Level 11, Exchange Plaza
2 The Esplanade
Perth WA 6000
Australia

Tel: +61 (0)8 9221 2837
Fax: +61 (0)8 9221 4839
www.sasolchevron.com

Please Quote on Return:
Our Ref No. TPDF/SCAC2006-03

22 February 2006

The Secretary
Senate Rural and Regional Affairs and Transport
Parliament House
Canberra ACT 2600
Email: rrat.sen@aph.gov.au

Dear Sir or Madam:

INQUIRY INTO AUSTRALIA'S FUTURE OIL SUPPLY AND ALTERNATIVE TRANSPORT FUELS

Please find enclosed a submission to the Inquiry into Australia's future supply and alternative transport fuels for consideration by the Committee, with reference in particular to item:

(b) Potential of new sources of oil and alternative transport fuels to meet a significant share of Australia's fuel demands, taking into account technological developments and environmental and economic costs.

Our submission to the Senate Inquiry is a description of the new and evolving gas to liquids industry; the technology, products, markets, costs and benefits of an alternative transport fuel for Australia: *GTL diesel*.

Note that the materials presented are not confidential, with the exception of Appendix D which has not yet been released. This document, the *Alliance for Synthetic Fuels in Europe brochure*, is confidential until after March 7, 2006.

Should the Committee wish to invite Sasol Chevron to discuss the submission in more detail please contact the undersigned, or our office directly on (08) 9221 2837.

Yours sincerely

A. M. Pytte
Australia Country Manager

Enc.1

Submission to the Inquiry into Australia's future oil supply and alternative transport fuels

Sasol Chevron Consulting Ltd.

Incorporated in England & Wales

ABN 46 096 439 404

Contents

1. Introduction

Australia is at a cross-roads regarding energy supply and security for the 21st Century. The declining domestic supply of oil combined with rising demand for transport fuels is increasing Australia's dependence on oil imports at a time when the cost and security risk of these imports is also increasing.

However Australia is a wealthy country, rich in natural resources (except oil) and technology and is well placed to adjust policy to promote indigenous solutions to this pending domestic oil shortage. The Government's white paper in 2004 on *Securing Australia's Energy Future* was a strong step towards establishing policies for dealing with these issues. This Senate inquiry into Australia's future oil supply and alternative transport fuels will add substantially to this important debate.

Sasol Chevron is the leader in developing a new global industry to convert natural gas into clean, environmentally friendly synthetic transport fuel, *GTL diesel*. Australia has an abundance of natural gas off the north western coast of the continent and has the potential to become a foundation of this new global industry. In addition to becoming a leading supplier of the next generation of super clean transport fuels, improving both the global environment and global energy security, Australia itself could become more energy independent with regards to transport fuels for the bulk of the 21st century.

This submission to the Senate Inquiry is a description of this new and evolving industry; the technology, products, markets, costs and benefits of an alternative transport fuel for Australia: *GTL diesel*.

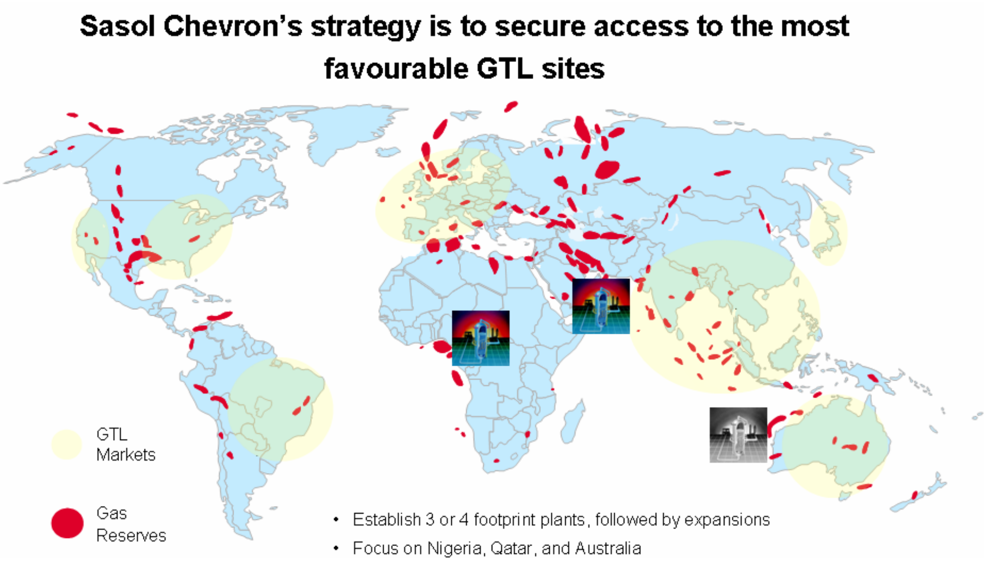
2. About Sasol Chevron

Sasol Chevron – GTL Centre of Excellence

Sasol Chevron was established in October 2000 as a 50/50 joint venture between Sasol and Chevron to build a global business converting natural gas into clean, fungible liquid hydrocarbons. The business draws on the proprietary technology, assets and resources of the parent companies.

Through this joint venture, Sasol and Chevron are able to develop Gas to Liquids (GTL) production facilities, either as an associated gas solution or as a field development proposition in its own right, in accordance with the Sasol Chevron strategic plan.

The Sasol Chevron business strategy is to establish 'foundation' plants in three or four advantageous locations and then increase capacity through expansion of these plants. These expansions will deliver economies of scale, increased efficiency of operations, and deliver products worldwide. This strategy is also supported by a continuous programme of technological development in order to drive down costs, improve plant performance and increase overall project efficiency.



The development of a GTL project is both resource and capital intensive. The Sasol Chevron business model depends on an abundant supply of competitively priced gas, robust and stable business, legal and fiscal frameworks in the producing country and year round access to the sea for receipt and delivery of supplies and products.

Sasol

Headquartered in Johannesburg, South Africa, Sasol is engaged in the commercial production and marketing of synthetic liquid fuels and chemicals; with a growing interest in oil and gas exploration.

Sasol was established in 1950 by the South African government to manufacture fuels and chemicals from indigenous raw materials. The company has developed world-leading technology for the commercial production of synthetic fuels and chemicals from low-grade coal and natural gas. Sasol is the world's largest producer of synthetic fuel (160,000 bbl/day) and together with conventional refining operations produces approximately 40% of South Africa's fuel. Sasol is committed to sustainable development and is a signatory of Responsible Care®, a worldwide initiative by the chemical industry that strives to improve performance in safety, health and environment.

A workforce of 30 000 strong deploy their skills and talents to drive the company forward in exploration, mining, science, technology R&D and business development. Sasol is listed on the Johannesburg Securities Exchange (JSE), symbol SOL and the New York Stock Exchange (NYSE), symbol SSL.

Chevron

Chevron is the fifth-largest integrated energy company in the world. Headquartered in San Ramon, California, and conducting business in approximately 180 countries, the company is engaged in every aspect of the oil and natural gas industry, including exploration and production; refining, marketing and transportation; chemicals manufacturing and sales; and power generation.

Chevron - including its share of equity affiliates - is among the largest publicly traded integrated energy companies in the world in terms of net proved crude oil and natural gas reserves, with approximately 11.3 billion barrels of oil-equivalent (BOE) as of December 31, 2004 and with daily net production of more than 2.4 million BOE as of

June 30, 2005. The company also has 20 wholly owned and affiliated refineries and asphalt plants and approximately 25,700 retail outlets worldwide.

In addition, Chevron brings an understanding of global fuel markets based on long-established market positions in Europe, Asia, and the US, as well as a global supply infrastructure. It also provides the proprietary hydrocracking process (ISOCRACKING™) for the production of the finished GTL products.

Chevron is a major stakeholder in the Australian oil and gas industry. Chevron is the operator of the Barrow Island and Thevenard Island oil fields and the Gorgon LNG project and is a partner in the North West Shelf Venture. Chevron is also a 50% shareholder of Caltex Australia.

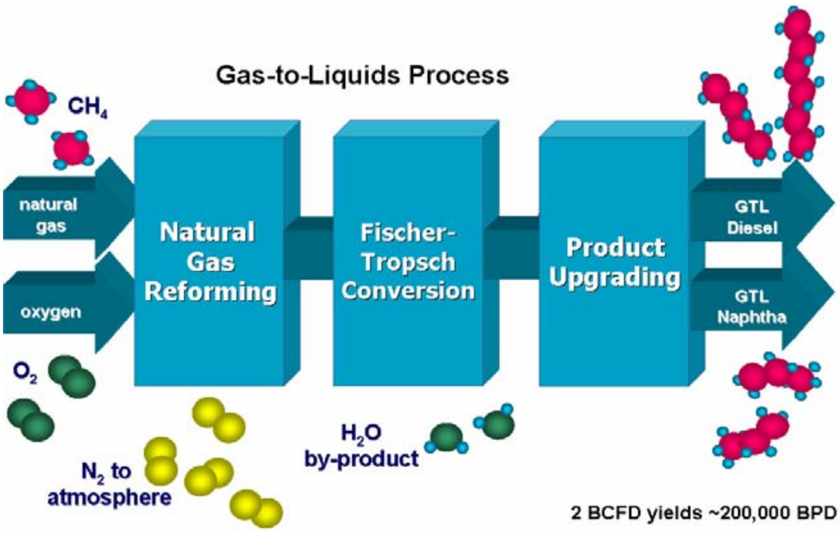
3. Gas to Liquids Technology

While there are a number of gas to liquids processes and technologies in various stages of research and development, the Sasol Chevron venture is built on the foundation laid by Sasol, a leader in state-of-the-art Fischer Tropsch technology. It utilises proprietary technologies of both parent companies -- Sasol's Slurry Phase Distillate (SSPD™) process and Chevron's ISOCRACKING™.

SSPD™ is a proprietary process for converting reformed natural gas into waxy syncrudes. Utilising commercially available reforming technology, methane, the main component of natural gas, is mixed with oxygen and reacted over a catalyst to create a mixture of carbon monoxide and hydrogen called synthesis gas or syngas. In a Slurry Phase reactor, the syngas is heated to about 240 degrees Celsius and mixed with another catalyst to form various liquid hydrocarbons (FT conversion), yielding condensates and waxy syncrudes.

ISOCRACKING™ is a Chevron proprietary process used to upgrade waxy syncrudes by separating heavier molecules, which are usually solid at room temperature, then rearranging them so they become liquid. This process yields lighter products such as synthetic diesel and naphtha, which contain virtually no sulphur and aromatics.

The product split from this process is approximately 60-70% GTL diesel and 30-40% GTL naphtha, with a small volume of Liquefied Petroleum Gas (LPG).



4. GTL Projects under Construction

Qatar – Oryx GTL Project

Oryx GTL, the first of a series of planned commercial plants in Qatar, will soon be in full commercial production, producing 34,000 barrels per day (BPD) of GTL products – diesel, naphtha and LPG. Oryx GTL, which utilises the Sasol and Chevron proprietary technologies, is a milestone for the industry. Oryx II, a 66,000 BPD expansion, as well as an 8,500 BPD GTL base oils production facility, are being evaluated with a target to come on stream later this decade. An even larger Sasol Chevron 130,000 BPD GTL facility, with integrated offshore upstream gas production and onshore GTL production is also being assessed.

Nigeria – Escravos GTL Project

The engineering, procurement and construction contract for the Escravos GTL project was awarded in mid 2005. This plant will have the same capacity and be based on the same technology as the Oryx plant. The plant is scheduled for start-up in 2009. Planning for future expansion is currently underway.

Nigeria - EGTL I is beginning construction

5. GTL Products

GTL Diesel is Environmentally Friendly

GTL diesel is cleaner than conventional diesel. The purity levels are difficult to attain economically and technically through conventional crude oil refining processes. As a result, these products display performance characteristics and environmental benefits that in many applications are superior to those of conventional crude oil based equivalents.

The SSPD™ process converts natural gas into high quality GTL diesel and GTL naphtha. This creates an opportunity to produce easily transportable and marketable products from abundant and remote natural gas resources.

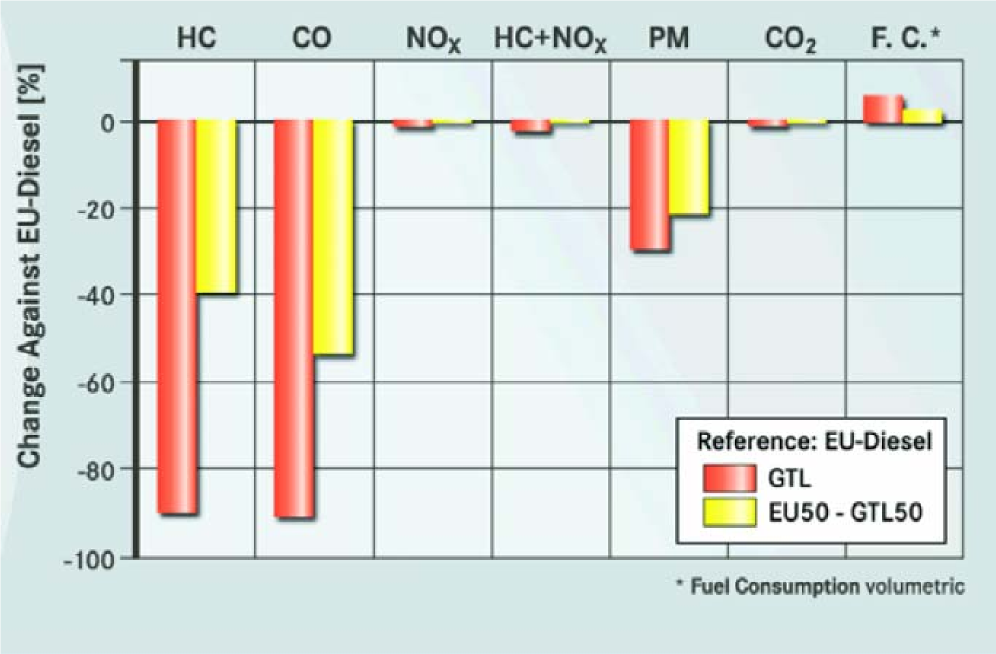
The GTL diesel produced by the process can be used in conventional compression ignition (diesel) engines. GTL diesel has a very high cetane number and virtually zero sulphur and aromatic content. These qualities significantly reduce exhaust emissions, offering considerable environmental benefits. GTL diesel exceeds current and proposed diesel fuel specifications except for the density of the product owing to the low aromatic content.

The properties of GTL diesel make it an ideal blending component to upgrade lower quality middle distillate streams to on-road fuel quality. In addition, GTL diesel is not in competition with other alternative transport fuels, it complements them. Specifically, GTL diesel has synergies with biodiesel - opening up possibilities for blended GTL/BIO fuels

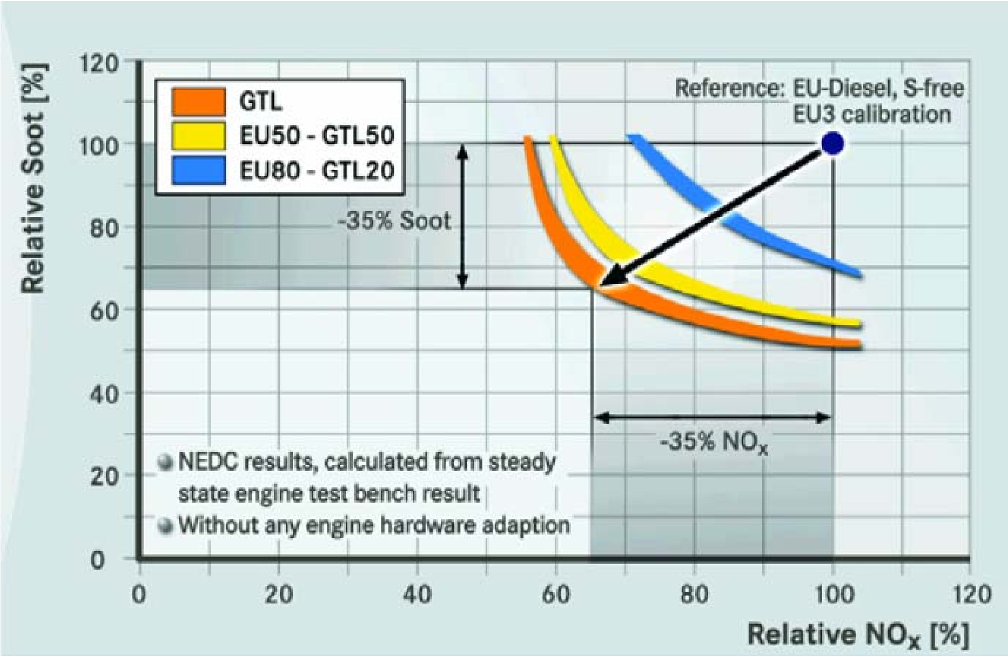
GTL diesel has also been confirmed in independent laboratory tests to be both *readily biodegradable* and *non-toxic to marine organisms* (Appendix D).

Auto Emissions

One of the factors most strongly supporting the use of cleaner-burning fuels which are compatible with existing engines and infrastructure, such as GTL diesel, is that the resulting emission reductions are realized across the entire fleet of vehicles which are operated with the fuel, both new and old. Provided there is sufficient fuel supply, the benefits will be broad, immediate, and at relatively low cost. In contrast, other fuel and fuel systems which require new engines and infrastructure will not only require substantial new investment, but possibly decades to penetrate the market broadly enough and deeply enough to have a substantial impact.



