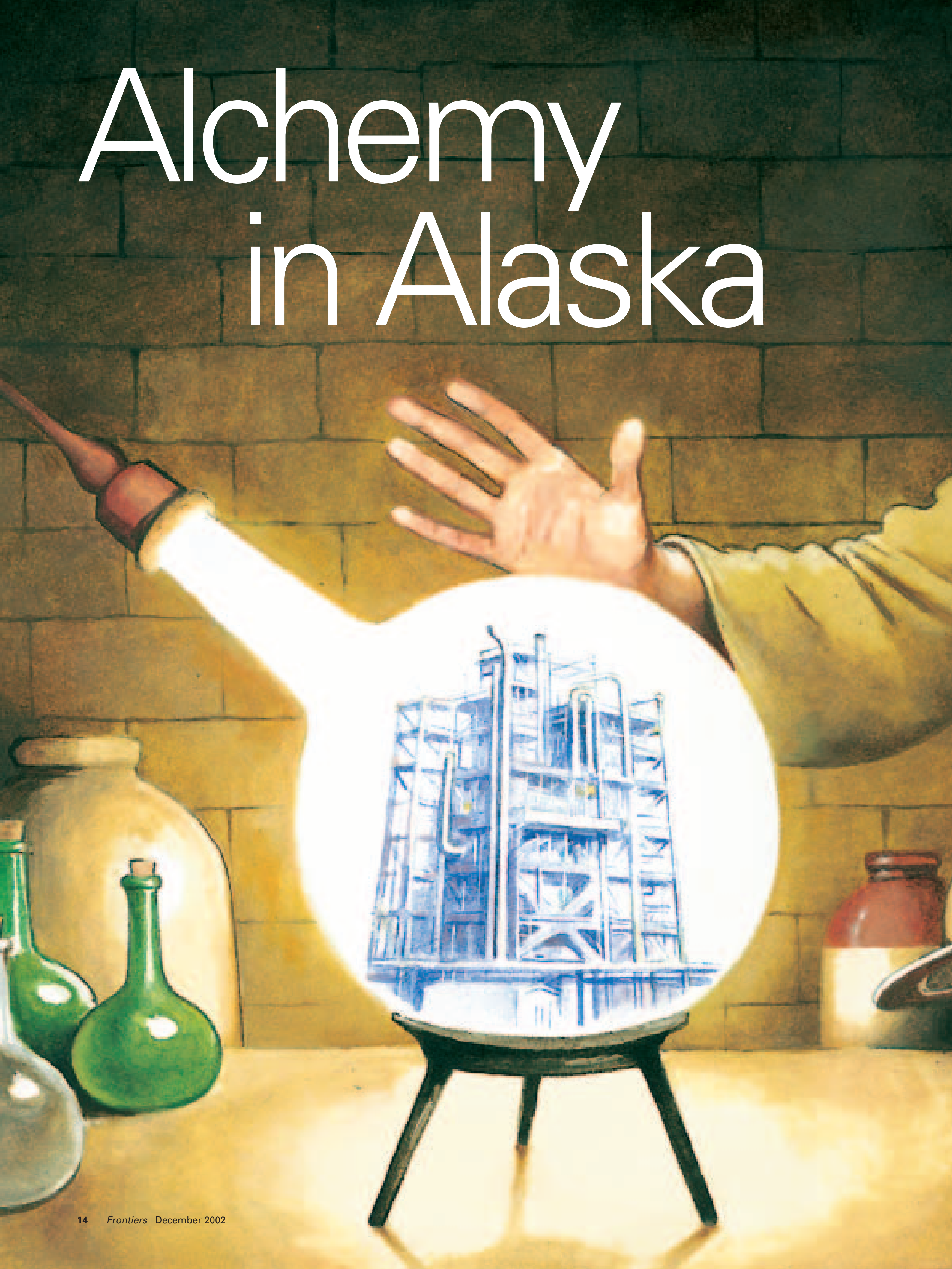
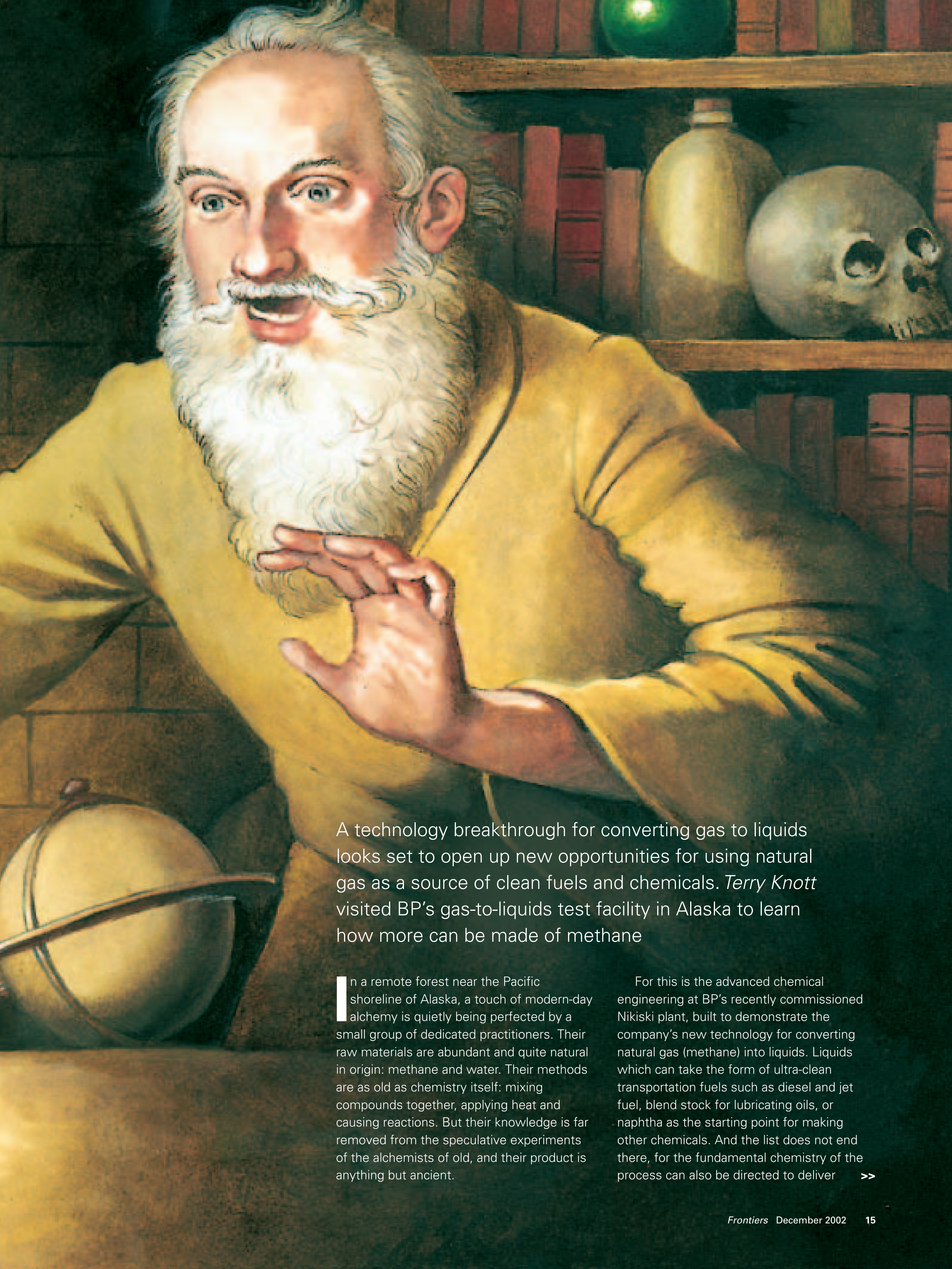
Alchemy in Alaska





