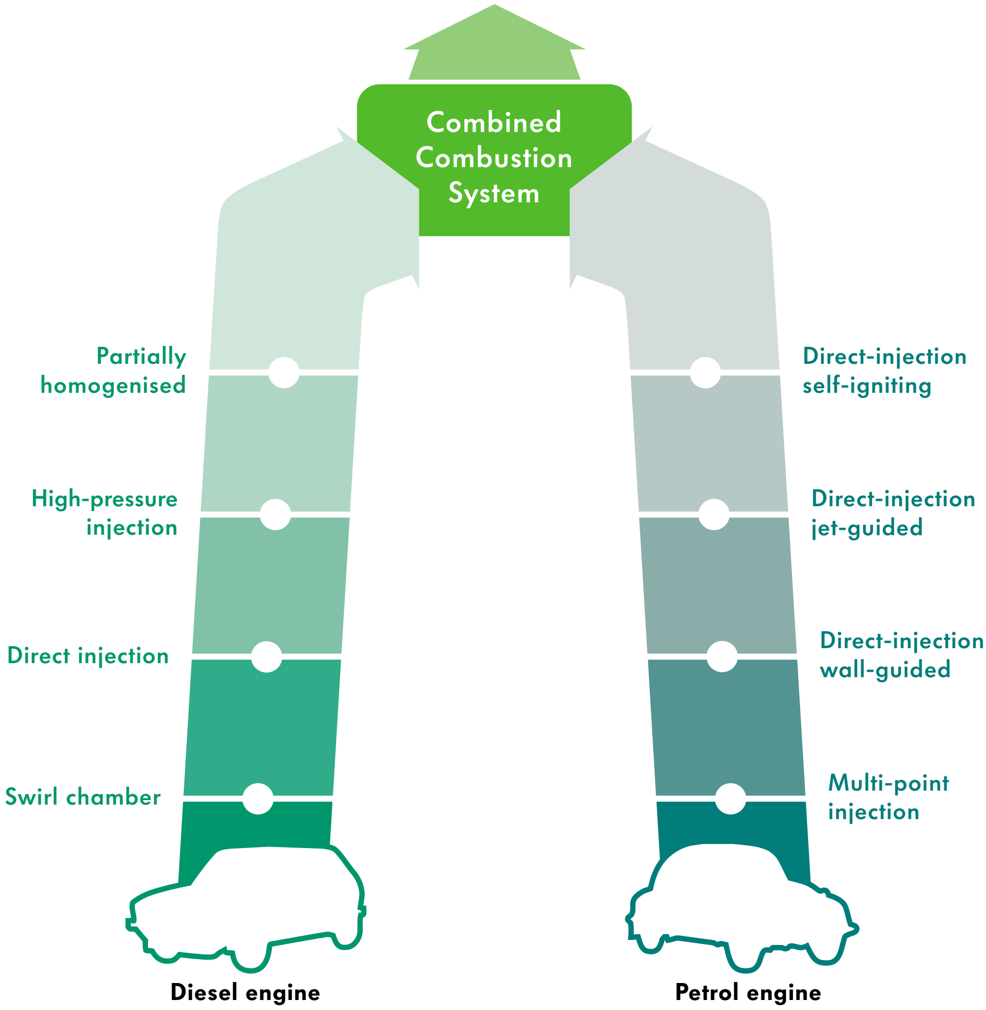
With the announcement by the oil companies Shell, Sasol and ConocoPhillips of the construction of additional industrial-scale SynFuel production plants in Qatar, the SynFuel chapter of Volkswagen's Fuel Strategy is set to become a reality before the end of the decade.

Producing high-purity SynFuel by Fischer-Tropsch synthesis since 1993: Shell's gas-to-liquid (GtL) plant in Bintulu, Malaysia (photo: Shell).

The Road to a Sustainable Future: A Golf TDI during the Berlin fleet test.

A vision of combustion process development

Over recent years, the combustion processes of petrol and diesel engines have become more and more similar. Volkswagen is developing the Combined Combustion System in order to fully exploit the benefits of this convergence.