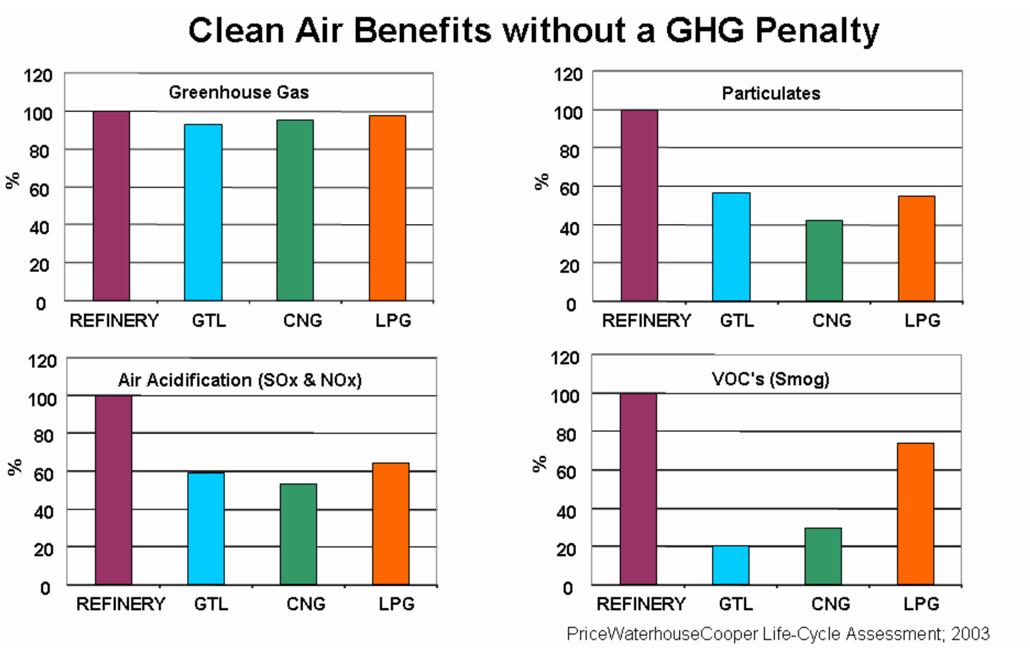
The figure above shows the results of tests on a Mercedes-Benz E220 CDI passenger car complying with EU3 emission standards using both a 50/50 EU diesel/GTL diesel blend and GTL diesel only, and is representative of the emissions reductions expected with current engine technology and no modifications. While the NO_x reductions were minimal with the unmodified vehicle, with re-tuning (software adaptation only) significant reductions in NO_x and Soot of 35% were achieved (below) (Hermann et al, 2004).



More recent studies have confirmed that significant additional reductions in emissions and improvements in performance may be achieved with minor engine hardware modifications (Hermann et al, 2006).

Greenhouse Gas

Sasol Chevron, ConocoPhillips and Shell International Gas commissioned a study by Five Winds International to report on the Life Cycle Analysis of GTL production. The study found that production and use of GTL fuel can contribute less greenhouse gas and reduced emissions to the atmosphere than production and use of conventional diesel fuel (Five Winds International, 2004).



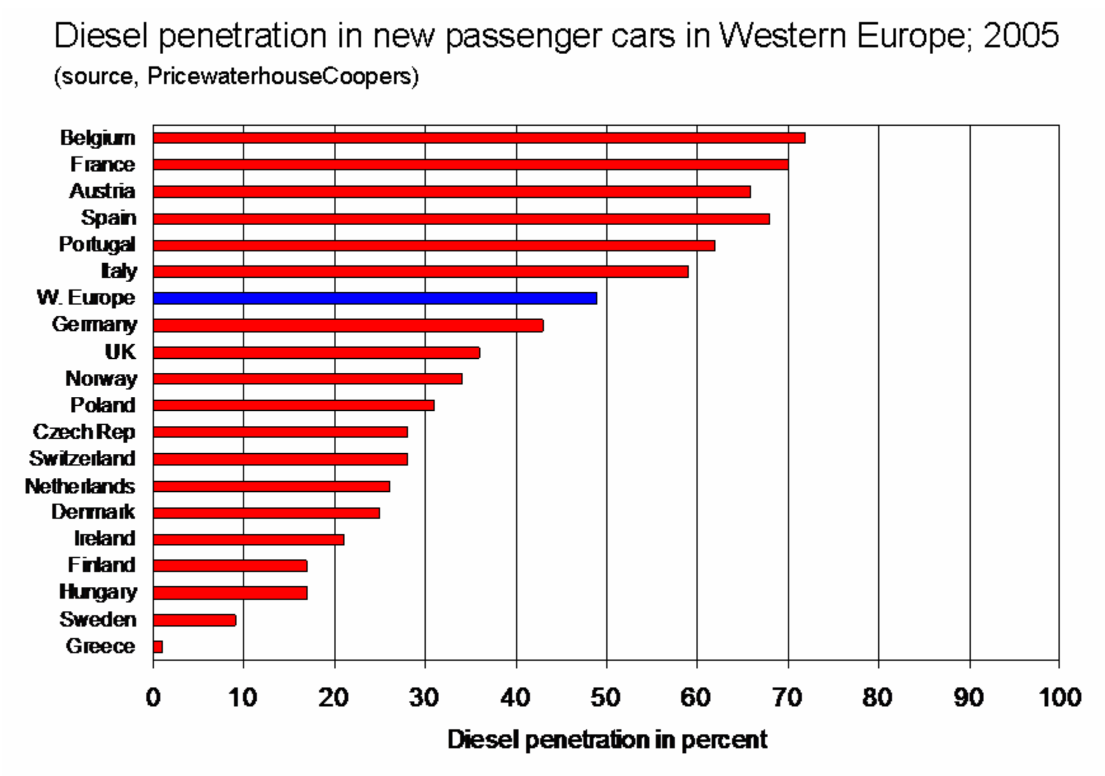
GTL Diesel Efficiency

GTL diesel can be stored and delivered by tankers to gas stations just like conventional diesel, with no expensive new infrastructure needed.

GTL diesel has the potential to provide not only significant environmental benefits, but also important fuel efficiency gains. Compression ignition (diesel) engines are currently 30-50% more efficient than spark ignition (petrol) engines. GTL diesel offers more kilometres per litre of fuel and fewer emissions per kilometre driven. On a fuel use basis, GTL diesel is already the most Greenhouse-efficient fuel.

In Europe, new purchases of diesel automobiles now exceed petrol automobiles, and moving to diesel engines for transport is a key component of the European strategy to reduce Greenhouse gas emissions.

GTL diesel is compatible with current and envisaged future engine and exhaust gas after-treatment technologies. GTL diesel should even be suitable as a fuel for hydrogen cars (with on-board reformers) when they eventually become available.



GTL Naphtha

The GTL naphtha produced by the SSPD™ process is a high paraffin content (95%+), light naphtha which is ideally suited for producing ethylene. Its properties result in superior ethylene and propylene yields compared with currently available naphtha feeds for this application.

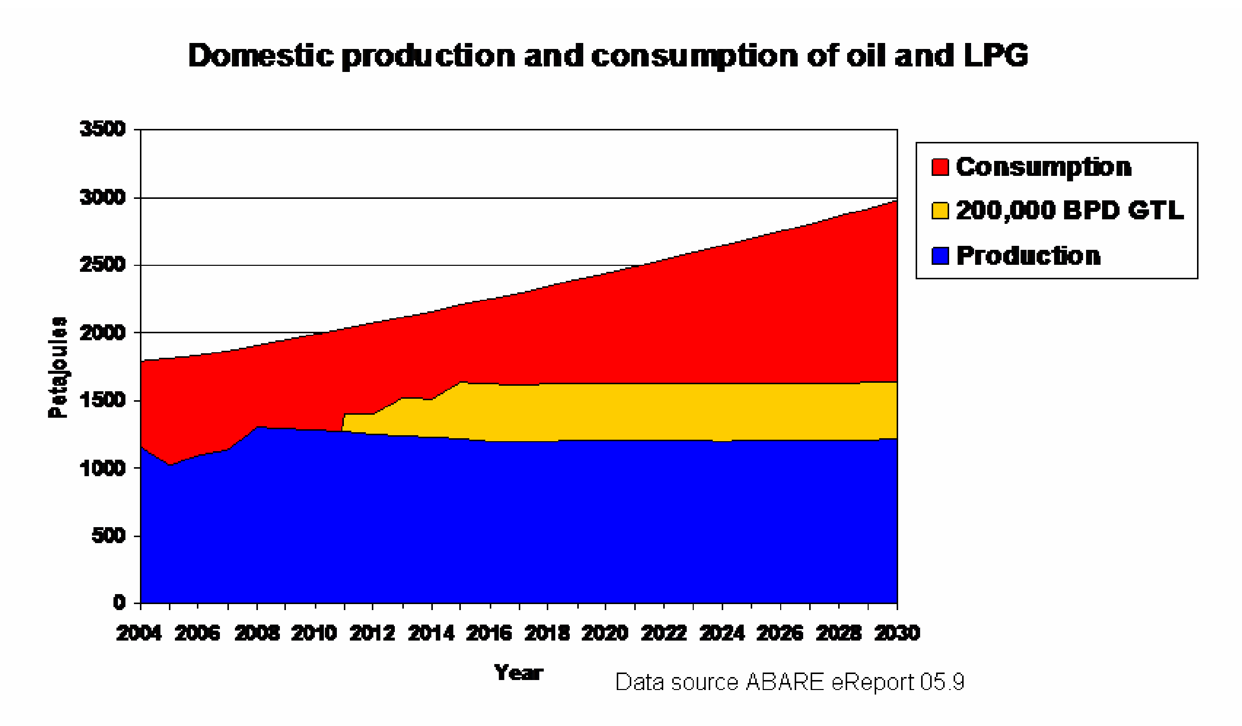
6. GTL Diesel as an Alternative Transport Fuel

ABARE has forecast that Australia's indigenous production of liquid hydrocarbon fuels (oil and LPG) will remain roughly constant over the next 25 years. Maintaining this constant production rate will require continued exploration success to replace the declining production from Australia's mature oil fields. Consumption is expected to grow by 1.5% per year compounding to a total increase in demand of almost 1000 petajoules, or 66%, to nearly 3000 petajoules by 2030. Over this period the share of net imports in liquid fuels required to meet this demand will increase from the current 22% to 51% by 2030 (ABARE, 2005). Should the oil exploration success rate be less than forecast, the import requirements will be even higher.

Roughly 70% of Australia's liquid hydrocarbon consumption is for transport.

In contrast to the limited oil supply outlook, Australia has large and rapidly increasing natural gas reserves. Recent discoveries have raised the known gas resource base to over 140 Tcf (or 170,000 petajoules). Most of this gas is offshore the remote Northwest of the continent and not accessible to the major markets on the east coast.

GTL technology can convert Australia's vast natural gas reserves into liquid petroleum products. Unlike many other gas conversion technologies, the Sasol Chevron technology converts natural gas into a clean, stable liquid at normal pressures and temperatures so no special storage or transport systems are required. 20 Tcf is enough gas to produce 200,000 BPD of GTL products for almost 30 years. This amounts to about 420 petajoules per year, and would make a substantial contribution to Australia's liquids fuel supply for many years.



In Europe, synthetic fuel, sourced from natural gas, coal or biomass is proposed as a key component of a long term strategy to a cleaner, more efficient, more independent and more prosperous transport energy system. DaimlerChrysler, Renault, Sasol Chevron, Shell and Volkswagen have formed a consortium called the Alliance for

Synthetic Fuels in Europe (ASFE) committed to reducing the environmental impact of road transport through improved energy efficiency and cleaner fuels.

ASFE has concluded that from the range of alternative fuel options, GTL is the most cost effective in reducing petroleum dependency and exhaust emissions, is available today, and will pave the way for advanced engine technology development and future biomass to fuel (BTL) technology commercialisation (Appendix D).

ASFE is seeking support from European policy makers for the introduction and increased market penetration of all synthetic fuels, and more specifically to include GTL fuel in addition to BTL fuel as an alternative fuel to achieve alternative fuel targets.

7. Benefits of a GTL Industry to Australia

Unlocking value-added resource wealth

Depending on oil price, a 200,000 BPD GTL business would convert 2000 mcf/day of natural gas into A$2 billion - A$8 billion of revenue per year. This is similar in scale to 12 mtpa of LNG, roughly comparable to the NWS LNG project. However, unlike LNG which is all exported, the bulk of the GTL diesel would be marketed within Australia, reducing the need for diesel imports.

Fuel supply security

A single large scale GTL project would substantially reduce Australia's net transport fuel imports for many decades. GTL diesel can be blended and stored with regular diesel and integrated into the existing retailing infrastructure. There are also potential blending synergies with bio-diesel.

Infrastructure and resource development

A large scale GTL project can underpin a Greenfield offshore gas development and associated infrastructure.

Clean transport

For the same price as regular diesel, Australians will be able to use the cleanest, most efficient, high performance fuel available. GTL diesel burns as clean as LPG or CNG (compressed natural gas) but with higher efficiency diesel engines.

Latest technology

The latest European direct injection, turbo-diesel engines in passenger cars are now being introduced to Australia. When coupled with GTL diesel, these engines can deliver even higher performance, higher efficiency, and lower tailpipe emissions (Hermann, 2004). Clean diesel engines and synthetic diesel fuels are an ideal transition to future hybrid electric-diesel engines and ultimately fuel cell vehicles.

Diversification of Australia's gas based industry

GTL diesel and GTL naphtha will complement LNG as new clean energy products from Australia to the domestic and Asia-Pacific transport fuel markets and the Asian petrochemicals market.

8. Costs and challenges of GTL investment

The Challenge

Gas to liquids is a capital intensive investment. A 200,000 BPD project could cost upwards of A$20 billion including offshore gas development. Hence, a staged development is most likely, with 66,000 BPD an efficient investment scale per stage for Sasol Chevron's technology.

A project of this scale requires support and alignment from multiple stakeholders; upstream and downstream proponents, State and Commonwealth governments, local and regional communities. A great deal of time and effort is required to negotiate and maintain alignment between these parties for any large scale gas project. In addition, the GTL business is new and there are limited technology providers and experienced plant operators.

Sasol Chevron has been working since 2000 to pull together the many parties necessary to move an Australian GTL project forward. As the major traditional investment for large, remote gas resources, LNG is the benchmark investment for GTL. With the current robust LNG market climate and LNG's long history, GTL must offer a more compelling value proposition to the gas resource holders to be successful. In Qatar and Nigeria, this has been achieved. In Australia, this has not yet happened.

Government's Role

Government has a key role to play to represent the Nation's interests. Fiscal and regulatory regimes are set up and modified to reflect these interests, and have a significant impact on major investment decisions, whether intended or not.

The issues and challenges of large, remote, gas development investments are well known in Australia. Lack of infrastructure, deep water, distant resources, low gas quality, cost of labour, extreme weather conditions, and sensitive environments to name a few.

What should also be considered is how the existing Australian fiscal regime may favour (or not) different investments. GTL can be a value adding domestic industry with enormous community, financial and strategic benefit to the nation. However, the current tax and PRRT regime does not facilitate such large, long term capital investments. The Australian fiscal regime is not internationally competitive with regards to capital depreciation and the facilitation of strategic, Greenfield investment. There are a number of mechanisms available which could allow a more competitive payback for the investor without compromising the value return to the nation. These should be considered if there is a desire to better attract GTL investment.

9. Conclusions

Australia faces a future of steadily increasing imports of transport fuels. Australia's natural gas resources combined with Sasol Chevron's gas to liquids technology is available today to produce large volumes of environmentally friendly synthetic diesel fuels.

With a new industry the uncertainties and costs are somewhat higher than for established businesses, but so are the potential rewards. Sasol Chevron continues to work to secure a GTL project in Australia and remains committed to Australia as a foundation of our global business strategy.

The Australian Government could play an important role in encouraging the development of an Australian GTL industry. Working together, and with the right incentives, Sasol Chevron is confident the many key stakeholders could be aligned to support a sunrise GTL industry in Australia which would;

- Create a new value adding market for Australia’s natural gas reserves
- Develop strategically important gas infrastructure
- Bring new technology and new jobs to Australia
- Reduce Australia’s dependence on imported transport fuels
- Reduce diesel air pollution in Australia’s urban centres
- Become a foundation for the emerging global synthetic fuels industry.

Sasol Chevron is ready to be a partner in Australia’s alternative transport energy future.

References

Akmal, M. and Riwoe, D. 2005, *Australian Energy: National and State Projections to 2029-30*, ABARE *e*Report 05.9, Prepared for the Australian Government Department of Industry, Tourism and Resources, Canberra, October.

Australian Government 2004, *Securing Australia's Energy Future*, produced by the Energy Task Force and published by the Commonwealth of Australia, Canberra.

Five Winds International, 2004, *Gas to Liquids Life-Cycle Assessment, Synthesis Report*, Prepared for ConocoPhillips, Sasol Chevron and Shell International Gas, August 2004.

Fundamentals of Gas to Liquids, 2005, produced and published by The Petroleum Economist Ltd, June 2005.

