
bp

Bottom of the barrel

Shifts in oil supply and demand are causing refiners to look at new ways to extract additional value from oil feedstocks. *Michelle Brown* learns more about BP's plans to apply technical know-how to get more from the 'bottom of the barrel'

The 'bottom of the barrel' is often regarded as the place to look when you've run out of better options. But when it comes to refining crude oil this old adage does not fully explain the recent upsurge in interest in processing more difficult crude oil fractions – those usually remaining at the bottom of the barrel. The fact is that recent trends in the demand for more energy mean that the bottom of the barrel is increasingly where BP's refining business is looking to find additional and profitable supplies of energy.

To put this in context, the global demand for energy has risen by 23 per cent in the last ten years and looks set to grow by a further 1.7 per cent on average every year until 2030. Despite significant and ongoing efforts by BP and many others in developing alternative sources of energy, around 90 per cent of the energy to meet that demand is likely to come from fossil fuels for the foreseeable future. Furthermore, oil is forecast to remain the biggest source of energy, and 75 per cent of the increase in oil demand will come from the transport sector.

'This means that refined products obtained from crude oil will provide the largest source of consumed energy,' says Paul Maslin, BP's technology vice president in refining. 'It also means that to obtain more transport fuels, we will need to convert more of the relatively difficult-to-process components of crude oil than we do now.'

The picture is also changing on the supply side. Today, most refineries process 'conventional' crude oil, which is the kind of 'light' oil that is relatively easy to recover from underground reservoirs and subsequently process in refineries. While there are many decades of conventional crude oil left – the recent *BP Statistical Review of World Energy* estimates that proven global oil reserves would last around 40 years at current usage rates – interest is already growing in 'heavier' crude oils, those which are more dense or viscous and therefore trickier to extract from reservoirs, and require different refining processes. 'With energy demand rising and the crude oil price going up, it's more attractive now to recover heavy oil. New technology for doing this is also making it easier,' adds Maslin.

Fuel security is another factor. For example, some of the largest reserves of heavy crude oil are in deposits in Canada and Venezuela, which are virtually on the doorstep of the USA, by far the largest consumer of oil and its products.

These complementary pressures on supply and demand are conspiring to make it more attractive than ever before to invest in processing heavier crude oil. According to Maslin, it's a simple equation: 'The trend is toward requiring more transportation fuels, which traditionally have been produced from lighter, conventional crude oil. But at the same time, oil supplies are increasingly coming from reserves of heavier crude around the world, so a normal refinery geared to treat light crude oil would produce less transport fuel than before. We therefore need to upgrade the refinery to handle the heavier crude oil.'

Delayed coking

This changing situation is driving major new investments within the refining sector, including a massive $3 billion upgrade project at BP's Whiting refinery in Indiana, the fourth largest refinery in the USA. Whiting currently processes a mix of mainly light sweet crude and medium sour crude from oil fields in the Gulf of Mexico. The upgrade will enable the refinery to process more heavy crude arriving from Canada, where new pipelines are expected to increase the capacity to export heavy crude by 1.2 million barrels per day between 2008 and 2010.

'The investment at Whiting is huge,' says Maslin. 'It's a direct result of the increasing volumes of crude being released from Canada at a time when the oil price is high. All the factors have come together to make Whiting the perfect investment.'