Source: Volkswagen AG

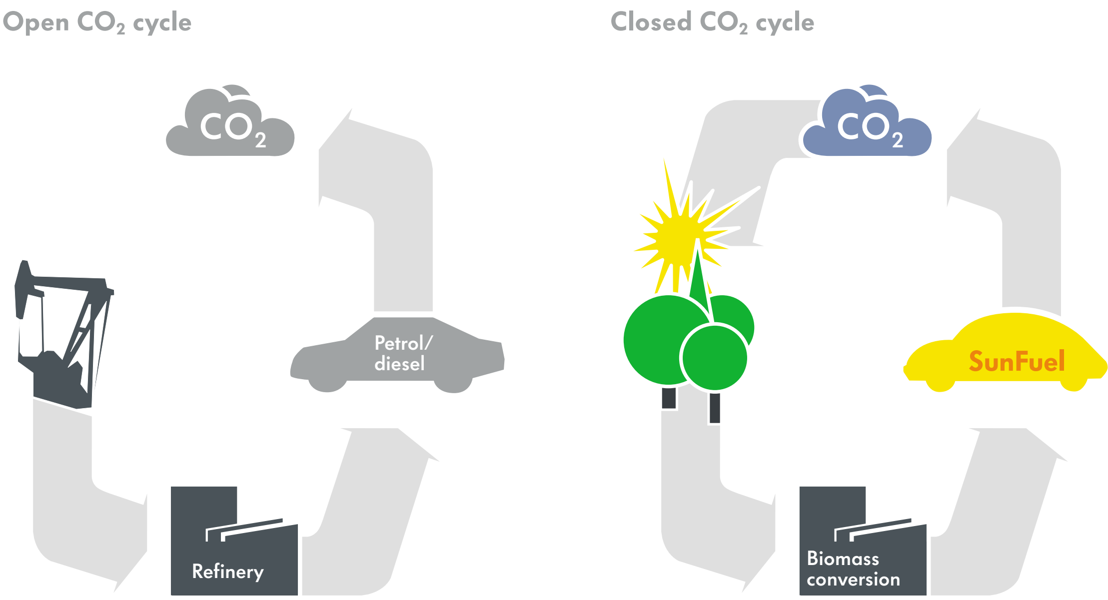
A sunny outlook: Fuel derived from biomass – SunFuel®

SunFuel® combines the advantages of SynFuel – lower emissions and problem-free use – with 85 percent greenhouse gas neutrality[2]. Instead of natural gas, 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 great variety of fast-growing and undemanding crops. Organic residues such as straw or wood residues can also be used.

[2] EUCAR/CONCAWE/JRC European Commission well-to-wheel analysis of future automotive fuels and power-trains in the European context; Brussels, November 2003.

The advantages of using biomass as a primary feedstock

The carbon dioxide generated by a car powered by SunFuel® has been taken up from the atmosphere by the plants that provide the energy. Effectively, the solar energy that made the plants grow is converted into liquid fuel by technical means. That is why we call this synthetic fuel derived from biomass SunFuel®. Fossil fuels, by contrast, lead to higher overall CO_2 concentrations as a result of ever-increasing volumes of CO_2 being released into the atmosphere.



Source: Volkswagen AG

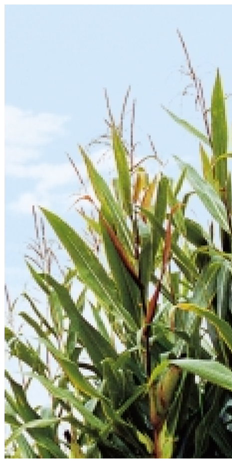
But there is also another attractive aspect to SunFuel®:
Using biomass as a primary energy resource for the production of fuel opens up new earnings potential in agriculture. This creates opportunities to master the problem of overproduction and the additional challenges that will face the agricultural sector in the future, not least as new eastern European nations join the European Union.

What does the use of biomass mean for the production process?
The SunFuel® production process is very similar to that of SynFuel – except that the synthesis gas is obtained not from natural gas but from biomass. The gasification of biomass into a synthesis gas has been successfully piloted at CHOREN Industries in Freiberg, for example, and at the Karlsruhe Research Centre, both in Germany. CHOREN puts the cost of manufacturing SunFuel® at approximately 60 euro cents per litre[3]. And as the German government has granted biofuels exemption from oil tax from January 2004, such production costs would mean that SunFuel® can compete with conventional diesel on price.

[3] According to several different sources (Institut Français du Petrol, Shell, Imperial College) production costs stand at between 45 and 83 euro cents per litre.

What potential does SunFuel® have?
The potential of SunFuel® is far greater than that of ethanol or biodiesel, for example. According to data from the Ludwig Bölkow Systemtechnik (LBST) company, about three times as much SunFuel® can be produced per hectare of farmland as biodiesel (in terms of energy equivalent). This is because biodiesel uses only the seed oil, while SunFuel® is derived from the entire plant. Moreover, SunFuel® can be obtained from a larger selection of fast-growing crops, helping to avoid monocultures. According to the Institute for Energy and Environment in Leipzig, Germany, if bio-residues are also used, SunFuel® can have up to seven times the potential of biodiesel. The limit factor, that is to say the amount of available arable land, is also better exploited with SunFuel®.