Herrmann, H., Pelz, N., Maly, R. R., Botha, J.J., Schaberg, P. W., and Schnell, M. 2004, *Effect of GTL diesel fuels on emissions and engine performance*, Paper presented at the 25th International Vienna Motor Symposium, 29-30 April 2004, Vienna, Austria.

Herrmann, H., Keppeler, S., Friess, W., Botha, J.J., Schaberg, P. W., and Schnell, M. 2006, *The Potential of Synthetic Fuels to meet Future Emission Regulations*, [to be published April 2006].

PricewaterhouseCoopers, eurocarprice.com, 2005, European automobile sales statistics.

Pullar, J. 2004, *AusGas: the energy choice for a low emissions economy*, National Gas Strategy, Discussion Draft #1, CSIRO Petroleum, 25 March 2004.

Pytte, A. M., 2003, *Global Trends in Transport Fuels and the Role of Natural Gas*, published by Sasol Chevron Consulting Ltd.

Sasol Chevron Consulting Ltd 2001, *Submission to the Fuel Tax Inquiry*, October 2001.

Appendices

A. Effect of GTL diesel fuels on emissions and engine performance, 2004.

B. LCA Executive Summary; extract from the Five Winds International Gas to Liquids life Cycle Assessment Report.

C. Global Trends in Transport Fuels and the Role of Natural Gas.

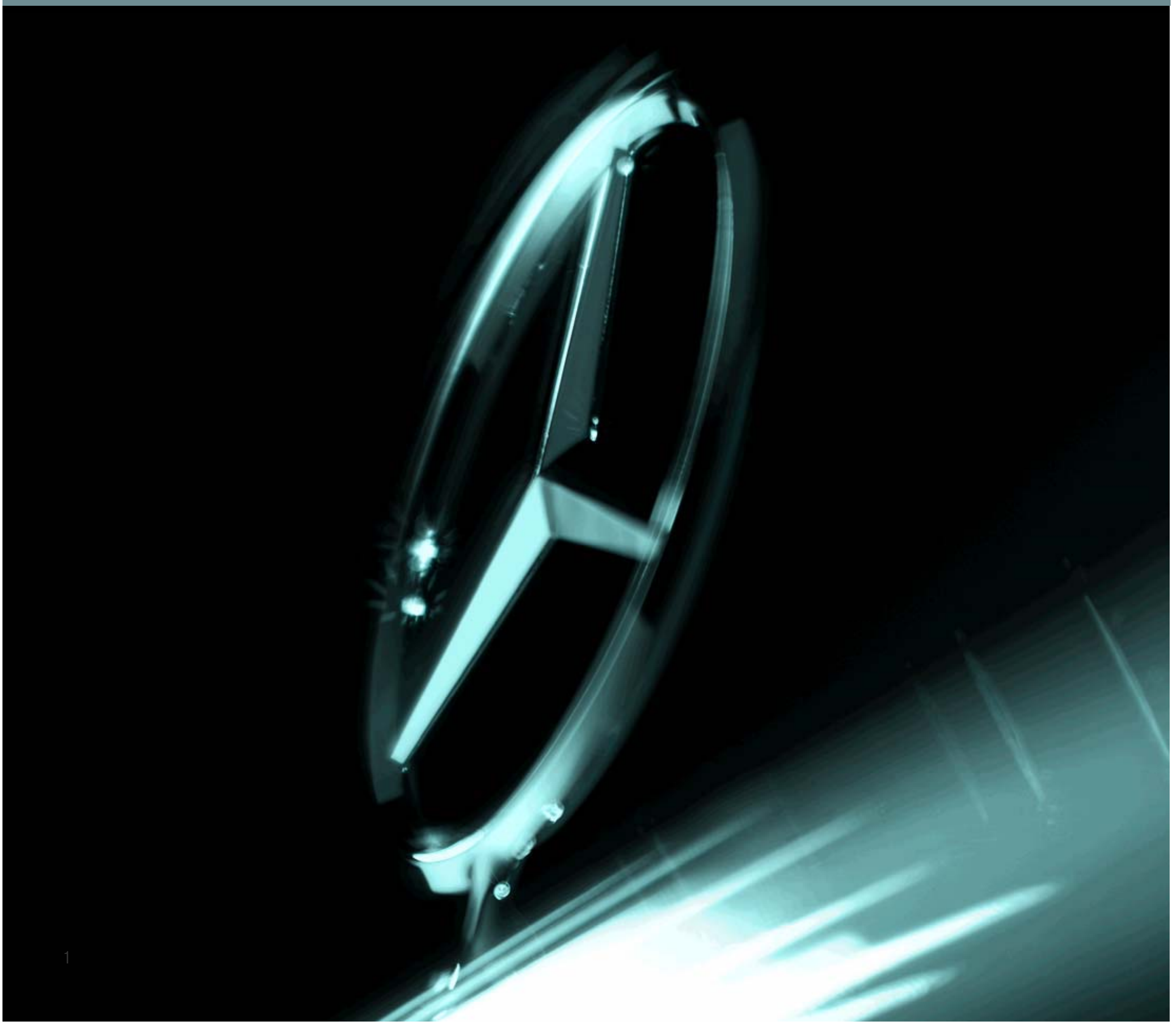
D. Alliance for Synthetic Fuels in Europe brochure – 2006.

APPENDIX A

Effect of GTL diesel fuels on emissions
and engine performance, 2004

DaimlerChrysler

Einfluss von GTL Dieselkraftstoffen auf Emissionen und Motorverhalten




Mercedes-Benz

Effect of GTL Diesel Fuels on Emissions and Engine Performance

Einfluss von GTL Dieselkraftstoffen auf Emissionen und Motorverhalten

Autoren:
Dr. Hans-Otto Herrmann, DaimlerChrysler AG, Stuttgart, D
Dr. Norbert Pelz, DaimlerChrysler AG, Stuttgart, D
Prof. Dr. Rudolf R. Maly, DaimlerChrysler AG, Stuttgart, D

Dr. Johan J. Botha, Sasol Oil (Pty) Ltd. Randburg, RSA
MSc.Eng. Paul W. Schaberg, Sasol Oil (Pty) Ltd. Randburg, RSA

MSc.Eng. Mark Schnell, SasolChevron Consulting Ltd, London, GB

Kurzfassung

Der Einfluss von GTL Dieselkraftstoffmischungen auf die Abgasemissionen und das Motorverhalten wurde detailliert untersucht. Als Referenz- und als Mischungs-Kraftstoff wurde sauberer schwefelfreier EU Dieselkraftstoff (EU Diesel) verwendet. Auf dem Rollenprüfstand ergab die Untersuchung eines E220 CDI im NEFZ (Neuer Europäischer Fahrzyklus), dass auch ohne Neukalibrierung der EU3 Motorauslegung die Emissionen mit GTL Dieselkraftstoff drastisch reduziert werden. Die CO und HC Emissionen sanken bei reinem GTL Dieselkraftstoff um mehr als 90%, die PM Emissionen um bis zu 30%. Bei den NO_x und CO_2 Emissionen wurden Verbesserungen im Bereich einzelner Prozent gefunden. Mischungen von GTL Dieselkraftstoff mit EU Diesel zeigten ein starkes nichtlineares Verhalten: eine 50%-Mischung wies nahezu die gleichen Eigenschaften wie reiner GTL Dieselkraftstoff auf. Um das Potential für weitere Emissionsreduktionen zu ermitteln, wurden auf dem Motorprüfstand Stationäruntersuchungen an ausgewählten Arbeitspunkten durchgeführt, die für den NEFZ charakteristisch sind. Mit Hilfe der Design-of-Experiments-Methode wurde daraus eine mögliche Software-Neukalibrierung berechnet mit optimierten AGR Raten und Einspritzzeiten. Für Rein-GTL Dieselkraftstoff ergab die Berechnung mögliche simultane Reduktionen von NO_x und Ruß von jeweils 35%. Die Nichtlinearität von Mischungen wurde bestätigt: für eine 50 bzw. eine 20%-ige Beimischung von GTL in EU Dieselkraftstoff wurden Reduktionen bei NO_x und Ruß ermittelt, die bei 30% bzw. 15% in Bezug auf EU Dieselkraftstoff lagen. Dies verspricht in Bezug auf Rein-GTL 86% der Vorteile mit 50%-Mischung und immer noch 43% der Vorteile mit einer 20% GTL - 80% EU Diesel-Mischung.

Die Wärmefreisetzung zeigte für GTL Dieselkraftstoff einen deutlich früheren Beginn der Verbrennung sowohl bei der Vor- als auch bei der Haupteinspritzung.

Summary

The effect of GTL diesel fuel blends on emissions and engine performance has been studied in a detailed investigation. A sulfur-free European diesel fuel (EU diesel) was used as reference and as a base stock. Dynamometer tests with an E220 CDI vehicle in the NEDC (New European Driving Cycle) emission test cycle, without any changes to the basic EU3 engine calibration, revealed that GTL diesel fuels may reduce emissions significantly, even with a non-adapted engine. For neat GTL diesel fuel the CO and HC emissions were reduced by over 90%, and PM emissions by up to 30%. Slight improvements in the range of a few percent were observed for NO_x and CO_2 emissions. Blending GTL diesel fuel with EU diesel revealed a strong non-linear characteristic: a 50% blend exhibited properties close to those of neat GTL diesel fuel. In order to explore the available potential for further emission reductions, steady state engine test bed runs were carried out at operating points characteristic for the NEDC. Based on these data, the range of emission reductions was calculated by a design of experiments (DOE) approach for a new soft-calibration with optimized EGR rates and injection timings. For neat GTL diesel fuel a conservative prediction projects possible simultaneous reductions of 35% both in NO_x and in soot. The non-linear blending characteristic was corroborated for 2 blending ratios: for a 50% and a 20% GTL blend with EU diesel, reductions in NO_x and soot were found to be 30% and 15% compared to EU diesel, respectively. This corresponds in relative terms to a 86% and 43% recovery of the benefits of neat GTL. The heat release revealed an earlier start of pilot and main combustion for GTL diesel fuels.

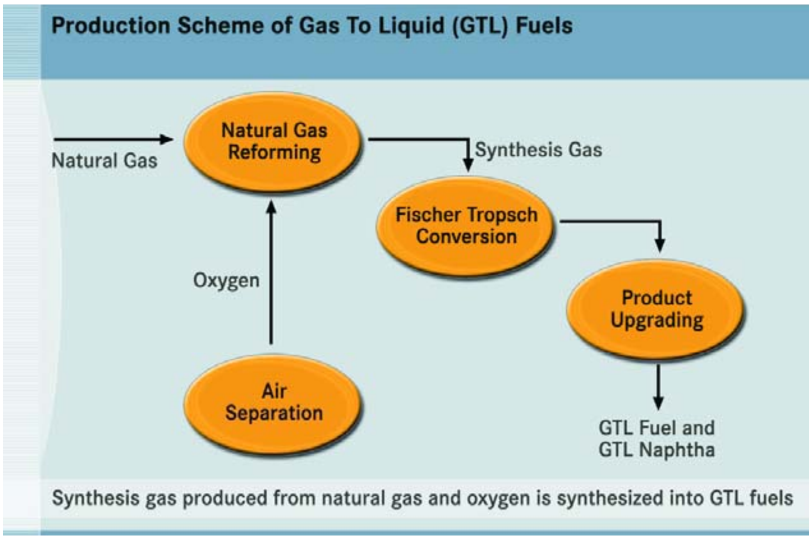


Fig. 1 **Schematic representation of the GTL production process.**
Bild 1 **Schematische Darstellung des Herstellverfahrens von GTL-Kraftstoff.**

1. Introduction

Synthetic fuels such as GTL (Gas To Liquids) diesel fuel have seen a significant rise in interest over the last years [1,2]. They are extremely clean fuels – no sulfur, no aromatics – and are odor-free with a cetane number of > 70. Hence they may facilitate the further reduction of engine-out emissions required to meet future emission regulations, once they have been certified as a road fuel. Major oil companies, for example Shell, SasolChevron and ConocoPhillips, have announced the establishment of several world-scale GTL plants for fuel production coming on stream around 2010. This could lead to production quantities in excess of 1 million barrels/day. It is estimated that by 2010 GTL diesel supply could correspond to 5% – 10% of the EU 2000 diesel demand. By 2020 it is possible that GTL diesel production could account for up to 29% of this demand.

Therefore, of the various alternative fuels currently being considered for road transport, GTL diesel fuel is considered to be the most likely to become available in significant quantities in the near future. GTL diesel fuel also has the advantage that large-scale manufacturing is not constrained by feedstock limitations (as would be the case with bio-derived fuels such as biodiesel or bio-ethanol) and, widespread introduction into the marketplace is not constrained by the requirement for a new distribution infrastructure (as is the case with gaseous fuels such as CNG and hydrogen). GTL diesel fuel production is already economically viable today and significantly less expensive than many other alternative fuel technologies. This has stimulated engine studies to identify the merits of such fuels [3-5].

In order to explore the potential benefits of GTL diesel fuel, a series of investigations were initiated at DaimlerChrysler. The results of a first survey using neat GTL diesel fuel from SasolChevron has been published recently [6]. The present paper represents the results of a cooperation between DaimlerChrysler and SasolChevron to evaluate the effect of blending GTL diesel fuel with clean, sulfur-free EU diesel using a non-adapted EU3 engine. Vehicle dynamometer and engine bench test investigations were undertaken to assess the benefits of GTL diesel fuel for non-adapted and modified software calibrations, respectively. The study focussed on the effect of GTL diesel blends on

existing engine technology without any hardware adaptation.

2. GTL Diesel Fuel Production and Properties

The GTL diesel fuel used in this study was supplied by SasolChevron and manufactured by means of the Sasol Slurry Phase Distillate (Sasol SPD™) process, which consists of three process steps [7], as depicted schematically in **Fig. 1**. Since this process has already been presented before, only a brief summary is given here.

In the first step an auto-thermal reforming process is used to convert the natural gas into the synthesis gas, a mixture of CO and H_2. In a second step the synthesis gas is converted by a Fischer-Tropsch process into a so-called syncrude, containing predominantly paraffinic hydrocarbons. This syncrude is primarily in the form of waxes and distillates, which are further refined in a third product upgrading step by means of mild hydro-processing, in order to produce products that meet commercial fuel specifications, such as diesel fuel and kerosene.

The properties of this GTL diesel fuel and its blends are shown in **Table 1** along with the characteristics of the EU reference diesel. The following differences between GTL and EU diesel should be noted: GTL diesel fuel has a density which is 8% lower (resulting in a volumetric energy content (kJ/l) which is 6% lower than the EU2005 diesel), a heating value which is 1.8% higher, virtually no aromatics, a much higher cetane number, and a boiling curve shifted by about 30 degrees centigrade to lower temperatures.

The properties of the blends change roughly proportionally to the blending ratio, as expected. In **Fig. 2** the measured boiling curves are shown. One notices a generally normal blending behavior with expected deviations only in first and last 10% fractions.

Characteristics of the Test Fuels

Properties of the EU reference Diesel and the different GTL fuels used

Property	Units	EU2005 Diesel (Reference Fuel)	blend EU/GTL 80/20	blend EU/GTL 50/50	GTL Diesel SasolChevron
Density @ 20°C	kg/L	0.832	0.821	0.802	0.765
Lower Heating Value	kJ/kg	43 073	43 200	43 500	43 836
Kinematic Viscosity @ 40°C	cSt	2.87	2.79	2.54	1.97
Cetane Number	-	53	58	62	75
Cold Filter Plugging Point	°C	-17	-17	-18	-19
Total Sulphur	ppm wt	8 (<10)	6	4	<1
Total Aromatics	% wt	28	21.5	13.5	0.14
H/C Ratio (molar)	-	1.83	1.91	1.98	2.1
Flash Point	°C	82	76	66	59
Lubricity Index (HFRR)	µm	394 (<460)	(<400)	(<400)	370 (<460)
ASTM D86 Distillation 10%	°C	221	212	201	187
ASTM D86 Distillation 95%	°C	354	339	337	321

Table 1 Characteristic properties of the fuels investigated in this study.

Tabelle 1 Charakteristische Eigenschaften der untersuchten Kraftstoffe.

Boiling Curves of the Test Fuels

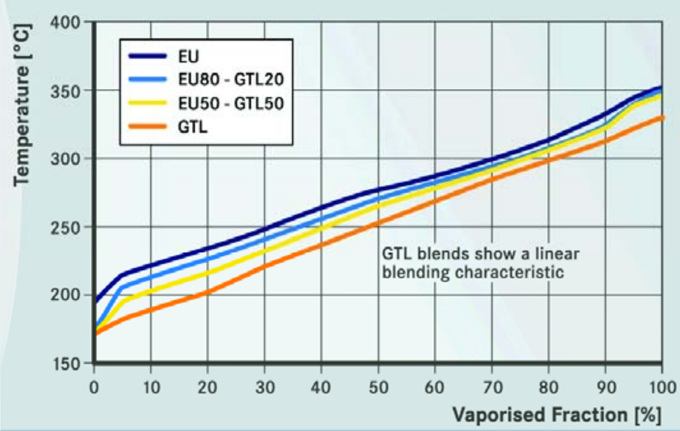


Fig. 2 Measured boiling curves for the 4 fuels tested.

Bild 2 Gemessene Siedekurven der 4 untersuchten Kraftstoffe.

