

# Fuelling a cle

Demand for cleaner automobile fuels is growing around the world, driven by tightening legislation and heightened environmental awareness. *Terry Knott* takes a closer look at BP's proactive approach and the technology involved in bringing cleaner fuels to consumers



# aner world



**Y**ou may fill up your tank with Amoco Ultimate, Super 2002, Cleaner Unleaded or Diesel Ecology, or indeed one of many other brand names depending where you are in the world. But what these names have in common is that they all belong to BP's growing family of cleaner fuels.

When BP launched its 'Forty Cities' programme in 1999, many believed the aim

of introducing cleaner automobile fuels into 40 large metropolitan areas around the world by the end of 2000 was too ambitious a target. But as that year closed, the initiative had proved more successful than envisaged, to the point that 59 cities were receiving new fuels. The target was raised again, aiming for 90 cities by the end of 2001. At year end, cities as widely spread as Chicago, >>

>> London, Cairo, Johannesburg and Brisbane, were all benefiting from the availability of cleaner fuels, bringing the total to 113 cities with over 6000 retail sites and annual fuel sales around 17 billion litres.

The cleaner cities programme is the spearhead of BP's wider strategy to provide customers with choice and opportunity to help improve their own environments, and places the company in a leadership position as a clean energy provider. The move has been a proactive one, well in advance of any forthcoming legislative requirements on fuel quality, through which BP is helping to shape the future of fuels development and marketing.

But what exactly is meant by 'cleaner fuels' and why is it not a simple matter to deliver them to all retail outlets that currently sell standard fuel?

'The nature of the clean fuel varies from region to region,' says Paul Beckwith, fuel and environment manager on BP's global retail brand team. 'For example, in some cities, such as Athens, removing lead from gasoline was the main driver, while in Cairo it has been the introduction of compressed natural gas. By far the biggest push has been for the introduction of ultra-low sulphur fuels, particularly in North America and Europe. Our vision is global, but we tailor it for local markets.'

Reducing sulphur in gasoline and diesel fuel – and not charging customers more for the new grades – is a primary objective in BP's clean energy strategy. While some of the sulphur compounds present in crude oil pass through conventional refining processes and into final fuel products, they do not normally contribute significantly to atmospheric emissions of sulphur dioxide, but they do have a direct effect on the performance of catalytic converters fitted to the exhaust systems of most modern automobiles. The converters act on exhaust gases to lower the emission of carbon monoxide, oxides of nitrogen, unburned hydrocarbons and aromatic compounds by oxidising and reducing these to carbon dioxide, water and nitrogen. The conversion efficiency of the catalysts used for these processes is adversely affected by the presence of sulphur in the fuel, hence if sulphur concentrations are low, the gases coming from tailpipes have less impact on the atmosphere.

BP's early focus on low sulphur fuels in North America and Europe has its roots

in the global supply and demand balance, as Ted Masiulianis of BP's refining technology group, explains.

'The world currently consumes around 76 million barrels per day (bpd) of oil products, of which Europe and North America together consume over half (see panel, below left). Of the total, some 20 million bpd is gasoline, while another 20 million bpd is accounted for by distillates, that is, diesel and heating oil. Over the period 1990 to 2000, gasoline demand grew by 2.4 million bpd and distillate by 3.3 million bpd. If you also add in the fact that the drop in demand seen in the former Soviet Union during this time period has now reversed, it would appear that demand for these fuels will continue to rise steadily.'

Within the overall growth picture, regional trends vary. Gasoline consumption in North America, which during the last decade accounted for 43% of the incremental growth in global gasoline demand and 20% of the diesel figures, has now slowed to around 1.5% per year. In Europe, gasoline demand is essentially flat, for although vehicle numbers are still rising, fuel efficiency is also improving. But European diesel growth is forecast to increase by 30% by 2015, and in other parts of the world the general trend for both gasoline and diesel demand is upwards.