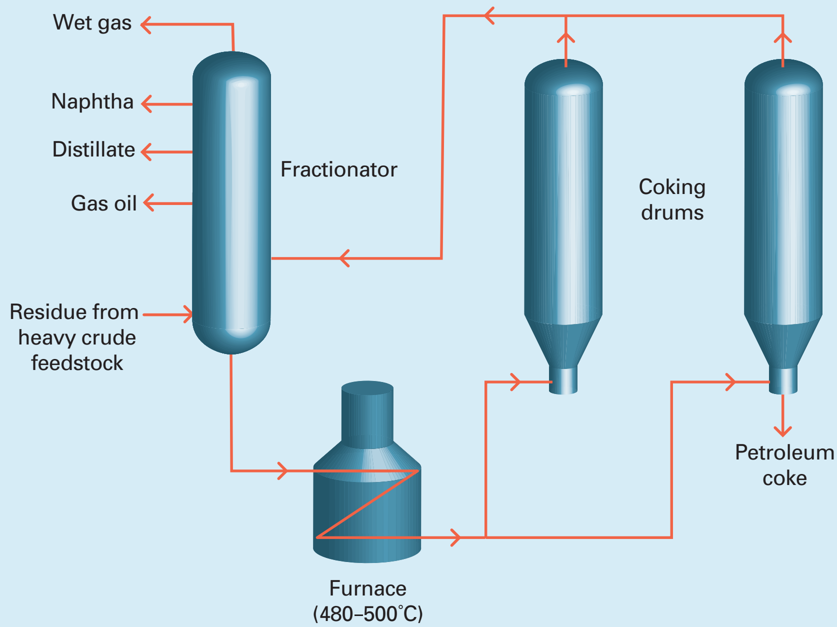
The project will increase the refinery's capacity to process heavy crude by 260,000 barrels per day and increase Whiting's production of transport fuels – gasoline and diesel – by 1.7 million gallons per day. Construction is expected to begin later this year.

The centrepiece of the Whiting upgrade is a very large process stage known as a delayed coker. In the early stages of the refining process, vacuum distillation removes the lighter fractions from the oil, which are further processed into useful products such as gasoline and diesel. The vacuum distillation stage produces a bottom fraction, or residue – the vacuum residue. This can be fed into a coker, a furnace where high temperatures are used to 'crack' the long chain, heavier residue hydrocarbons into 'gas oil' containing shorter hydrocarbon molecules – these smaller molecules can be subsequently converted into additional transportation fuels. (see diagram on page 40).

The hot liquid product stream from the coker passes into a coking drum where the gas oil vaporises and separates from the mixture for further processing, leaving a residue which condenses to form solid petroleum coke. ›

DELAYED COKING AT WHITING REFINERY

In the planned upgrade of BP's Whiting refinery (above), vacuum residue from heavier crude oil feedstock will be treated in a 'delayed coking' process (right) to produce additional transportation fuels, and petroleum coke



The term 'delayed coking' arises from the requirement not to deposit petroleum coke in the furnace where the cracking begins. Operators avoid this by keeping material moving through the furnace at a relatively high velocity, preventing the coke from forming until it reaches the coking drum. When the drum is full of coke, the feed is switched to an empty drum and the solidified coke in the full drum is removed using high-pressure water jets.

While coking is a batch process, refineries ensure that the process continues uninterrupted by operating the coking drums in pairs, so one drum is always being cooled, emptied and reheated while coke builds up in the other.

The Whiting coker will produce 6000 tonnes of coke per day using three pairs of drums. The coking cycle will run over 18 hours, with one pair switching every six hours.

'It's an enormous project,' says BP coking advisor Mike Kimbrell. 'This may not be the largest grass roots coker in the world but it's in the top three or four.'

The Whiting coker will also be one of the most technologically advanced coking operations. Most delayed cokers are labour-intensive and manually operated, requiring operators to clamber about on the structure and operate dozens of valves over the course of a drum cycle. And since the Whiting design uses three pairs of drums, a manual solution would involve carrying out three times as many valve operations by hand.

'These are large valves that take a significant effort to turn manually,' says Kimbrell. 'On the Whiting design, we will be able to switch a set of drums, remove the top and bottom heads and drill the coke out, all without manual intervention. It's a huge step forward in automation for delayed coking and an enormous technical achievement.'