Engine Data
Characteristic data of the Mercedes-Benz engine

Designation	MB OM 646, EU3 emission level
Displacement, configuration	2.2 l, in-line 4 cylinder 4 valves per cylinder
Compression ratio	18 to 1
Fuel management	Common rail fuel injection (peak 1600 bar)
Air management	Turbocharged, intercooled
Emission control	Cooled EGR; inlet swirl control; close coupled and underfloor oxidation catalysts
Rated Torque	340 Nm from 1800 to 2600 rpm
Rated Power	110 kW at 4200 rpm

Table 3 Characteristic engine data of the MB E220 CDI.
Tabelle 3 Charakteristische Motordaten des MB E220 CDI.

3. Vehicle Tests

The vehicle emission tests were conducted with a Mercedes-Benz E220 CDI passenger car complying with EU3 emission standards, over the NEDC test cycle. In addition to the usual bag samples, pre- and post-catalyst modal emissions were also measured. The vehicle was tested in its standard calibration without any adaptation for EU diesel, the 50% blend and for the neat GTL diesel fuel. The vehicle test data are shown in **Table 2**, and the engine data in **Table 3.**

Mercedes-Benz E 220 CDI Limousine
MY 2003
MB OM 646 engine
6-speed manual gearbox
New European Driving Cycle, NEDC 2000
Cold and hot tests on a chassis dynamometer

Table 2 Characteristic vehicle test data of the Mercedes-Benz E220 CDI.
Tabelle 2 Charakteristische Fahrzeugtestdaten des Mercedes-Benz E220 CDI.

The results of the unadapted vehicle emission tests are depicted in **Fig. 3**. Five NEDC test runs were carried out for each of the 3 fuels: EU diesel, EU50-GTL50, and GTL diesel fuel. The test data were averaged to provide reliable results. They are presented as the percentage changes relative to the sulfur-free EU2005 diesel reference fuel. For neat GTL diesel fuel an extremely high reduction of > 90% for HC and CO emissions was observed. The absolute figures were so low that they were difficult to measure accurately. The CO and HC reduction values for the 50% blend scale roughly with the blending ratio.

The NO_x emissions were reduced only marginally by a few percent. The 50% blend again showed about half the reduction of the neat fuel value. The same applies for the $HC+NO_x$ data.

PM emissions were reduced by up to 30% with a strong non-linear characteristic: the 50% blend also showed a large reduction of about 22%.

The somewhat higher hydrogen content of the GTL fuel resulted in a slight reduction in the CO_2 emission. Part of the reduction is also attributed to an improved thermal efficiency.

PC Emission Test NEDC 2000
Results from the NEDC test on the dynamometer

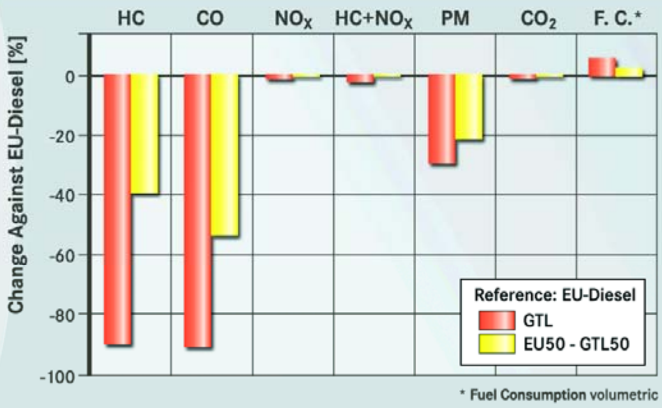


Fig. 3 Results of the chassis dynamometer tests in the NEDC.
Bild 3 Ergebnisse der Rollenprüfstandsmessungen im NEFZ.

The fuel consumption data exhibited the expected behavior. The volumetric fuel consumption, measured in l/100 km, was about 6% higher with GTL diesel fuel than for EU diesel. This is due to the 8% lower density of the GTL diesel fuel. This is an indicator that conventional reference parameters lose their significance if alternative fuels with properties deviating from conventional fuels, are used. The 6% increase in volumetric fuel consumption actually translates into a decrease in gravimetric fuel consumption of 1% – 2% for the neat GTL diesel fuel.

In **Figs. 4** and **5**, the effect of GTL diesel fuel on the evolution of HC and CO emissions is shown. In order to clarify the reasons for the large HC and CO reductions with the GTL diesel fuel, the temporal evolution of these emissions was recorded. As can be clearly seen by comparing engine-out and tail pipe emissions, there are already very low HC and CO emissions from the very start of the test, although the oxidation catalyst is still cold until about 90 s into the test. These low emissions are due to absorption processes in the catalyst even under cold conditions. However, the amount of HC and CO which can be absorbed is limited. It can be seen that the somewhat higher engine-out HC and CO emissions with the EU50-GTL50 blend result in a breakthrough. The absorption effect is strongest for CO emissions. These are removed almost completely in case of neat GTL.

These very attractive properties of GTL diesel fuel have potential for improving the cold start characteristics of vehicles by further adapting the absorption performance of the oxidation catalyst to the low HC and CO emissions of GTL diesel fuel.

4. Engine Tests

After the intial investigation into the effect of GTL diesel fuel on the performance of a modern, unadapted diesel vehicle, a more in-depth analysis was performed into the potential for further emission reductions. To this end a number of steady state test bench runs were carried out at five operating points, chosen as being characteristic for NEDC emissions. Since it was the aim of this study to explore the potential of GTL diesel fuels without any hardware changes, only software parameters were investigated which could easily be adapted by reprogramming the control unit.

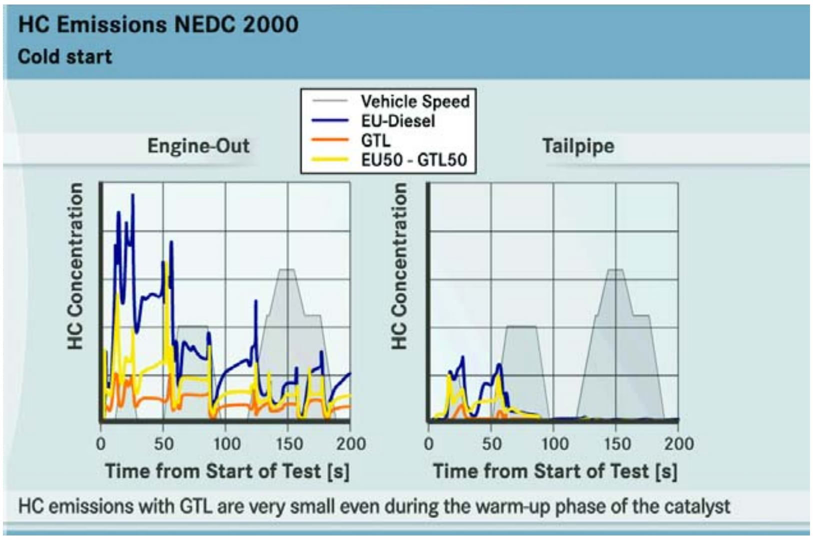


Fig. 4 Temporal evolution of the HC emissions in the NEDC.
Bild 4 Zeitliche Entwicklung der HC Emissionen im NEFZ.

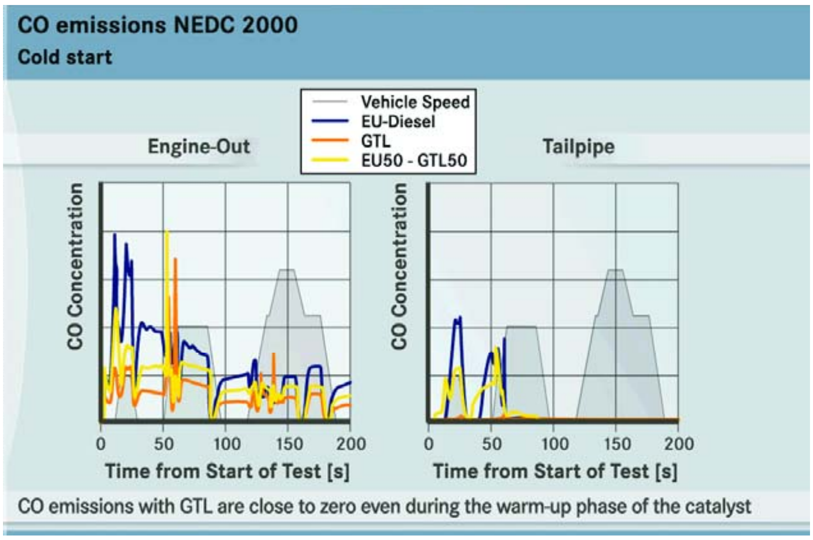


Fig. 5 Temporal evolution of the CO emissions in the NEDC.
Bild 5 Zeitliche Entwicklung der CO Emissionen im NEFZ.

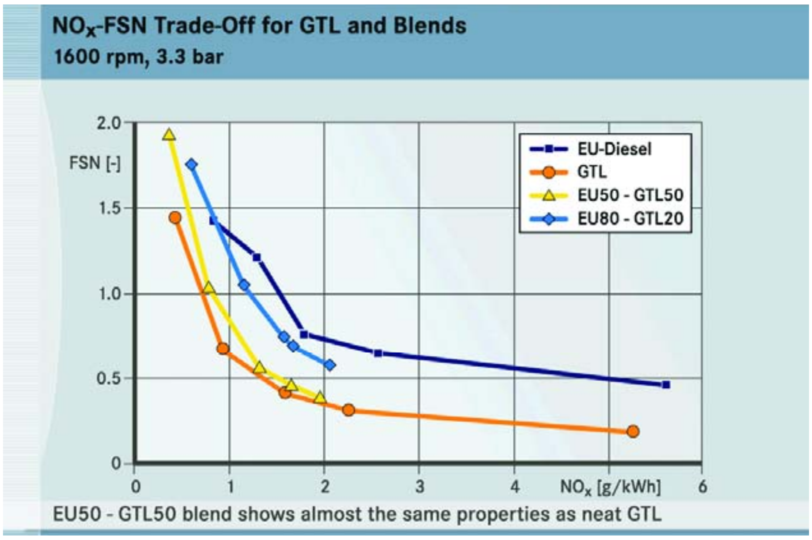


Fig. 6 **FSN and NO_x tradeoff at 1600 rpm and a bmep of 3.3 bar.**
Bild 6 **FSN und NO_x Tradeoff bei 1600 1/min und einem eff. Mitteldruck von 3,3 bar.**

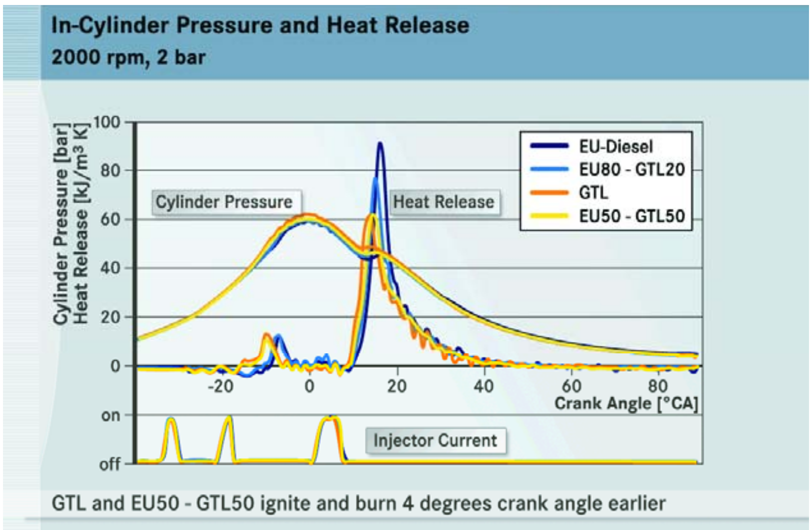


Fig. 7 **In-cylinder pressure and heat release rates at 2000 rpm and a bmep of 2 bar.**
Bild 7 **Zylinderdruckverlauf und Wärmefreisetzungsrate bei 2000 1/min und einem eff. Mitteldruck von 2 bar.**

They comprised of varying the EGR rate, the start of pilot injection (SOPI), and the start of main injection (SOMI).

In **Fig. 6** an example is shown of typical results obtained from the steady state bench test work. In this figure representative data for the effect of GTL diesel fuel and its blends on the FSN-NO_x trade-off are shown for one characteristic operating point. Here the EGR rate was varied, while the SOPI and SOMI were kept constant and equal to the reference values.

It is obvious that GTL diesel fuel offers a significant reduction of both FSN and NO_x for all EGR rates, with these reductions being larger than the values measured under transient conditions on the chassis dynamometer. The FSN increase with decreasing NO_x values is not abnormal, thereby allowing a wide range of possible alternative calibrations. Interestingly, the strong non-linear behavior of the blends is again evident: a EU50-GTL50 blend exhibits almost the same benefits as neat GTL diesel fuel. This is a welcome result and a very attractive feature since this would increase the available volume of fuel with "GTL diesel fuel-like" emission performance considerably during the early phase of GTL production, when quantities are still limited.

The different fuel properties of GTL diesel fuels are reflected in the in-cylinder pressure development and in the heat release rates which are presented in **Fig. 7**. For fixed injection timings (SOPI, SOMI) - see curves at the bottom of the figure - the GTL diesel fuel and the EU50-GTL50 fuels ignite about 4 degrees earlier than the EU80-GTL20 and the EU diesel.

The same behavior is also observed for the main combustion. Further combustion analysis is required to extract the detailed reasons for the differences in the heat release rates.

Based on these measured data, the method of design of experiments (DOE) was used to assess the potential benefits of GTL diesel fuel and its blends in a NEDC test, with an optimised calibration. This was done by numerically optimizing all three software parameters simultaneously. Boundary conditions for the optimization were chosen in such a way, that emissions, fuel consumption and noise never exceeded the values with EU diesel. The DOE predictions were verified by

actual experiments. In order to account for the effect of the transient nature of the NEDC test, the computed optimized DOE data were reduced by an empirical factor. This factor was determined from the difference in PM – NO_x tradeoff for neat GTL diesel fuel, between the measured vehicle dynamometer results and the predicted DOE values, using the unmodified engine calibration. This procedure should give conservative estimates for the potential of optimsing the software of the engine for the GTL diesel fuels (see **Fig. 8**). Thus a general insight into the soot versus NO_x reduction potential of GTL diesel fuel and diesel blends is possible.

All results from the selected operating points have been normalized and combined into one universal plot to mimic the behavior in a NEDC test with an optimized calibration for each fuel. As outlined above, a DOE method was used to project the likely characteristics. A surprisingly large gain appears possible for all fuels, even without any hardware changes.
The projected improvements compare favorably with the dynamometer data shown earlier.

The neat GTL diesel fuel would allow for a simultaneous soot and NO_x reduction of at least 35% compared to the EU diesel calibration. For constant engine-out soot emission a NO_x reduction of a remarkable 45% seems possible. Due to the non-linear characteristics of the GTL blends, major benefits could also be obtained by using blends with lower amounts of GTL diesel fuel.

A 50% GTL blend would reduce soot and NO_x emissions of the EU calibration by 30% and a 20% GTL blend still by 15%. This corresponds in relative terms to a 86% and 43% recovery, respectively, of the benefits of neat GTL: a very promising result for the introduction phase of synthetic fuels.

It should be noted that the results shown so far have been projected by a simple and cost-efficient software adaptation only. It is to be expected that further improvements will be possible if additional hardware changes, for example in the injection system and/or the combustion chamber design, are taken into account.

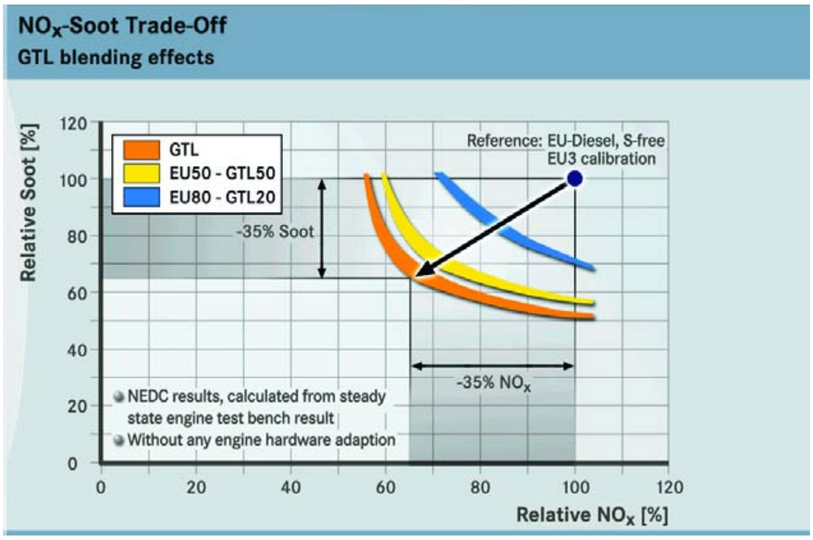


Fig. 8 **Predicted soot and NO_x tradeoff for all investigated GTL diesel fuels computed and optimized with DOE. The optimization was based on 3 parameters only: EGR rate, start of pilot injection and start of main injection.**

Bild 8 **Prognostizierter Ruß und NO_x Tradeoff für alle untersuchten GTL Kraftstoffe, mit der DOE-Methode optimiert bezüglich der 3 Parameter AGR Rate, Piloteinspritz- und Haupteinspritzzeitpunkt.**

5. Conclusions

The use of GTL diesel fuel in unmodified vehicles enables significant reductions of HC, CO, and PM emissions, without compromising NO_x emissions, when compared to a clean sulfur-free European diesel fuel.