Our vision is global, but we tailor it for local markets

## Global oil supply and demand

### Supply

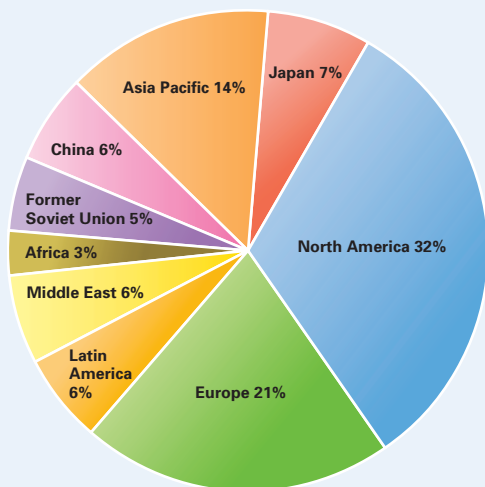
(in millions of barrels per day)

Crude oil	68.0
Natural gas liquids	6.0
Processing gain	1.7
<b>Total supply</b>	<b>75.7</b>

### Demand

(in millions of barrels per day)

Liquid petroleum gas	6.5
Propylene	0.5
Naphtha	4.2
Aromatics	0.9
Gasoline	19.7
Jet fuel and kerosene	6.0
Distillate	20.0
Lubricants	0.7
Residual fuel (inland)	8.7
Residual fuel (marine)	2.1
Asphalt	1.5
Coke (fuel oil equivalent)	0.9
Other	0.7
Refinery fuel (fuel oil equivalent)	3.3
<b>Total demand</b>	<b>75.7</b>

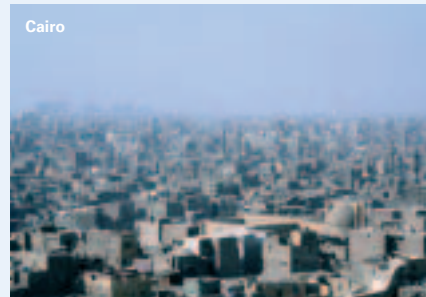
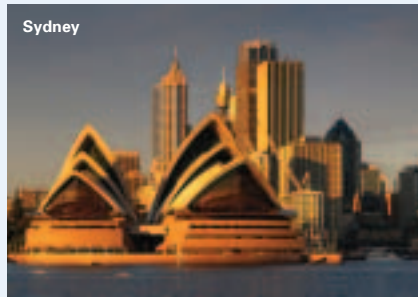


World oil consumption by region for year 2000 (Source: BP)

### Below the limit

Just as growth trends for fuels vary around the world, so does the level of sulphur permitted in gasoline and diesel. The UK and Germany have used the mechanism of differential tax incentives to encourage transition of their domestic markets to fuels containing less than 50 parts per million (ppm) of sulphur – commonly referred to as ultra-low sulphur fuel – while other countries in the European Union (EU) have levels up to 150ppm for gasoline and 350ppm for diesel. However, an EU directive now nearing completion is aiming for 'sulphur free' fuels – less than 10ppm – beginning in 2005, with the transition throughout Europe to be completed probably by 2008 or 2009. But some countries are jumping ahead, notably Germany which is calling for sulphur free fuels by 2003 and is offering duty incentives to help achieve this, a move likely to have a knock-on effect in other parts of Europe.

In the US, limits are currently higher, generally at 250ppm in gasoline and 500ppm for on-road diesel, although California requires lower levels. But this situation is also changing,



## BP's cleaner cities programme around the world

The following are among the 113 cities worldwide now using BP cleaner fuels:

- |                                |                                    |                              |                                |                                 |
|--------------------------------|------------------------------------|------------------------------|--------------------------------|---------------------------------|
| <b>Atlanta</b> (US)            | <b>Cleveland</b> (US)              | <b>London</b> (UK)           | <b>Paris</b> (France)          | <b>Valencia</b> (Spain)         |
| <b>Amsterdam</b> (Netherlands) | <b>Den Haag</b> (Netherlands)      | <b>Lyon</b> (France)         | <b>Perth</b> (Australia)       | <b>Warsaw</b> (Poland)          |
| <b>Athens</b> (Greece)         | <b>Detroit</b> (US)                | <b>Manchester</b> (UK)       | <b>Portland</b> (US)           | <b>Washington, DC</b> (US)      |
| <b>Baltimore</b> (US)          | <b>Durban</b> (South Africa)       | <b>Melbourne</b> (Australia) | <b>Philadelphia</b> (US)       | <b>Wellington</b> (New Zealand) |
| <b>Birmingham</b> (UK)         | <b>Edinburgh</b> (UK)              | <b>Memphis</b> (US)          | <b>Rotterdam</b> (Netherlands) | <b>Zurich</b> (Switzerland)     |
| <b>Brisbane</b> (Australia)    | <b>Glasgow</b> (UK)                | <b>Milwaukee</b> (US)        | <b>St Louis</b> (US)           |                                 |
| <b>Cairo</b> (Egypt)           | <b>Indianapolis</b> (US)           | <b>Munich</b> (Germany)      | <b>Seattle</b> (US)            |                                 |
| <b>Cardiff</b> (UK)            | <b>Johannesburg</b> (South Africa) | <b>Nashville</b> (US)        | <b>Sydney</b> (Australia)      |                                 |
| <b>Chicago</b> (US)            | <b>Lisbon</b> (Portugal)           | <b>Orlando</b> (US)          | <b>Thessaloniki</b> (Greece)   |                                 |

with federal legislation now in place which requires all gasoline to contain less than 30ppm sulphur by 2006, by which time 80% of on-road diesel is to be below 15ppm.