The solids handling part of the process is also highly automated. The coke will be cut out into a pit, transported by crane and fed to a crusher, all automatically. And it's not just increasing automation that will help the Whiting coker to outshine its predecessors. Mechanical improvements are also being introduced. 'The existing coker in Whiting has some old technology that has been largely unchanged since around 1900,' says Kimbrell. 'Some of the technology we're planning to use has only been around for five years.'

The shift towards heavy crude feedstock and the increased coking operations also calls for significant work on some of the other processes at Whiting.

Although the coker will make products that are light enough to convert into transport fuels, they will be relatively high in sulphur and nitrogen – arising from the nature of the heavy crude feedstock – and will therefore need these contaminants removed. This will be achieved in expanded hydrotreatment facilities, which in turn will demand an increase in hydrogen production at Whiting. Hydrotreatment (*Frontiers*, August 2004) produces hydrogen sulphide and ammonia, which will be treated in an expanded sulphur plant to produce sulphur, nitrogen and water.

The main by-product of creating the additional transport fuel is the petroleum coke, which also has a value. Although the decision about where to sell it has not yet been made, Kimbrell says that the pellets of coke produced at Whiting could typically be used as a support fuel in coal-fired boilers.

Alternative coke

On the other side of the country in California, however, a project planned near BP's Carson refinery, some 30km south of Los Angeles, has proposed a more novel use for petroleum coke. The idea is to use it as the feedstock for a first-of-a-kind process to generate low-carbon electricity.

The project is a joint venture between Hydrogen Energy and Edison Mission Group – Hydrogen Energy is a new company that was established in May 2007 by BP Alternative Energy and mining giant Rio Tinto to promote low-carbon projects (see page 7).

Petroleum coke currently produced at the Carson refinery is exported overseas. In the proposed clean power project, around 5000 tonnes per day of coke would instead be 'gasified' by reacting it with oxygen and steam in a vessel at around 70 bar and over 1100°C. This produces a synthesis gas – a mixture primarily of carbon monoxide and of hydrogen – which then undergoes a water-gas shift reaction (see diagram below) to produce a gas stream rich in hydrogen and carbon dioxide (CO_2).

The process would capture around 90 per cent of the carbon in the coke feedstock as CO_2, which would be compressed and piped for storage. The CO_2 would be sequestered permanently underground in oil reservoirs or other geological formations, thereby avoiding the emission of some four million tonnes of CO_2 per year to atmosphere. If stored in oil reservoirs, this could potentially provide an added benefit of helping to stimulate further oil extraction from the reservoirs.