GTL diesel fuel allows a drastic reduction of HC and CO emissions, even during the early startup phase of the test cycle when the oxidation catalyst is still cold. By improving the adsorption characteristics of the catalyst a further reduction appears feasible.

The high cetane number of the GTL diesel fuel is beneficial during cold-start and low temperature operation.

The lower smoke and soot emissions with GTL diesel fuel facilitate NO_x reductions by exploiting the higher EGR tolerance of GTL fuels. Thus a more favorable NO_x/FSN tradeoff may be selected reducing both NO_x and soot.

There is a significant still unexploited potential for further reductions of exhaust emissions with GTL fuel by optimizing the software calibration for the engine using easily accessible parameters e.g. EGR rate, start of pilot injection and start of main injection. For neat GTL a conservative prediction projects possible simultaneous reductions of 35% both in NO_x and in soot.

An even greater potential for improvement is to be expected if hardware adaptations of the engine are taken also into account.

Very promising results were achieved also with GTL diesel as a blending component for conventional diesel fuels. A strong non-linearity was observed recovering large fractions of the potential of neat GTL diesel: for a 50% and a 20% GTL blend with EU diesel, reductions in NO_x and soot were found to be 30% and 15% compared to EU diesel, respectively. This corresponds in relative terms to a 86% and 43% recovery of the benefits of neat GTL diesel.

6. Acknowledgements

The authors would like to thank Dipl.-Ing. Walter Friess, Dipl.-Ing. Dirk Hafenbraedl, Dipl.-Ing. Sebastian Kess, Rainer Kessler and Peter Lehnert of DaimlerChrysler Stuttgart, as well as all others for their valuable contributions to this project.

7. Literature

[1] Kohler, H.K., Proposal for a European Energy Strategy for Road Traffic”. VDA Technischer Kongress "Kooperation zum Einsatz regenerativ erzeugter Kraftstoffe”, April 2003

[2] R.R. Maly and W. Steiger, Strategie für nachhaltige Kraftstoff / Antriebs-Systeme, 20. Internationale VDI/VW – Gemeinschaftstagung, "Kraftstoffe und Antriebe der Zukunft - Synergien für eine nachhaltige Zukunft?”, Wolfsburg, 3. - 5. Dezember 2003.

[3] Schaberg, P.W., Myburgh, I.S., Botha, J.J., Roets, P.N.J., Viljoen, C.L., Dancuart, L.P., and Starr, M.E., "Diesel Exhaust Emissions Using Sasol Slurry Phase Distillate Process Fuels". SAE Paper 972898, 1997

[4] Schaberg, P.W., Myburgh, I.S., Botha, J.J., and Khalek, I., "Comparative Emissions Performance of Sasol Fischer-Tropsch Diesel Fuel in Current and Older Technology Heavy-Duty Diesel Engines”. SAE Paper 2000-01-1912, 2000

[5] Payri, F., et al, "Characterisation of the Injection-Combustion Process in a Common Rail D.I. Diesel Engine Running with Sasol Fischer-Tropsch Fuel”. SAE Paper 2000-01-1803, 2000

[6] W. Friess, H.-O. Herrmann, R. R. Maly, M. Schnell and P. Schaberg, Reductions in Exhaust Emissions with GTL Diesel Fuel, 20. Internationale VDI/VW – Gemeinschaftstagung, "Kraftstoffe und Antriebe der Zukunft - Synergien für eine nachhaltige Zukunft?”, Wolfsburg, 3. - 5. Dezember 2003.

[7] Schaberg, P.W., et al, "An Overview of the Production, Properties, and Exhaust Emissions Performance of Sasol Slurry Phase Distillate Diesel Fuel". 2nd International Colloquium on Fuels, Technische Akademie Esslingen, 1999

Notizen

DaimlerChrysler AG
Stuttgart, Germany
Auburn Hills, USA
www.daimlerchrysler.com

25. Internationales Wiener Motorensymposium 2004, Auflage 1.500, M. L. Gaukler Werbeagentur, Stuttgart

APPENDIX B

LCA Executive Summary;
Extract from the Five Winds International Gas to Liquids life Cycle Assessment Report.

EXECUTIVE SUMMARY

This Executive Summary summarizes important findings from the three LCA studies and presents them as key findings for each of three audiences: policy makers, civil society and automotive OEMs and fleet operators. As mentioned, these groups share some of the same similar concerns and as result certain key findings are included in more than one section.

KEY FINDINGS FOR POLICY MAKERS & REGULATORS

i) Greenhouse Gas performance goals

Production and use of GTL fuel can contribute less greenhouse gas to the atmosphere than production and use of conventional diesel fuel. The study commissioned by ConocoPhillips indicated the reduction in greenhouse gas emissions is significant if the GTL fuel is produced from associated gas[2] that is otherwise flared in amounts of 10% or greater. More conservatively, and in cases where the feedstock is from other sources, the greenhouse gas contribution of GTL fuels is comparable to conventional diesel technology. In the expanded GTL technology system, available natural gas is used for space heating and electricity generation, whereas conventional refining technology uses more carbon intensive light fuel oil and residual fuels respectively, to meet these needs. While the GHG emissions from production and upstream processes of the GTL system are higher compared to the refinery-based system, the advantages in the use phase, at a minimum, compensate for the disadvantages in those phases.

ii) Protecting & extending resource availability

Fuelling vehicles with GTL fuel consumes fewer petroleum resources per distance travelled than with conventional diesel. In addition, the study commissioned by ConocoPhillips indicated that, given forecasts of the rate of development of stranded gas projects, GTL fuel production will continue after crude oil reserves are depleted based on today's assessment of the life span of crude oil reserves. This is because GTL technology exploits remote gas reserves and not crude oil. Extrapolating from this point, using remote gas to create GTL fuel will extend the lifetime of crude oil reserves accordingly.

However, producing GTL fuel currently requires more energy and resources per unit mass produced than conventional diesel production. For both production of GTL fuel and across the full life cycle, GTL requires fewer petroleum resources than conventional diesel production.

iii) Reliability of feedstock supplies for fuel

Natural gas is the cleanest fossil fuel. There is potential for remote natural gas to provide energy to the global market for many decades. With respect to environmental impacts, remote natural gas can provide this energy in a manner comparable or better than petroleum reserves.

[2] Associated gas is natural gas by-product from crude oil production.

iv) Air quality in urban centres

GTL fuels are virtually free of sulphur and aromatics. Per distance travelled, GTL fuels contribute fewer emissions and negative impacts on urban air quality than conventional diesel. According to the studies, GTL technology creates fewer air pollutants (SO_2, NO_x, VOCs and particulate emissions) and therefore contributes less to acidification of the air and formation of smog. Although the results of each of the studies are somewhat different, it appears that there are fewer environmental and health impacts from GTL fuel than from conventional diesel.

v) Air acidification

With significantly lower emissions of acidifying gases, GTL technology potentially cause less air acidification than the conventional diesel technology. While the emissions from GTL are lower, there is no direct link between the amount of emissions and actual acidification, because actual acidification depends so heavily on factors specific to the environment where the emissions are received (such as climate, soils, geology, etc.).

vi) GTL Technology can be used without new capital & infrastructure

GTL fuel can be used either directly or blended with conventional diesel and burned in conventional diesel-powered vehicles. Tanks, pumps and other fuelling infrastructure can be filled with GTL fuel without significant retrofitting or capital investment. While there is potential to optimize vehicle engines to run even more efficiently on GTL fuel, such re-design is not essential. Technological advances in design of advanced engines can be a longer-term goal consistent with the growth of GTL markets.

vii) Waste reduction

The Shell and ConocoPhillips studies indicated that the GTL system generates less solid waste (up to 40% less according to the Shell study) and less hazardous waste than conventional refining technologies.

KEY FINDINGS FOR CIVIL SOCIETY & NGOS

i) Balanced environmental profile of GTL

GTL technology is complementary to the conventional refinery based system. GTL is able to extend the availability of energy sources for a variety of functions. The overall environmental footprint of the GTL system offers advantages for a range of environmental impacts.

The studies suggest, that, based on current estimates, producing GTL fuel requires more energy than the conventional refinery system and results in comparable GHG emissions.

Being at an earlier stage of its technical development, the GTL technology has room for improvement. GTL fuels have the potential to help alleviate several environmental concerns around fuel and energy systems in such areas as air quality improvements in urban areas and reducing the GHG intensity of fuel systems.

ii) Air quality concerns

Reductions in air acidification, particulate emissions, VOC emissions and the related environmental concerns are important aspects of improving urban air quality. The GTL system offers important advantages. GTL fuels are virtually free of sulphur and aromatic compounds resulting in cleaner and more controlled combustion. The result is reduced emissions of particulates, lower (and sometimes eliminated) pollutant emissions and lower emissions of NO_x in urban areas. Significant reductions in all three categories make the GTL system attractive.

iii) Use of existing infrastructure

Consumers can immediately benefit from the advantages of the GTL system by using existing fuelling infrastructure. GTL fuels can be used in existing vehicle engines directly or in a blended fashion. Expensive modifications to the fuelling infrastructure that could delay adoption of a new fuel technology are not required.

iv) Greenhouse Gases

From a systems (i.e. holistic) perspective, GTL technology has comparable GHG emissions to the conventional refinery based system. In the GTL system, higher GHG emissions are associated with the production phase due to the higher process energy requirements. These are offset by lower GHG emissions in the use phase, and by replacing higher carbon content fuels such as heavy fuel oil with less carbon intensive alternatives such as natural gas.

KEY FINDINGS FOR AUTOMOTIVE OEMS & FLEET OPERATORS

i) GTL technology provide clean fuel

GTL fuels offer significant advantages by providing cleaner fuels to help meet emission limits. With respect to sulphur content and aromatics, the GTL technology has significant advantages meeting recent public and societal health concerns. GTL fuel also enables the development and use of advanced exhaust systems and engines.

ii) Opportunity for efficiency and performance gains

GTL fuels may in some cases offer performance advantages, such as higher distance travelled per unit mass of fuel. There is a further possibility to also reduce other environmental impacts such as the specific GHG or particular matter emissions intensity per unit distance travelled.

iii) Resource base extended

Being based on remote natural gas reserves, the GTL technology extends the lifetime of the crude oil resource base. These complementary and additional sources for fuels extend the lifetime of oil reserves by allowing oil extraction more slowly than would otherwise occur. This protects existing assets and extends time for research and development for alternative systems and technologies.

iv) Fuels can support fleet owners to document positive contribution in urban areas

The GTL fuel system offers advantages in pollutant emissions, such as SO_2, particulates and VOCs (between 26% to 82% less VOCs, according to the LCA studies). Fleet operators can significantly reduce their impact by utilizing GTL fuels. This may help in maintaining access to certain urban areas, lower cost licenses and other economic incentives.

v) Use existing engine designs, fleet operator infrastructure and general infrastructure

While being able to reduce the environmental footprint of fuel use, no additional investments are necessary to distribute and use GTL fuels. The existing infrastructure is completely compatible with the GTL system and blended GTL fuels, including filling stations, storage, fuelling, etc. Also existing assets can make use of GTL fuel. No engine adjustments or new vehicles are necessary and costly R&D investments are not required.

APPENDIX C

Global Trends in Transport Fuels and the Role of Natural Gas.

Sasol Chevron

Global Trends in Transport Fuels and the Role of Natural Gas

An Australian Perspective

Article produced April 2004

Tony Pytte, Project Director

Australia, Sasol Chevron

A native of New Hampshire, Tony was educated in the United States where he received degrees in Geological and Geophysical Sciences from Princeton University and from Dartmouth College.

Tony began his petroleum career in 1982 in Houston with the Gulf Oil Exploration and Production Company. With the Chevron/Gulf merger in 1985, Tony relocated to California, and held a series of international exploration and production assignments followed by stints supporting the Corporation's Executive staff and with Strategic Planning. Tony then came to Australia in 1994 where he has held a number of commercial and managerial assignments with the Chevron Australasian Business Unit in both Melbourne and Perth.

Tony was appointed to his current position with Sasol Chevron in January 2000 and is responsible for developing a new Gas to Liquids business based on Australia's abundant gas resources.

Introduction

It is well known that the developed world wants future transport fuels and technologies that deliver:

- Lower toxic emissions
- Lower greenhouse emissions
- Greater efficiency of energy use
- Less dependence on foreign oil imports
- Affordable transport

For many people, this kind of energy future invokes the idea of a “hydrogen economy”. In 2002, the European Union committed 2.1 billion euros (about US$2.2-2.3 billion) to hydrogen research. Japan has a national goal of 50,000 fuel cell vehicles on the road and 2,100 megawatts of fuel cell power plants by 2010. US President George W. Bush laid out a vision of a hydrogen-powered future and announced US$1.2 billion in hydrogen research funding over five years to jump-start a long-term research program – the key here is “long-term”.

For the foreseeable future, hydrogen will remain an industrial feedstock rather than a fuel and, whilst it may find niche fuel markets over the next decade, it will require major technological breakthroughs to become commercially viable. Hydrogen is expensive to produce, costly and complex to transport and store and uncompetitive because of its low volumetric energy density. Research will need to focus on the best source of hydrogen since the use of fossil fuels will not resolve energy security or supply issues. A second research focus area will be to establish hydrogen as a serious player in reducing greenhouse emissions. Today, other technologies can deliver the same greenhouse benefits at lower cost. Then there is the “chicken-and-egg” problem – without hydrogen re-fuelling stations, consumers will be reticent to use hydrogen-powered vehicles and, without customers, investors will be unwilling to build refuelling stations.

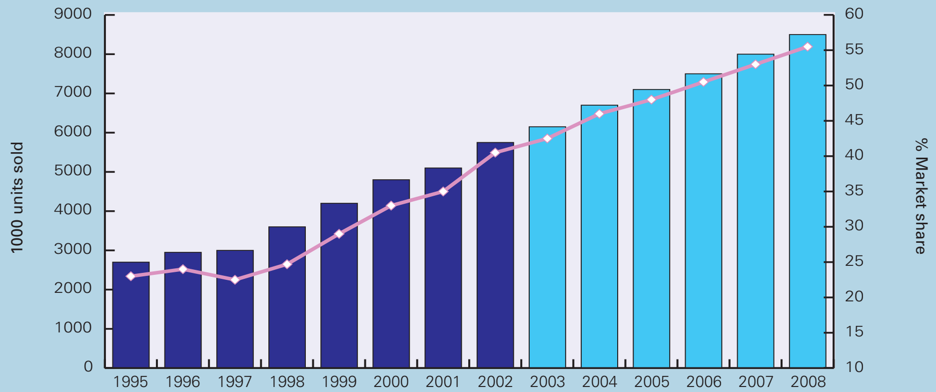
The only certainty about a shift to a hydrogen-powered world is that it is still a long way in the future. The extent of investment in research and development highlights how little is known and how much effort is still required to develop hydrogen technology and new energy innovation. Can the world wait to see what happens with hydrogen? The answer is that it can't; and neither is it.

Over the last decade, Europe has led the world in developing clear policy and implementing incentives and regulations to ensure it meets the sustainable transport objectives listed above in the near to mid-term. The pathway Europe identified as best delivering these objectives involves ultra-clean diesel fuels and advanced diesel engine technologies. There are a number of reasons for this:

- Diesel cars use 30-50% less fuel than petrol cars of similar power
- Diesel cars produce more drive force at lower engine speeds
- Diesel engines are built to last well over 300,000 kilometres, require less maintenance and have longer service intervals than petrol engines (Diesel Technology Forum 2001)
- Diesel fuel efficiency means lower emissions of greenhouse gases
- The latest diesel technology is both clean and quiet, offering a good alternative to less efficient petrol cars

In 2002, 40% of new passenger cars in Europe had diesel engines compared with less than 20% a decade earlier (Diesel Technology Forum 2001), highlighting Europe's success in implementing its chosen transport policy (Figure 1). This transition has not occurred without government intervention. European governments encourage the use of diesel technology through fuel tax structures and vehicle sales taxes. At the same time, stringent emissions regulations encourage advances in emissions reduction technology and maintain the market viability of diesel vehicles.

Figure 1 - European diesel car market share



Source: AID: Diesel Car prospectus to 2008; Nov, 2002

In the US and Australia, many policy-makers and consumers still see diesel as both dirty and noisy. Until recently, most policy and discussion in these jurisdictions has centred on alternative fuels such as CNG, LPG, biofuels and hydrogen. All of these fuels, however, are limited in the extent to which they can penetrate markets and achieve each of the objectives above. This is now being recognised in the USA with California leading the way in defining the increasing role that diesel needs to play in the near to mid term on the path to sustainable transport fuels and technologies (CEC and CARB, 2003).