Interlinked to standards set for fuels, the automobile manufacturing industry is also subject to legislative controls on exhaust emissions, which have fallen sharply over the past decade and are set to continue along this path. Automakers can tackle tighter emissions controls through better engine and catalyst designs, or through the fuels they use. The latter has led to closer collaboration between them and the fuel suppliers – when BP's ultra-low sulphur, high performance Amoco Ultimate fuel was launched in Detroit two years ago, representatives of Ford Motor Company took part in the ceremony to acknowledge the importance of cleaner fuels.

'By introducing low sulphur fuels much earlier than regulatory requirements, BP has led the way with its clean fuels programme,'

notes Beckwith. 'Historically, there may have been a perception that the oil industry was resistant to change, but we have now made a clear and proactive demonstration of our intention to provide society with what it wants – cleaner air.'

### Next step technology

BP has the refining capability to produce most of the base fuel it sells to customers, the remainder being purchased from other fuel makers to give full market coverage in areas where BP does not have refinery operations. However, additive packages, incorporated into the fuel prior to sale, typically to control deposit formation in combustion chambers and on valves, remain proprietary. Currently, BP's own equity share fuels production totals

around 1.2 million bpd of gasoline and 0.6 million bpd of on-road diesel, coming from the company's 17 refineries around the world

Our intention is to provide society with what it wants – cleaner air

– the recent acquisition by BP of the refining assets of Veba Oel in Germany and its associated Aral retail stations will see these figures rise by 75,000 bpd of gasoline and 67,000 bpd of diesel, after regulatory refining divestments.

At present within BP's production, excluding that from Veba, one third of gasoline and diesel class as ultra-low sulphur grades. By 2005 the plan is to increase manufacturing capacity for ultra-low sulphur grades to make up over 80% of gasoline and 50% of diesel. By 2008, effectively all of BP's fuels – around 99% – will contain less than 50ppm sulphur, and half of this will be 'sulphur free', >>

>> containing less than 10ppm sulphur.

To achieve these low sulphur targets and meet future regulatory standards, BP is focusing on introducing new technology into its refining processes, requiring capital investment in excess of \$1 billion by 2008.

'The clean cities targets we have achieved to date have been based largely on a major exercise in co-operation between our refining, supply and trading, and retail businesses,' explains Masiulianis. 'For example, we have had to establish the logistics to ensure clean products were kept separate in terminals, distribution pipelines and tankers. Logistics considerations, refinery coverage and manufacturing capability are the reasons why it is not easy to switch over fully to clean fuels overnight.

'In our refineries we have been able to select different feedstocks and load new process catalysts, but changes to the processes themselves have been limited and

capital investment relatively low to date, measured in tens of millions of dollars. But as we now move to the next level of clean fuels production that is set to change.'