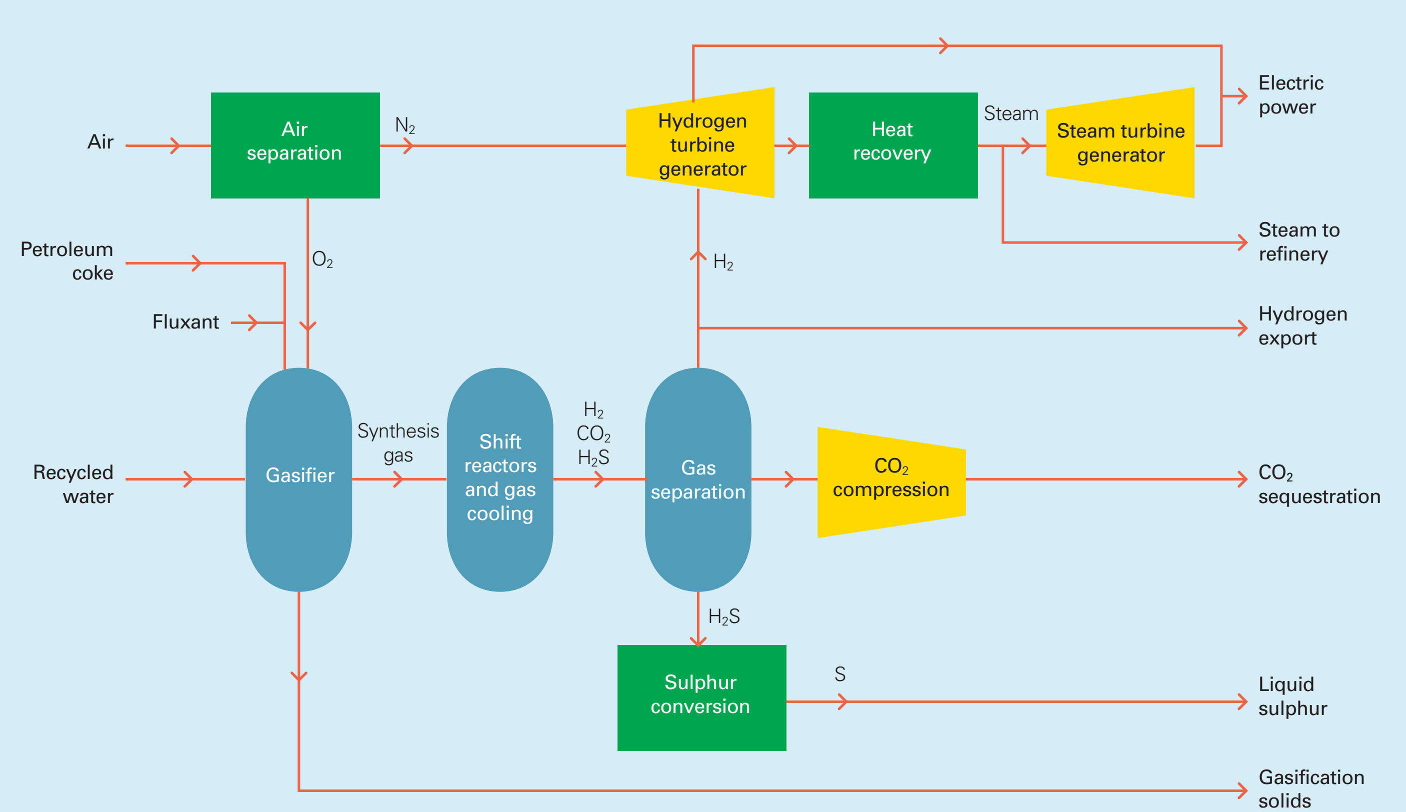
The hydrogen from the coke gasification would be used to fuel a gas turbine, with waste heat from this being channelled to generate steam to drive a steam turbine, bringing the total power which could be generated to around 500 megawatts – enough to serve around half a million homes in southern California.

The Carson project could also have the potential to export hydrogen and high-pressure steam to nearby industrial users, including BP's refinery.

The overall development is known as integrated gasification combined cycle (IGCC) technology with carbon capture.

'All the technologies in IGCC have been used ›

CLEAN POWER GENERATION AT CARSON REFINERY

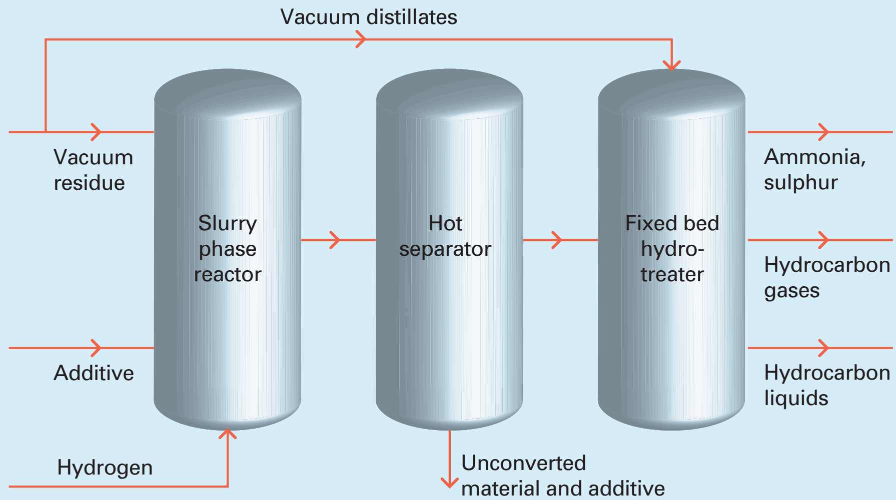


N_2	Nitrogen
O_2	Oxygen
H_2	Hydrogen
CO_2	Carbon dioxide
H_2S	Hydrogen sulphide
S	Sulphur