In all jurisdictions, understanding is growing that natural gas can be an important part of the diesel pathway. The role of natural gas in liquid transport fuels and gas-to-liquids technology (GTL) is not widely understood in the broader community although the technology has been around since the 1920s. The Fischer-Tropsch process, fundamental to GTL technology, has been successfully used on a large scale in South Africa where it is used to produce about 40% of South Africa's domestic liquid transport fuels. GTL technology has not been used on a global scale before simply because global oil supplies have been so abundant and crude oil refining has been less expensive. The cost of the technology today is increasingly competitive with crude oil refining because refining costs for cleaner fuels are increasing and because GTL producers can target the product slate to produce diesel and other middle distillates, for which demand growth is highest. In addition, GTL diesel is already ultra-clean with virtually no sulphur or aromatics. Because of this, there is continuing research and development focus on GTL technology to further lower capital and operating costs. A number of companies are active in GTL process development, including Sasol Chevron, Sasol, ExxonMobil, Shell, and ConocoPhillips.

Sasol, with over 50 years GTL experience in South Africa, together with Qatar Petroleum, is currently building the largest and first truly commercial-scale GTL plant in the world – a 34,000 barrel per day facility, ORYX GTL, in Ras Laffan in Qatar. This is scheduled for start-up in 2005. Sasol is targeting selected Asian and European markets for its premium, ultra-clean GTL diesel and naphtha (http://www.sasol.com). Chevron Nigeria (CNL) and the Nigerian National Petroleum Corporation (NNPC) are planning a further 34,000 barrel per day GTL plant in Escravos in Nigeria and this will use the same technology as ORYX GTL. Products from this plant are aimed primarily at the European market (http://www.sasolchevron.com).

Further, Sasol and ChevronTexaco, through their joint venture, Sasol Chevron, have announced the most ambitious slate of GTL projects to date with a six billion dollar package that will include an expansion for ORYX (65,000 bbl/day), an integrated project (130,000 bbl/day plus 80,000 bbl/day associated condensates) and a GTL base oils production facility.

Both Shell and ConocoPhillips have also announced large-scale GTL projects and Shell's 12,500 barrel per day plant in Bintulu in Malaysia is selling GTL diesel and naphtha into Asia Pacific markets, including Thailand, Japan and California.

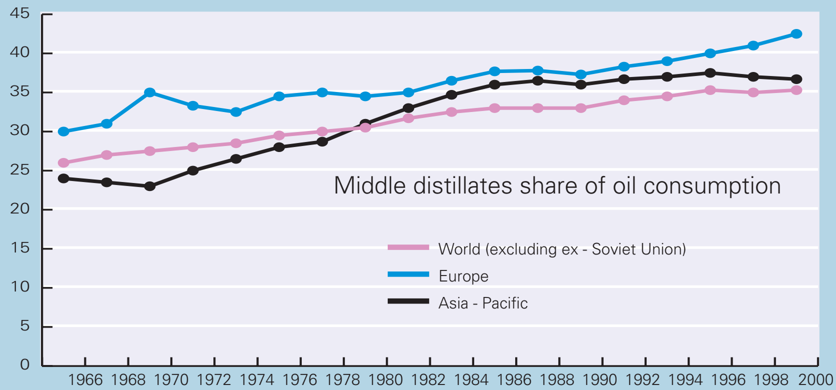
For Australia, with its abundant but remote natural gas resources, GTL technology offers the opportunity to create a new value-adding industry whilst capitalising on the global trend toward dieselisation and building a pathway to best meet the sustainable transport objectives listed above.

This paper explores the global trend towards diesel technology, highlighting the role of natural gas in the diesel pathway, comparing the European and American experiences and commenting on the sustainable transport possibilities for Australia in the future.

The Global Diesel Market and the Role of GTL Diesel

World diesel demand in 2001 was about 12.5 Mmbbl/day (Petroleum Economist 2003). Demand has grown close to 3% per year for the past decade, making diesel the fastest growing segment of the refined products market (Figure 2). In the first half of the 1990s, global demand growth was dampened by the decline of the Soviet Union and in the second half by the Asian slowdown (Petroleum Economist 2003). Diesel demand is closely correlated to economic growth since it is the fuel used to drive the global economy and is preferred for mining, agriculture and road freight. In Europe, passenger transport is now contributing to demand growth. Globally, diesel demand is likely to continue to grow at around 3% per year while demand for certain other refined products is likely to flatten and even decline (Petroleum Economist 2003). Against this backdrop, refiners are facing significant challenges to meet diesel demand into the future.

Figure 2 - Market outlook for diesel; increasing share of the oil barrel



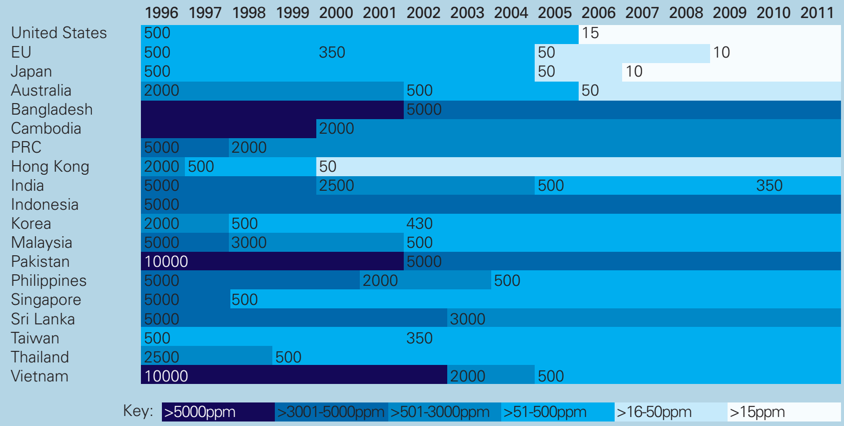
Source: BP Statistical Review of World Energy, June 2003

A second area of pressure for refiners arises from global demand for cleaner diesel. Concerns over air pollution in many jurisdictions have led to a continuing tightening of diesel vehicle emission specifications. Vehicle manufacturers have improved exhaust treatment technology and enhanced engines significantly, but these technology advances have required the introduction of cleaner diesel fuels. Even in developed economies there is still some way to go to achieve the "sulphur-free" diesel (10ppm sulphur or less) that is required by vehicle manufacturers for further advancement of emission control systems.

The European Union is in the final stages of adopting legislation which will mandate sulphur-free diesel for on-road use by 2009. Most parts of Europe are already using 50ppm or lower sulphur diesel well ahead of the target date of 2005. The US will introduce 15ppm sulphur diesel by 2006 while Japan is likely to mandate the use of sulphur-free diesel by 2008 (World Diesel 2003). Australia will introduce 50ppm sulphur diesel in 2006 and could go to "sulphur-free" diesel by the end of the decade. At the end of the 1990s, "clean" diesel around the world still contained about 500ppm sulphur, highlighting the magnitude of clean fuel advances in recent years (Figure 3).

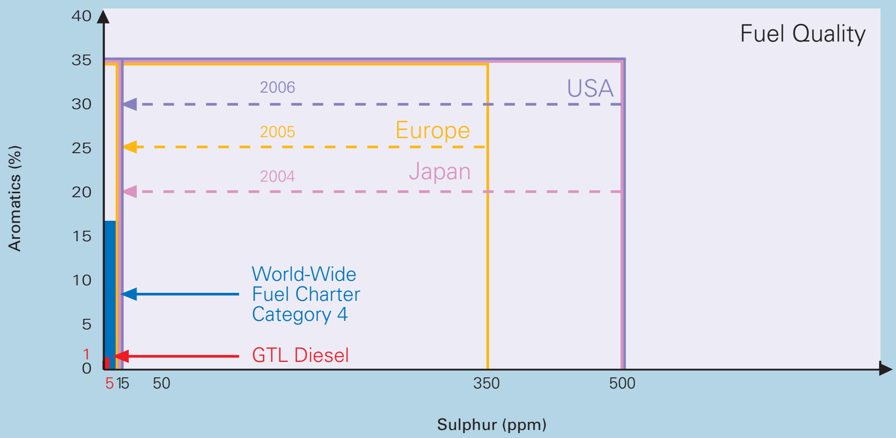
Significant refinery investment will be required to meet the sulphur-free specifications. In Europe, tight specifications for other parameters such as cetane (min 51) and polyaromatic hydrocarbons (max 11%wt) pose additional challenges to refiners.

Figure 3 - Supply side challenges; Systematic removal of sulphur



GTL diesel could play a significant role in assisting refiners on both fronts – quantity and quality. Typically, the diesel yield of GTL plants is around 70%, much higher than refineries at around 40% (Petroleum Economist 2003). In terms of quality, GTL diesel fits the future. With virtually no sulphur or aromatics and a very high cetane of over 70, GTL diesel today exceeds the clean fuel specifications of tomorrow (Figure 4). GTL diesel can be used as a neat fuel or as a fuel blend in existing diesel engines and future advanced diesel, diesel electric hybrid and some fuel cell technologies. It can also utilise existing fuel distribution infrastructure, which provides significant market penetration and economic efficiency advantages compared to many other clean fuels. The UK's Green Fuels Minister commented on the positive economic potential for GTL diesel because it can be used in conventional diesel engines and can utilise the current supply infrastructure (Jamieson, 14/07/03).

Figure 4 - GTL diesel quality in perspective



The properties of GTL diesel make it an ideal blending component to upgrade lower quality middle distillate streams to on-road diesel fuel quality. This could be particularly valuable in Europe where refinery configurations make upgrading these streams increasingly difficult and expensive. GTL diesel's lower density, low aromatics and high cetane are the properties needed. On a volume basis alone, GTL diesel will allow refiners to increase their diesel output.

GTL diesel has already demonstrated its potential in the global diesel market. The availability of fuel from Bintulu has allowed the product to be trialled extensively in international markets (The GTL fuels produced in South Africa are consumed domestically). GTL diesel from Bintulu is being used in the Thai, Japanese and Californian markets and has just been introduced to a bus trial in central London.

One of the most frequently raised concerns about the GTL production process is that it produces more CO2 than the refinery process, although the end use of GTL fuels is more efficient. In 2002, PricewaterhouseCoopers was commissioned by Sasol Chevron to conduct a lifecycle assessment of transportation fuel processes, including a modern complex refinery and a GTL production facility, using the ISO 14040 standard for such assessments. The finding was that GTL offers substantial air quality benefits compared to a refinery as a result of its lower sulphur dioxide, nitrogen oxide and hydrocarbon emissions. These benefits are achieved without incurring a greenhouse gas penalty compared to crude oil refining. One benefit of GTL technology lies in the fact that it can produce ultra-clean GTL diesel without producing the heavy residual fuel (with its high associated environmental burden) that a refinery produces. The GTL process thus facilitates the move towards cleaner forms of electricity generation through natural gas instead of heavy residual fuel oil or petroleum coke.

Unlike other fuel lifecycles, where greenhouse emissions are predominantly generated through distributed exhaust emissions, one of the advantages of the GTL production process is that the waste is a single-source, CO2-rich stream that can be sequestered, further reducing CO2 emissions to the atmosphere (CSIRO 2002).

In summary, the outlook for the global diesel market is very strong and natural gas, together with GTL technology, could play a significant part in supplementing supply and meeting future fuel specifications in developed countries.

Advanced Diesel Technology

Diesel technology has long dominated the heavy duty vehicle sector around the world because of its inherent fuel efficiency, power and durability. The Europeans have now taken this advantage, together with the technologies that were developed for the heavy duty sector in the US, into the light duty vehicle sector without sacrificing vehicle performance (Diesel Technology Forum 2001). There are two key areas of technological advancement:

- Advanced direct injection lean-burn combustion technology
- Advanced light duty diesel emissions control technology (combined with a shift to ultra-low sulphur diesel fuel)

Lean-burn internal combustion engines are engines that operate at an air-to-fuel ratio higher than that necessary for complete combustion of the fuel. Advanced lean-burn operation provides a 20-40% improvement in fuel efficiency over conventional diesel technology and 40-60% compared to conventional petrol engines (Diesel Technology Forum 2001). The technology also delivers better efficiency than petrol-electric hybrid cars. Lower toxic emissions are also achieved. Using the latest Peugeot direct injection engines as an example, hydrocarbon emissions are reduced by 40%, CO and CO2 by 20%, particulate matter by 60% (without particulate filter systems) and ozone precursors by 50% (Diesel Technology Forum 2001).

Advanced lean-burn combustion incorporates a number of specific advanced engine technologies including direct fuel injection, electronic fuel injection, common rail fuel injection, improved combustion chamber design and advanced turbo-charging. Sophisticated computer-controlled technology is used to optimise the lean-burn process. This allows for direct injection of fuel into the combustion chamber, rather than use of a pre-chamber, and eliminates heat loss that decreases efficiency. Common rail fuel injection makes engine operation smoother and quieter by allowing pre-injection of a carefully controlled ultra-high-pressure "mist" of fuel and air into the engine before the main injection. This cushions the impact of sudden temperature and pressure changes that caused vibration and noise in older diesel engines.

While diesels naturally perform better than petrol engines in terms of hydrocarbon, CO and CO2 emissions, they tend to produce more particulate matter and NOx than petrol engines. Historically, the sulphur in diesel fuel has prevented use of effective exhaust treatment technologies such as catalysts and particulate filters in diesel vehicles, although catalysts are widely used in petrol cars. With the advent of ultra-low sulphur diesel fuels, however, both of these technologies can now be used effectively in diesel cars. "Sulphur-free" diesel (10ppm sulphur or lower) has been used in Sweden for more than a decade and will be mandated throughout the European Union by 2009, allowing further improvements in the longevity and effectiveness of these technologies. Engine enhancements like air-to-air charge cooling and exhaust gas recirculation have also contributed to significant NOx emission reductions in the latest diesel engines (Diesel Technology Forum 2001).

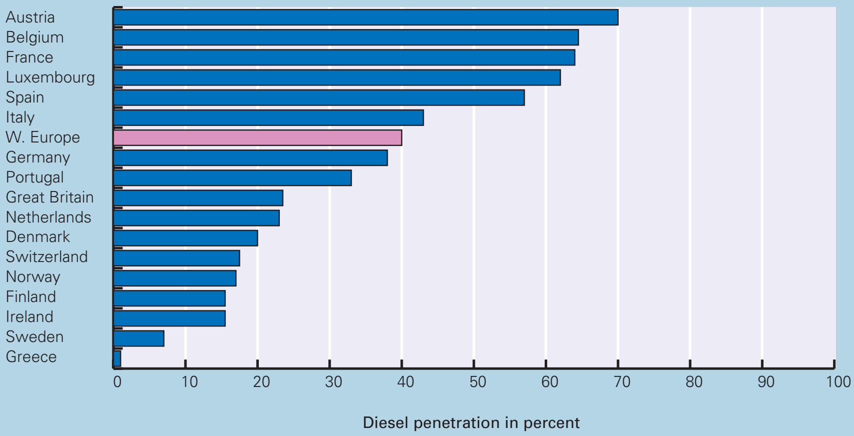
Peugeot again provides a good example of the significant advances in emissions control technology. The latest Peugeot particulate filter is regenerative and has achieved particulate emissions reduction of more than 95% (Diesel Technology Forum 2001). The Peugeot system uses common rail fuel injection to increase the temperature of the exhaust when necessary to oxidise or burn excess soot from the filter. This occurs every 400-450km, takes only two to three minutes, and has no effect on driving (Diesel Technology Forum 2001).

In summary, advanced diesel passenger cars deliver all of the key sustainable transport objectives that the developed world desires in high performance vehicles if they are to have broad-based consumer appeal. Numerous studies around the world have confirmed that the diesel (and diesel-electric hybrid) technology pathway consistently and cost-effectively delivers the best overall energy, greenhouse efficiency and environmental outcomes of today's transport technologies (Ricardo 2002; CSIRO 2002).

Comparison of the European and American Experience

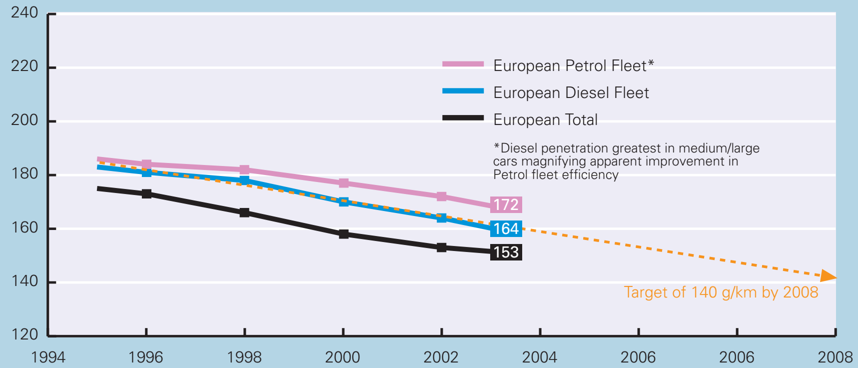
Over 40% of new passenger cars in Europe now have diesel engines compared with less than 20% a decade ago. In France, Austria and Belgium, well over 60% of new passenger cars are diesels and over 80% of luxury cars are diesels (Figure 5). European consumers are taking up advanced diesel technology to get better fuel efficiency, more power, and more durability as well as quiet, clean, premium vehicles that were previously the domain of petrol cars. Because European consumers now have first-hand experience with the performance advantages of advanced clean diesel technology, sales growth continues to accelerate.

Figure 5 - Diesel penetration in new passenger cars in Western Europe; 2002



In the year 2001-2002, diesel car sales across Europe increased by a record 12%, outstripping the record set during the previous twelve months (World Diesel Fuel 2003). Governments and some environmental groups are encouraging this trend, which reduces greenhouse emissions and improves fuel efficiency (Figure 6). Initially, fuel tax and vehicle sales tax policies drove diesel uptake in Europe, although it is likely that consumer preference for power and comfort is now a significant factor due to the performance of the latest diesel technology and diesel fuels.