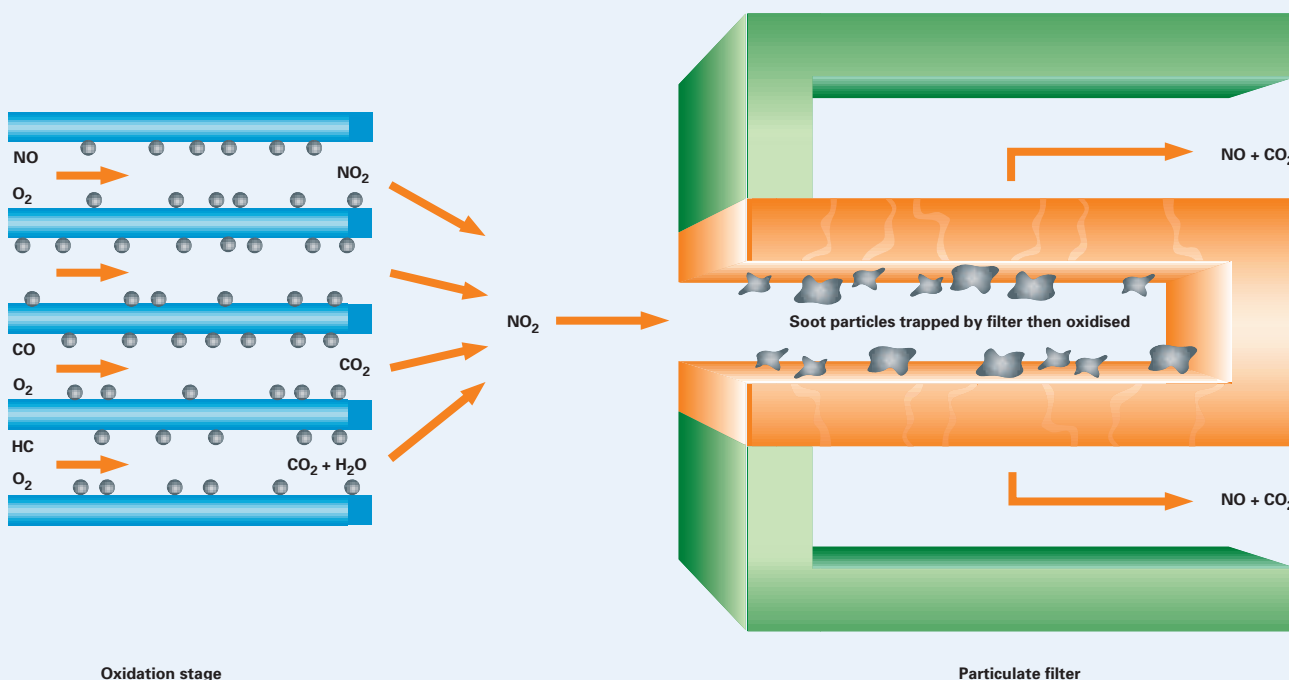
Over the past few years BP has been developing and preparing its own low sulphur refining processes for plant applications. At the same time, it has also performed a thorough evaluation of the commercial processes available from external sources in order to make the best technology selection decisions.

BP's flagship process for making ultra-low sulphur gasoline is its proprietary OATS process, based on the olefin alkylation of thiophenic sulphur (REview December 2000). OATS is capable of reducing sulphur in gasoline to less than 10ppm without significantly affecting the octane rating of the fuel, a measure of fuel quality which gives smooth 'knock-free' engine running and good performance. The OATS breakthrough was announced in November 2000 and the

process has recently entered into commercial service at the joint venture Bayernoil refinery in Germany late last year. A second OATS unit is to be commissioned at Bayernoil in May, and a third at the Nerefco refinery in The Netherlands which BP operates jointly with ChevronTexaco. BP is also evaluating the Prime-G+ process, developed by Axens in France, with which BP has an alliance. Prime-G+ is being trialled at BP refineries at Texas City in the US and at Coryton in the UK. Other potential technologies which are claimed to achieve 10ppm sulphur levels include ExxonMobil's Scanfining process and Phillips Petroleum's S-Zorb, a solid adsorption process which is not yet fully commercialised.

'As recently as four or five years ago, no-one in the industry had a clear idea of how to make 10ppm sulphur gasoline on the commercial scale without a disastrous loss of octane rating,' observes Masiulianis. 'It had

## The CRT filter system for diesel exhausts



The CRT (continuously regenerating technology) particulate filter is a patented emissions control technology for 'trapping' particles in diesel exhausts. Developed by Johnson Matthey, the CRT filter consists of two chambers. The first chamber is an oxidation stage using a platinum catalyst, where a portion of the nitric oxide (NO) in the exhaust is combined with oxygen (O<sub>2</sub>) to form nitrogen dioxide (NO<sub>2</sub>), which is the key to the oxidation of soot particles subsequently collected in the filter stage. The catalyst also converts carbon monoxide (CO) and hydrocarbons (HC) into carbon dioxide (CO<sub>2</sub>) and water (H<sub>2</sub>O).

In the second chamber, the exhaust flows through a particulate filter which allows gaseous components to pass through, but traps the carbon-containing soot particles on the walls of the filter. The nitrogen dioxide from the first stage reacts with soot to produce NO and CO<sub>2</sub>, which exit the system through the tailpipe.

The CRT filter is capable of removing over 90% of particulate matter, HC and CO. Oxides of nitrogen are reduced by 5–10%. CRT is one of the traps currently on trial in California.

not even been seriously contemplated in the technical literature. Now here we are doing it.'

New industry knowledge in understanding the chemistry of desulphurisation to ultra-low levels is being applied to the development of new process techniques, catalysts and equipment designs for both gasoline and diesel fuels.