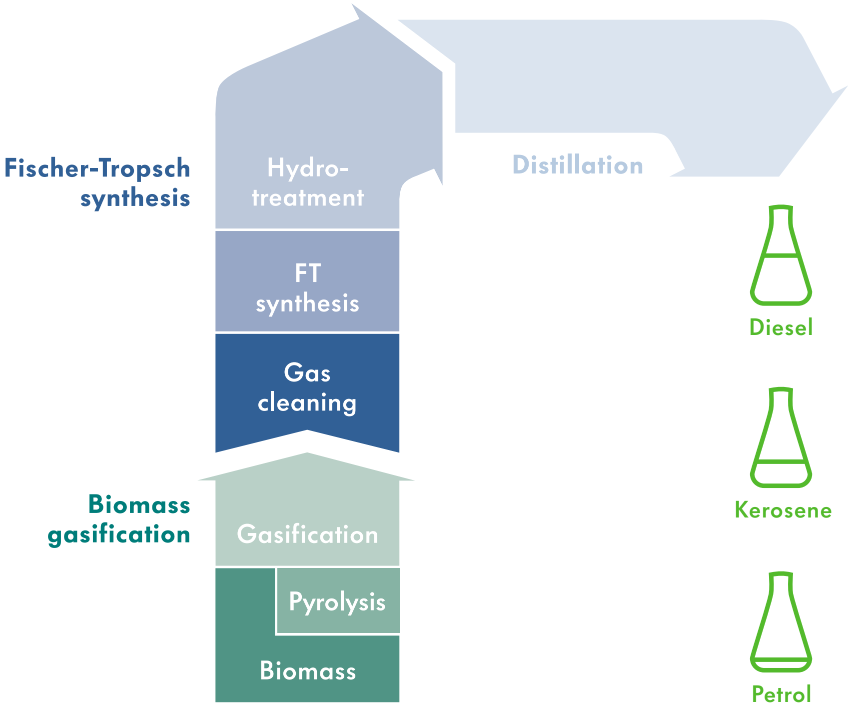
In technical terms, too, SunFuel® runs out superior to biodiesel. Biodiesel has very different properties from diesel derived from crude oil and can only be used in technically modified diesel cars. SunFuel® by contrast, can be used to power all vehicles. The SunFuel® production process is equally suitable for the production of all important fuels: petrol, diesel and even aviation kerosene.



If increasingly stringent emission requirements are to be met, this will call for the ongoing development of both engine technologies and fuels. Even today, the optimum match between engine and fuel is already an essential. As a result, with the introduction of the Euro 4 emissions standard, Volkswagen will no longer be granting general approval for its cars to be run on biodiesel. In future it will be necessary to tailor the fuel not only to its specific task but also to the engine. To this end, both engine and fuel must be the joint objects of ongoing development work, for it is here that the great advantages of SynFuel and SunFuel® lie. In the case of biodiesel, by contrast, a lack of flexibility in terms of development and optimisation potential means that we can already envisage the fuel reaching its limits for use in advanced engines[4].

[4] In a modern diesel engine, a fuel with a lower boiling/evaporation point is a big advantage. Biodiesel needs excessively high temperatures before it boils.

Biomass-to-Liquid Process
via Fischer-Tropsch synthesis



Source: Volkswagen AG

According to a study conducted in 2004 by the Institute for Energy and Environment, in Europe today the potential production volume of SunFuel® in technical terms – without reducing production of food crops – stands at 70 million metric tons. This would meet about one third of the total demand for vehicle fuel (diesel and petrol for cars and commercial vehicles) of the 15 EU states for the year 2000.

Political support for synthetic fuels: Volkswagen employees meet members of parliament from the German Federal States of Brandenburg and Lower Saxony in Wolfsburg.

SunFuel® will enable us to reach the goals we have set ourselves: reducing emissions, reducing the output of greenhouse gases, and reducing dependency on oil imports, while at the same time creating new opportunities for agriculture and industry.

Hydrogen from renewable resources: a supporting role

Hydrogen is a fuel, in other words it is derived from a feedstock. If it is obtained from natural gas or other fossil fuels, it loses its advantages. It is like an electric car which may run with zero local emissions, but the power it needs does not originate in a power socket but has to be generated by a power station. And the non-local pro rata CO_2 emissions of power stations can be greater than those of an efficient conventional powertrain. So in fact, only hydrogen obtained from renewable energy resources (renewables) represents a real step forward.

Bora HyMotion with fuel cell drive: output 75 kW, torque 255 Nm, 0-100 km/h in 12.6 seconds, range: 350 km using liquid hydrogen (-253°C).

But before hydrogen from renewables is 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 our opinion, using hydrogen as a fuel only makes sense 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 here is to use hydrogen in the production of SunFuel®, as this could double the potential production volume of SunFuel®. However, hydrogen from renewables can make a considerable contribution to reducing the output of carbon dioxide at a far lower initial outlay: by serving to desulphurise conventional fuels, for example, at refineries.

Volkswagen can only see hydrogen becoming a meaningful fuel for mobility applications in 20 or 30 years' time. 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.

Our solution is SunFuel®.

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