A new 'clean power' plant is proposed adjacent to BP's refinery in Carson, California (left). Petroleum coke – a by-product from refining heavier crude oil – would be processed (as shown above) to produce a synthesis gas stream containing hydrogen and carbon dioxide. The hydrogen would be used to generate electricity, while the carbon dioxide would be captured and sequestered in underground geological formations.

COMBI-CRACKING AT GELSENKIRCHEN REFINERY

The Veba Combi-Cracking (VCC) process, demonstrated in the 1980s at BP's Gelsenkirchen refinery in Germany (above), could make a comeback for converting heavy hydrocarbons into useful products. The basic VCC process is shown on the right



before, but no-one has yet produced low-carbon power by using them in this combination,' says Craig Skinner, BP's engineering manager for the project. 'From the point of view of exploiting the bottom of the barrel, this project is a new way of upgrading petroleum coke into higher-value products.'

Cracking solution

In addition to the well established process of delayed coking, changing economics are also prompting refiners to take a fresh look at other technologies to handle heavy hydrocarbons that may not have been financially attractive in the past. One promising contender is the proprietary Veba Combi-Cracking (VCC) process, acquired by BP when it took over Veba in Germany in 2002.

Until now there has been just one VCC plant in the world. This 3500 barrels per day demonstration unit was built in the 1980s at what is now the BP-operated Gelsenkirchen refinery in Germany. It was subsequently shut down in 2000 due to unfavourable economic conditions at the time, but BP believes that the conditions could now be right to develop the process commercially over the next five to ten years.

In the VCC process, vacuum residue is fed into a slurry phase reactor at 200 bar, along with an additive that prevents foaming (see flow diagram above). Hydrogen gas is bubbled through the slurry mixture from below.

'While coking effectively breaks up heavy hydrocarbons by removing carbon, the VCC reactor achieves a similar result by adding hydrogen,' says BP's refining technology integration manager, Martin Rupp.

Following the slurry reactor, a separator vessel removes unconverted material plus the additive, while the lighter products pass on to a fixed-bed catalytic hydrotreatment vessel. Here the hydrogen levels are 'topped up' in order to remove nitrogen and sulphur and meet clean fuel specifications. The valued hydrocarbons leave the process as both gases and liquids.

According to Rupp, there are two main reasons why VCC might be a serious contender when compared to conventional coking. First, there's the high vacuum residue conversion rate of 95 per cent for VCC – coking typically manages a little over 70 per cent.

The second reason is the high liquid yield, which is critical because the liquid fraction includes all the most desirable products that form the basis of transport fuels. 'For this process the liquid yield is above 100 per cent, whereas a coker is below 80 per cent,' he says. This is possible because the process is adding hydrogen, rather than removing carbon as coke.'

For now, the coker remains king in capturing the bottom of the barrel, but Maslin says that the Veba process will be a formidable competitor and is not the only one on the horizon. 'We have a long-term strategy of looking at technologies for upgrading the bottom of the barrel and we're always looking to develop new ones,' he says.

He also stresses that making the most of the changing nature of refinery feedstocks is about more than developing new processes. It's also about running existing facilities as effectively and safely as possible.

BP recognises that the growing need to extract more value from the bottom of the barrel will continue to be a major driver for future refinery investment – and the company's expanding portfolio of technology solutions is designed to ensure it can meet the challenge. ■

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