Development effort is going into finding ways to improve hydrotreatment – the 'workhorse of the industry'. BP has been actively evaluating new catalyst formulations for the hydrotreatment of distillates to remove sulphur from diesel, working with AKZO Nobel, which jointly developed the catalysts with ExxonMobil. Some of the earliest applications of the first generation 'Stars' catalyst were at Nerefco and also at BP's Grangemouth refinery in Scotland, where it has been put through its commercial paces supplying fuel to the clean cities programme. A second generation catalyst known as 'Nebula' is now coming into play.

Another approach, not yet commercialised, is to add an oxidative desulphurisation stage following conventional hydrotreatment. This is a polishing process to bring sulphur in diesel down from around 50ppm to 5ppm. BP is working on this catalytic technique at its Naperville facility in Illinois.

'Although most existing hydrotreating units operating at medium and high pressures – above 50 bar – could be modified by other means to achieve the same result, low pressure hydrotreaters would struggle to get to 10ppm with conventional modification,' says Masiulanic. 'But oxidative desulphurisation will even work for low pressure units.'

BP's research and development includes other avenues of investigation which are being kept under wraps at present. Alongside these the company is working on the next generation of fuels for powering alternatives to the internal combustion engine, for example, vehicles driven by hydrogen-powered fuel cells.

#### Aftertreatment

While conventional diesel engines emit less carbon dioxide than their gasoline counterparts, particulate matter in diesel vehicle exhausts is higher, sometimes evidenced by sooty tailpipe gases. Beckwith

## BP-operated and joint venture refineries



identifies 'one exciting technology' which could be applied to eliminate almost 95% of particulates from exhausts. Known as a 'trap', this is typically a ceramic filter preceded by an active oxidation catalyst which converts nitrogen oxides (NO<sub>x</sub>) into nitrogen dioxide (see panel opposite). The

nitrogen dioxide in turn reacts with carbon in the sooty particulate matter to form carbon dioxide (CO<sub>2</sub>), the net result being tailpipe particulate emissions equivalent to those from very clean compressed natural gas fuels. But for the catalyst to function correctly, the diesel fuel must be low in sulphur. A vehicle trial of particulate traps is currently under way in southern California, using

the ultra-low sulphur diesel fuel ECD-1 made by ARCO, BP's US west coast business.

Catalytic 'aftertreatment' technologies are becoming more complex but could provide a step change toward lowering CO<sub>2</sub> emissions in exhaust gases. A case in point centres on new regulations in the European automotive industry, which is faced with significantly improving fuel economy and emissions, measured by the amount of carbon dioxide emitted per kilometre travelled. By 2008 this must be down to an average of 140 grammes of CO<sub>2</sub> per kilometre for new cars, a reduction of more than 20% over six years, with the prospect of even tighter limits to follow.

To achieve greater efficiency, one route

automakers are pursuing is lean burn direct injection engines, where air in excess of the stoichiometric volumes needed to burn hydrocarbon fuels is supplied to the combustion process, providing greater efficiency. But one drawback is that conventional 'three-way' catalytic converters – which reduce carbon monoxide, hydrocarbons and NO<sub>x</sub> simultaneously – will not reduce NO<sub>x</sub> to nitrogen under the oxidising conditions created by excess oxygen. One solution to this is to install a NO<sub>x</sub> 'storage trap', typically a barium oxide catalyst, which chemically traps NO<sub>x</sub> and stores them in the exhaust system as nitrates. Periodically, the operating conditions of the engine are changed to run on a stoichiometric air and fuel mixture, during which the trap is regenerated and the stored nitrates are emitted as nitrogen and oxygen to the atmosphere.

However, for such NO<sub>x</sub> storage traps to be effective, the fuel for the vehicle must be sulphur free, as the trap will more readily store sulphur in the form of sulphate than it will NO<sub>x</sub> as a nitrate, thereby reducing the capacity to trap NO<sub>x</sub> and therefore requiring more frequent regeneration. To support the introduction of more efficient lean burn engines, BP is actively working with auto-makers to ensure sulphur free grades of fuel are available in the immediate time frame.

With customers increasingly choosing cleaner fuels on the retail forecourt, the development of technologies underpinning the production of environmentally friendly gasoline and diesel – and the logistics of getting these to market – are fast gathering pace. What may have seemed unthinkable only a few years ago is happening right now. ■

Only five years ago, no-one knew how to make such low sulphur gasoline commercially without losing octane rating

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