Figure 6 - Increasing efficiency and decreasing CO^2 emissions of the European passenger car fleet



Source: Ricardo Consulting Engineers, “Carbon to hydrogen Roadmaps for Passenger Cars”, 2002

The UK Government provides a good example of the range of tax and regulatory incentives which initially drove European automotive technology and fuel development, as well as consumer uptake. Incentives are provided to vehicle users, manufacturers and researchers, and fuel and infrastructure providers. Vehicle excise duty, related to CO2 emissions and fuel type, and company car taxation, related to vehicle CO2 emissions, favour diesel because of its greater efficiency. Other incentives to vehicle users include grants towards retrofitting emissions reduction equipment in pollution hotspot areas and in road haulage vehicles.

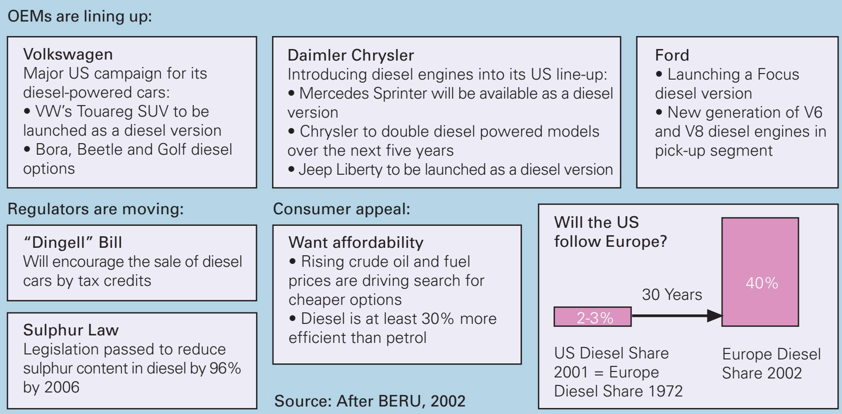
Manufacturers and researchers benefit from grants of up to 50% of the cost of research into future automotive industry products and processes and funding for demonstration projects of new, low carbon, vehicle technologies and fuel cell, sustainable and green technology research. Fuel and infrastructure providers were able to introduce 50ppm sulphur diesel three years ahead of schedule because of a three pence fuel duty differential. Other incentives for the future include exemption or reduction of duty rates on alternative transport fuels for pilot projects (e.g. the GTL diesel bus trial in London) and the funding of renewable, sustainable and green technology research.

In the US, however, consumer uptake and automotive technology development of diesel cars is negligible. A significant factor is that the advanced diesel technology available to Europeans is not available in the US. In part, this is because the application of the advanced engine technology is dependent on the diesel fuel quality which, in the US, is lagging behind the European Union. Consequently, Americans associate diesels with historically lower performance standards than petrol cars, the reverse of the European perception and experience. Lower fuel prices in the US, and taxation and emissions regulation structures that do not encourage diesel fuel and technology, also detract from both consumer uptake and technology development. However, the big change driver of the future for the US could be market-based, with accelerated uptake likely to occur when high performance European diesel cars and SUVs are experienced by American consumers.

As motor manufacturers seek to develop the market for new diesel cars in the US, it is increasingly likely that a number of European diesel cars will be able to meet US "Tier 2" emission standards within the next few years, particularly with the emergence of advanced exhaust treatment technology, cleaner diesel fuels and engine enhancements.

US emission standards have historically created barriers to light duty diesel vehicles because of their focus on particulates and NOx rather than the broader suite of toxic and greenhouse emissions that Europe has focussed on in developing its automotive technology (Diesel Technology Forum 2001). The US approach favours petrol technology and explains the paucity of diesel cars currently available in the US marketplace. The introduction of a broader range of emission-compliant diesel cars to the US market will allow consumers to make their own choices about diesel technology. If the European experience is emulated, high performance, coupled with efficiency, is likely to drive significant uptake of diesel cars in the US by the end of this decade with flow-on benefits in all of the key sustainable transport objectives listed earlier (Figure 7).

Figure 7 - Diesel technology is starting to make an impact in the US at all levels

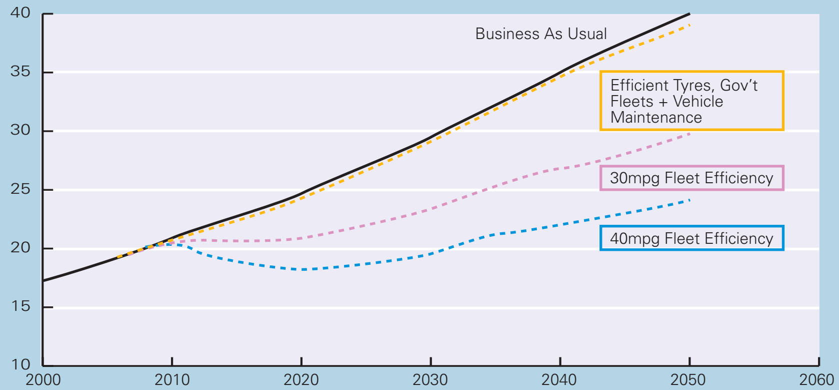


Source: After BERU, 2002

In addition to market-based factors, there is emerging evidence that US regulators may also encourage a shift to diesel. The US Department of Energy has estimated that increasing the market share of light-duty diesel technology to 30% would reduce net crude oil imports by 700,000 barrels per day by 2020 – an amount equivalent to one half of California's total daily energy consumption (Diesel Technology Forum 2001). The California Energy Commission (CEC) and Air Resources Board (CARB) released a report in May 2003 that recommends promoting fuel efficiency improvements combined with use of alternative fuels as a means of reducing the State's dependence on petroleum. The paper warned that unless Californians make a major change to their transport demands, they will have to accept major expansions of refinery and delivery infrastructure, price volatility, further dependence on foreign oil supplies, lower environmental quality and reductions in public health (CEC and CARB 2003).

The Californian agencies looked primarily at fuel efficiency and fuel substitution options to reduce the state's dependence on petroleum. They found the most dramatic reduction in petroleum demand was possible by improving vehicle fuel efficiency. If the fuel economy of new cars and light trucks were improved to 10-15km/l by the year 2010, the growth in demand would be reduced to zero by the year 2020 and would not increase again until 2030 (Figure 8). Existing and emerging technologies, including improvements in engines and transmissions, aerodynamic styling, weight reduction and increased use of hybrid electric and diesel propulsion systems, are available to achieve this target. The agencies concluded that, if these technologies were used, the increased purchase price of a new car would be more than offset by the lifetime fuel savings in most cases. In some cases, vehicle purchase cost is lower anyway. For example, a 2001 turbo-diesel Jetta GLS cost $500 less than the turbocharged gasoline-powered Jetta GLS and the owner of a diesel Jetta could expect to save over $2300 in fuel costs over a 100,000 mile vehicle life at year 2000 fuel prices (Diesel Technology Forum 2001).

Figure 8 - Modelled California demand reduction from fuel efficiency options



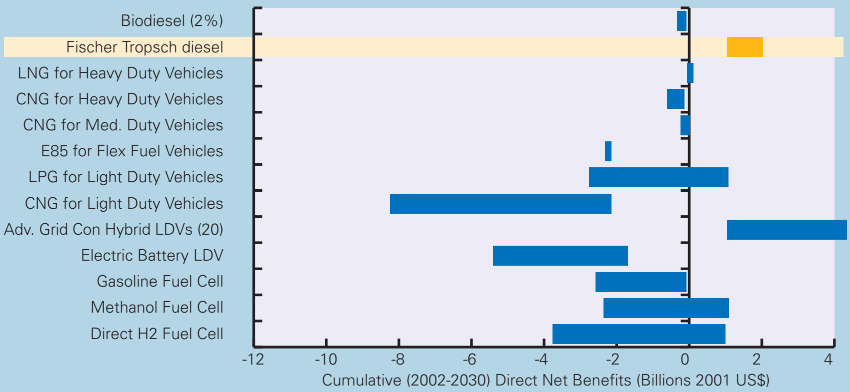
Source: California Energy Commission and California Air Resources Board 2003, Reducing California's Petroleum Dependence, California US

The fuel substitution options examined in the California study were:

- CNG and LNG
- Ethanol blends
- LPG
- GTL diesel and biodiesel blends
- Electric vehicles
- Hydrogen fuel cell vehicles

In general, a penetration rate of 10% of new vehicle sales per year was assumed, with the exception of fuel blends (eg ethanol/petrol and GTL diesel/diesel). The GTL diesel blend (at 33%) was the only fuel substitution option modelled that resulted in a positive direct net benefit at today's fuel prices (Figure 9).

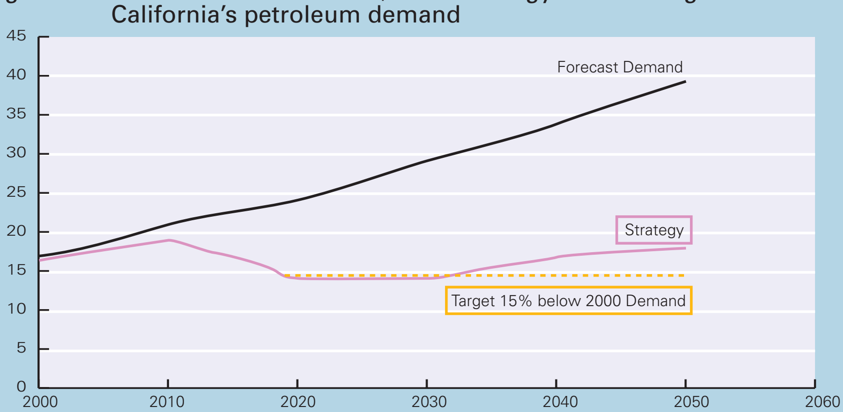
Figure 9 - Modelled direct net benefit of fuel substitution options



Source: California Energy Commission and California Air Resources Board 2003, Reducing California's Petroleum Dependence, California US

Even if used only in heavy duty vehicles, it would reduce the state's total petroleum demand by about 6%. A shift to 10% direct hydrogen fuel cell vehicles in the light duty fleet would reduce petroleum demand by about 8%, but with a negative direct net benefit at today's fuel prices. The recommended combination of vehicle fuel efficiency improvements and increased use of alternative fuels was modelled to reduce petroleum demand in California to 15% below 2000 levels (Figure 10). Although some of the recommendations in this report may be contentious and the modelling results disputed, diesel fuels and technology could play an important role in California's transport energy future.

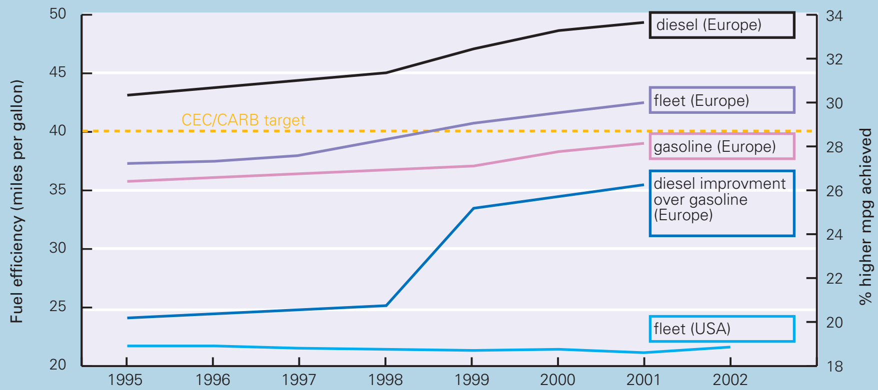
Figure 10 - Modelled results of CEC/CARB strategy for reducing California's petroleum demand



Source: California Energy Commission and California Air Resources Board 2003, Reducing California's Petroleum Dependence, California US

The momentum behind diesel vehicle technology and fuel development is an established fact in Europe and, while it will take some time to flow through to the US, the evidence suggests that diesel will have come into its own in the light duty sector as well as the heavy duty sector by the end of this decade. The fuel efficiency benefits of this transformation for the US will be immense (Figure 11).

Figure 11 - Diesel delivers real fuel efficiency benefits



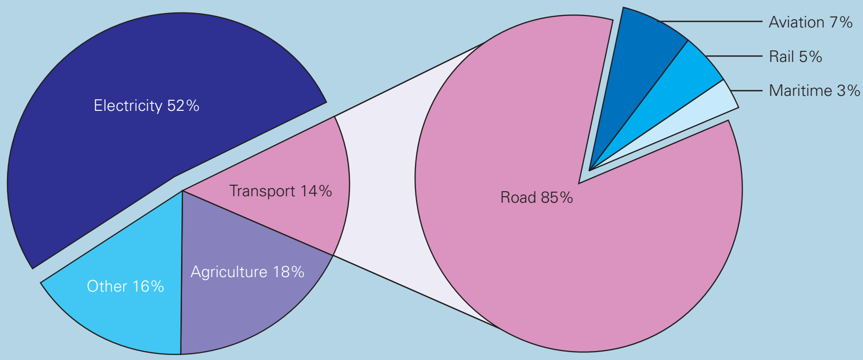
Source: ACEA, US EPA

Sustainable Transport Possibilities for Australia

So where does diesel fit in the Australian transport outlook?

Transport accounts for 41% of Australia's domestic demand for energy and produces 14% of its greenhouse emissions (CSIRO 2002). Road transport generates 85% of these emissions and is the segment where greenhouse emissions reductions are most required (Figure 12). Transport demand growth over the next two decades is forecast to be highest in air transport (4.5% per annum), road freight (2.9% per annum), and sea transport (2.3% per annum) (CSIRO 2002). All of these growth sectors predominantly use diesel and other middle distillate fuels (e.g. jet fuel and marine fuel oil). Combined with the potential for broader migration to diesel in the passenger car market, in line with global trends to achieve greater energy and greenhouse efficiency, diesel demand growth in Australia could rise significantly, whilst petrol demand growth could remain flat or decline over the next two decades.

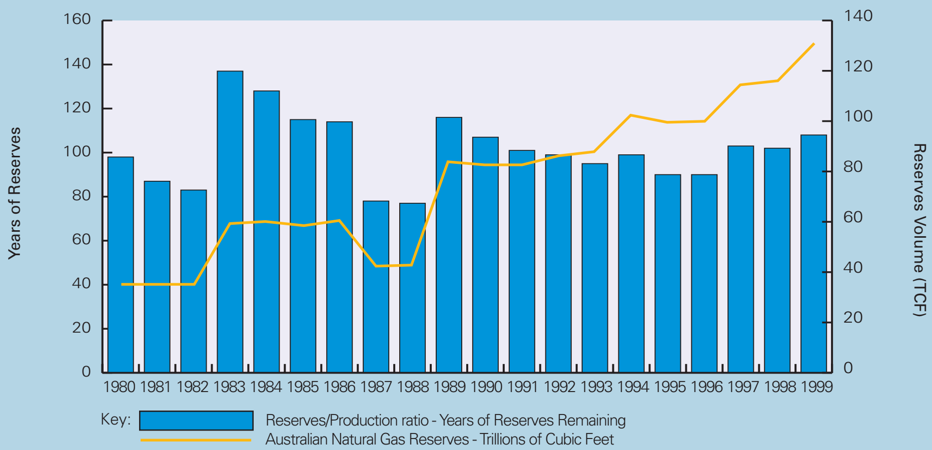
Figure 12 - Australian energy market greenhouse gas emissions



Australia is facing a significant decline in crude oil production and a reduction in refining capacity. For the seven years, to 2002, domestic crude oil consumption outstripped discovery rates by three times (CSIRO 2002). By 2010, Australia will need to import 50-60% of its crude oil requirements which will have a negative impact on balance of payments of $7-8 billion (CSIRO 2002). It will also be increasing its imports of refined products, primarily diesel and jet fuel.

Conversely, Australia has abundant natural gas reserves and, over the past 20 years, new natural gas discoveries have exceeded gas production (Figure 13). Reserves are estimated to have increased fourfold to about 115Tcf, or 105 years supply at 2002 production levels (CSIRO 2002). In 2003, appraisal drilling in northwestern Australia has further increased reserves, probably to around 140Tcf. More than 130Tcf of these reserves are located in the far northwest of the country and away from the gas markets of the eastern States. This is energy equivalent to over 20 billion barrels of oil. Liquefied natural gas (LNG) markets for power generation and natural gas distribution in Japan, China, Korea and the US are the primary focus to develop these reserves but GTL technology could open up the diesel fuel markets in these countries, and Australia, to these resources.

Figure 13 - Australia's growing gas reserves and production



Australian LNG has made inroads to Asia Pacific markets because it provides diversification of supply away from Middle East sources and it is a clean fuel for power generation and direct energy. Australian GTL diesel could offer the same benefits in the transport sector of these Asia Pacific markets.

In the Australian transport market, GTL technology would allow fuel manufacturing to target the growth sector of the market – diesel and other middle distillates. A GTL industry would reduce Australia's growing dependency on foreign crude oil and refined products and replace lost capacity in Australia's refining industry. In addition, the availability of GTL diesel and refined ultra-low sulphur diesel in the marketplace later this decade would allow introduction of advanced diesel technology in Australia. With increased consumer uptake of diesel in the passenger car sector where greenhouse emissions are currently highest, Australia could achieve significant reductions in greenhouse emissions on a scale experienced in Europe over the past decade. Only 8% of Australia's overall vehicle fleet runs on diesel today, mostly in the heavy duty vehicle sector. There is enormous scope for diesel to make inroads into the Australian market in the future. In its 2002 report titled, "The Energy and Transport Sector Outlook to 2020", CSIRO noted:

"The global future for the evolution of transport fuels and vehicles is driven by greenhouse gas and oil supply issues and is very uncertain. Australia's strategy must be flexible and segmented. The proposed strategy, offering a 60% reduction in GHG emissions, decreased dependence on oil and a platform for future H2 use, involves:

- Migration to diesel, using best practice technology and fuel standards
- Production of "clean" diesel from natural gas or coal with CO2 sequestration
- Development of hybrid cars and light vehicles, fuelled by diesel
- Niche segments may be developed for compressed natural gas, with the added advantage of commencing infrastructure options for future hydrogen-based systems"

In addition to the transport benefits, a GTL industry would offer Australia the tangible economic benefits that come with multi-billion dollar investments:

- Employment growth
- Resource value-adding
- Increased Government revenue
- Higher GDP
- New exports
- National infrastructure that could provide a platform to deliver natural gas to remote domestic markets in the future

There is no doubt that Australia's abundant world-class natural gas resources, combined with GTL technology, offer the opportunity of creating a new, value-adding industry. Australia is well-placed to capitalise on the global trend toward diesel, building and reinforcing strategic trading partnerships whilst forging a pathway to a sustainable domestic transport future.

Conclusion

Ultra-clean diesel fuel and advanced diesel and diesel electric hybrid technology offers the most cost-effective near to mid term transport solution for the developed world to achieve:

- Lower toxic emissions
- Lower greenhouse emissions
- Greater efficiency of energy use
- Less dependence on foreign oil imports
- Affordable transport

Natural gas and GTL technology have a significant role to play in the diesel transport pathway by introducing GTL diesel to the marketplace. Developing remote gas fields for this market could also underpin the infrastructure necessary to bring more natural gas to markets where CNG can be used in niche urban transport applications.

Australia has already had success with its remote northwest gas developments and in marketing LNG as a clean fuel for power generation and distribution in the Asian region. There is no doubt that Australia has the skills and resources required to be equally successful in the fast-developing global GTL industry. As a leading GTL company, Sasol Chevron is confident that Australia will become a major player in the industry and that, as a result, substantial economic benefits will flow from our industry to the Australian people.

References

California Energy Commission and California Air Resources Board 2003,
Reducing California's Petroleum Dependence, California US

CSIRO 2002,
Energy and Transport Sector Outlook to 2020, North Ryde Australia

BERU Group, Corporate Conference Call Presentation "9 month results",
February 13, 2003.

BP Statistical Review of World Energy,
June 2003.

Diesel Technology Forum 2001,
Demand for Diesels: The European Experience, Virginia USA

Petroleum Economist 2003,
Fundamentals of Gas to Liquids, The Petroleum Economist Ltd, London UK

Ricardo Consulting Engineers Ltd 2002,
"Carbon to Hydrogen" Roadmaps for Passenger Cars: A Study for the Department for Transport and the Department of Trade and Industry, West Sussex UK

Hart Energy Publications and Axens IFP Group Technologies.
World Diesel 2003: *Global Facts, World Trends; supplement to World Refining*

Sasol Chevron

93 Wigmore Street
London W1U 1HJ
Tel: 020 7487 8955
Email: inquiries@sasolchevron.com
Web: www.sasolchevron.com

APPENDIX D

Alliance for Synthetic Fuels in Europe brochure – 2006 alliance for synthetic fuels in europe

SYNTHETIC FUELS:

"Driving Towards Sustainable Mobility"

A PUBLICATION BY ASFE – ALLIANCE FOR SYNTHETIC FUELS IN EUROPE

DaimlerChrysler | Renault | Shell | Sasol Chevron | VOLKSWAGEN AG

DaimlerChrysler's product portfolio ranges from small cars to sports cars and luxury sedans; and from versatile vans to heavy duty trucks or comfortable coaches. DaimlerChrysler's brands include Maybach, Mercedes-Benz, Chrysler, Jeep®, Dodge smart and Freightliner, Sterling, Western Star, Setra and Mitsubishi Fuso. More information on: **www.daimlerchrysler.com.**

DaimlerChrysler is promoting synthetic fuels through appropriate commitment in pilot projects and in accompanying test rig investigations and vehicle trials. Synthetic fuels are enablers for further emission reduction with additional potential in combination with high efficient powertrains. They are clearly positioned in the DaimlerChrysler Fuel Strategy.

The Renault group consists of the Renault, Samsung (South Korea) and Dacia (Romania) brands. It designs, develops and markets passenger cars and light commercial vehicles. The group sold 2.53 million vehicles worldwide in 2005. The Renault-Nissan Alliance is a unique group of two global companies linked by cross-shareholding. More information on: **www.renault.com**.

Renault undertakes major R&D efforts in advanced engine and fuel technology. In particular, Renault has developed significant know-how on synthetic fuels with the objective of minimizing fuel consumption and engine-out emissions. This has been acquired through active participation in many projects, such as the EU-funded programme RENEW, the French national programme on Bio-Energy and the EUCAR-CONCAWE-JRC well-to-wheel studies.

Royal Dutch Shell plc has operations in more than 145 countries with businesses including oil and gas exploration and production; production and marketing of Liquefied Natural Gas and Gas to Liquids; manufacturing, marketing and shipping of oil products and chemicals and renewable energy projects including wind and solar power. More information on: **www.shell.com.**

Shell companies are engaged in the development of synthetic fuels technology and are the leading marketer of synthetic GTL products from their plant in Malaysia. Shell is planning to build a worldscale GTL plant in Qatar, is developing BTL with Choren in Europe, and CTL in China. Shell V-Power Diesel, a premium diesel containing GTL Fuel, is currently sold at more than 3000 retail sites across Europe.

Sasol Chevron is a joint venture between Chevron of the USA and Sasol of South Africa. Sasol Chevron was established in 2000 to develop Gas to Liquids (GTL) production facilities worldwide and market GTL products. Sasol's fifty year track record in the production of synthetic fuels and Chevron's global reach give Sasol Chevron an unparalleled combination of operating experience and commercial range. More information on: **www.sasolchevron.com.**

Sasol Chevron is currently engaged in the development of a number of GTL projects throughout the world and also supports both the ORYX GTL plant in Qatar, which begins production in mid-2006, and the EGTL plant in Nigeria. Between them, these plants will produce almost 70,000 barrels of GTL products per day by 2009.

Volkswagen Group is the largest European car producer with its headquarters in Wolfsburg. In 2004, its brands (Volkswagen, Audi, SEAT, Škoda, Commercial Vehicles, Bentley, Bugatti, Lamborghini) delivered 5.079 million vehicles. The Group operates 47 manufacturing plants in eleven European countries and seven non-European countries. More Information on: **www.volkswagen.com.**

Synthetic Fuels are one key element of the Fuel & Powertrain Strategy of Volkswagen Group. Strategic alliances, focused R&D projects, and engine and fleet tests allow Volkswagen Group to conduct a combined development of fuels and engines. This will lead to fuel-efficient and low-emission drive train technologies. More information on: **www.mobility-and-sustainability.com** and **www.volkswagen-sustainability.com.**

Introduction

As energy demand continues to rise, so does concern over the future availability of conventional fuels. There is a growing need to find alternative fuel options, such as synthetic fuels. These fuels can be used in existing diesel engines and fuelling infrastructure and significantly reduce exhaust emissions, while diversifying energy sources and improving security of supply.

While conventional transport fuels are products of crude oil refining, synthetic fuels can be produced from natural gas, biomass, or coal feedstock. Synthetic fuels derived from natural gas are already available and the supplies are due to increase over the next few years. Once commercially available, synthetic fuels made from biomass could substantially decrease global greenhouse gas emissions.

Much progress has been made in the refinement and optimization of modern engines and fuels to deliver both improved efficiency and reduced emissions. The car manufacturers are working together with the fuel suppliers to make a new generation of engines, with further improvements in engine efficiency and reduced exhaust emissions using synthetic fuel. Synthetic fuels can have a positive impact on European competitiveness and employment.

The creation of ASFE

The Alliance for Synthetic Fuels in Europe (ASFE) brings together leading automotive and fuel supply companies - DaimlerChrysler, Renault, Royal Dutch Shell, Sasol Chevron and the Volkswagen Group. We all share a commitment to contributing to a reduction in the environmental impact of road transport through improved energy efficiency and cleaner fuels. Our common view is that synthetic fuels have a key role to play in this.

ASFE objectives

- To promote synthetic fuels because of their unique and consistent composition and hence their significant contribution to vehicle emission reduction.
- To support a range of activities in the field of synthetic fuels and sustainable mobility, including research, projects demonstrating the benefits of synthetic fuels including vehicle trials, co-operation with governments and promotion of public awareness.

ASFE's commitment

In view of future EU policy proposals on energy efficiency, security of energy supplies, air quality, and climate change, ASFE members look forward to exploring possible policy options and incentives to boost the availability and encourage wider use of synthetic fuels.

What are synthetic fuels and their benefits?

Three feedstocks: one product.

process characteristics

Process name:	Gas to Liquids (GTL)	Biomass to Liquids (BTL)	Coal to Liquids (CTL)
Feedstock:	Natural gas	Biomass (agricultural and forestry biomass)	Coal
Likely plant location:	Countries with abundant remotely located gas reserves and/or where natural gas is otherwise flared	In proximity to large biomass production centres (e.g. France, Germany)	In countries with abundant coal reserves (e.g. South Africa, China, USA)
Greenhouse gas emissions:	Comparable to crude oil refining, potential for reduction through technology improvement	Most promising potential for substantial reduction of greenhouse gas emissions	Carries carbon penalty to crude oil refining, though significant reductions possible with CO_2 sequestration
Supply potential:	Announced global capacity equivalent to 10% of EU diesel demand by 2015	Biomass feedstock theoretically available in the EU for up to 50% of EU diesel demand	CTL plants currently under discussion in the US and China could provide around 2% of world diesel demand by 2020
Industrial status:	Operating units already available (South Africa, Malaysia)	Pilot plant scale only	Large scale plant (8.4 million tons/year) based on high-temperature Fischer Tropsch process operational for decades in South Africa
State of technology:	Proven and well-known	Further R&D and scale-up required	Proven and well-known
Outlook:	Further commercial-scale plants in construction or detailed engineering design	Prototype plant planned	Number of large plants under discussion in the US and China

product characteristics

Regardless of the feedstock, all paraffinic Fischer-Tropsch fuels have the following properties :

Composition: sulphur-free, low aromatic, odourless, colourless liquid synthetic fuels

Local emissions: allow significant reduction of regulated and non-regulated vehicle pollutant emissions (NOx, SOx, PM, VOC, CO)

Diversification of energy supply: contribute to oil substitution, diversification and security of energy supply

Distribution infrastructure: can be used in existing diesel fuelling infrastructure

Compatibility with existing engines: can be used in existing diesel engines

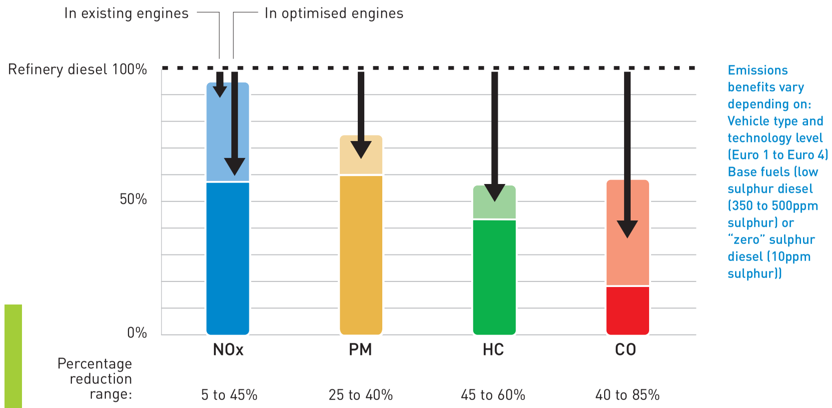
Potential for future engines: enable the development of new generation of internal combustion engine technologies with improved engine efficiency and further reduction of vehicle pollutant emissions

Impact on bio-sphere: are readily biodegradable, and non-toxic / not harmful to aquatic organisms

Emission benefits of synthetic fuels

Local emission benefits

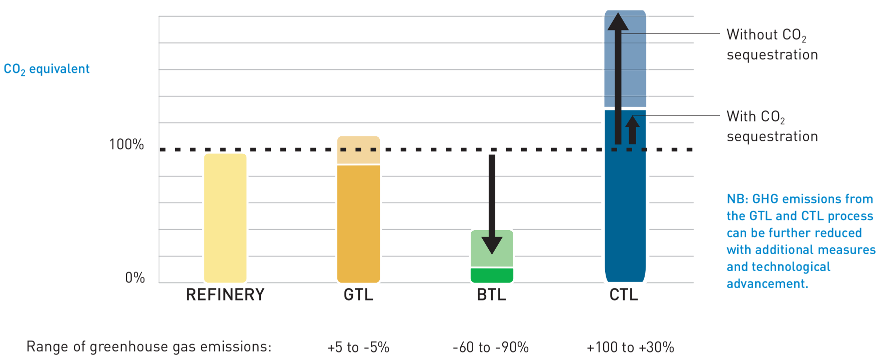
Road trials of synthetic fuels in several European capitals and elsewhere demonstrate that they provide significant local air quality improvement by reducing tailpipe emissions (particulate matter, nitrogen oxides, carbon monoxide and hydrocarbons). Whereas the application of successive Euro-standards applies to new vehicles only, the introduction of synthetic fuels will have an immediate positive impact on the local emissions from the existing vehicle fleet, particularly in urban areas. When engines are optimized to run on synthetic fuels further reductions of nitrogen oxides can be obtained.



Greenhouse gas emissions

The environmental attributes of the conventional and synthetic fuel technologies are assessed by measuring the impact caused through production, transportation and fuel usage, the so-called well to wheel basis or life cycle assessment. Industry studies show that greenhouse gas emissions of the GTL process are comparable to a refinery system (+/- 5%). Relative to a refinery system, BTL offers clear benefits in the range of 60 to 90% improvement. CTL has a carbon penalty, which can be reduced through CO2 sequestration. By linking development of advanced engine and synthetic fuels production technology it is expected that greater vehicle efficiency gains will lead to further reductions in CO2 emissions.

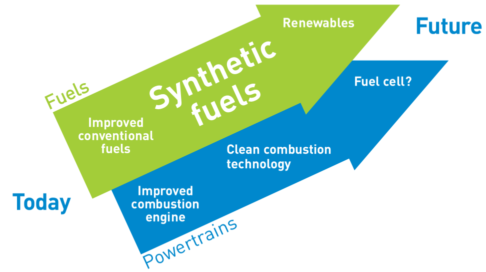
Comparison of GTL, BTL and CTL processes with refinery systems (on a well-to-wheel basis)



The strategic role of synthetic fuels: "**pathway to the future**"

ASFE vision

Over the longer term, for environmental, energy security and continued economic development reasons petroleum derived transport fuels will need to be supplemented by alternative fuels. ASFE's vision is for synthetic fuels to play a bridging role from today's conventional fuels to the future renewable transportation fuels and associated vehicle technologies.



From the range of alternative fuel options, GTL is the most cost effective in reducing petroleum dependency and exhaust emissions. It is already available today. Once commercially available, BTL is expected to contribute a reduction in CO2 of up to 90% compared to crude oil derived fuels. As synthetic fuels share a large part of the production technology, they provide a continuous development path to a low-carbon transport future. Synthetic fuels are compatible with hybrid engine technologies and, thanks to their unique properties, could enable advanced combustion engine technology such as homogeneous combustion.

Role of policy-makers

Diversification of energy supply and further emission reductions with synthetic fuels can best be achieved through the coordinated efforts of fuel suppliers and automotive manufacturers working together with policy makers.

ASFE members seek political & fiscal support from EU and national policy makers for the introduction and increased penetration of all synthetic fuels, and more specifically to:

- Include GTL fuel, in addition to BTL fuel, as an alternative fuel that can help EU reach its 2020 alternative fuel targets
- Put in place mechanisms to help achieve alternative fuels targets in a cost effective manner
- Recognise GTL will pave the way for BTL commercialisation
- Increase support, including R&D, for BTL production pathways
- Increase R&D support for advanced engines optimised around synthetic fuels
- Recognise advanced fuel and engine technologies could provide European industry with new business opportunities
- Acknowledge BTL production could provide Europe with a new and sustainable business in the agricultural sector

Synthetic fuels represent a critical step on the path to a European future of sustainable mobility. Through the ASFE, the companies with the greatest experience and expertise in maximizing the potential of synthetic fuels have united to take that step together.

DaimlerChrysler	Tel.: +49-711-17 93 271
Renault	Tel.: +33-176-84 61 66
Royal Dutch Shell	Tel.: +44-20-7934 3828
Sasol Chevron	Tel.: +44-207-487 89 94
Volkswagen	Tel.: +49-171-870 34 98