A technology breakthrough for converting gas to liquids looks set to open up new opportunities for using natural gas as a source of clean fuels and chemicals. *Terry Knott* visited BP's gas-to-liquids test facility in Alaska to learn how more can be made of methane

In a remote forest near the Pacific shoreline of Alaska, a touch of modern-day alchemy is quietly being perfected by a small group of dedicated practitioners. Their raw materials are abundant and quite natural in origin: methane and water. Their methods are as old as chemistry itself: mixing compounds together, applying heat and causing reactions. But their knowledge is far removed from the speculative experiments of the alchemists of old, and their product is anything but ancient.

For this is the advanced chemical engineering at BP's recently commissioned Nikiski plant, built to demonstrate the company's new technology for converting natural gas (methane) into liquids. Liquids which can take the form of ultra-clean transportation fuels such as diesel and jet fuel, blend stock for lubricating oils, or naphtha as the starting point for making other chemicals. And the list does not end there, for the fundamental chemistry of the process can also be directed to deliver

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BP's new test facility in Nikiski, Alaska, is putting gas-to-liquids technology into action

>> hydrogen or methanol as the end product, from which a wide range of useful industrial chemicals can be derived under the banner of 'gas-to-products' technology.

Construction of the $86 million gas-to-liquids (GTL) test facility at Nikiski on the Kenai Peninsula began in February last year, with startup coming two months ago. For BP it represents the culmination of a research and process development programme with its roots in the 1980s.

'The fundamentals of the GTL process have been known about since the 1920s, but only now can we confidently apply them economically,' says Joep Font Freide, BP's GTL technology manager and advisor in the upstream technology group. Having been involved with BP's investigations into synthetic fuels over the past two decades, he acknowledges that there have been many daunting technical challenges along the way. 'Getting the capital cost of the process down has been an intriguing problem to solve. But we are about to show that GTL can work economically as a standalone process in a remote location. If we can do that here, we can do it anywhere. The result is a credit to the efforts of many people over many years.'

A wide range of useful industrial chemicals can be derived under the banner of 'gas-to-products' technology

The drivers for the increasing interest in GTL across the energy industry are numerous. There is desire to commercialise gas reserves in remote regions of the world, where the primary means of bringing gas to markets through either long distance pipelines or as liquefied natural gas (*Frontiers*, December 2001) are not feasible. One estimate indicates there to be around 900 trillion cubic feet of gas which is considered to be 'stranded' in remote regions; GTL could offer an alternative solution to unlocking the value of these reserves.

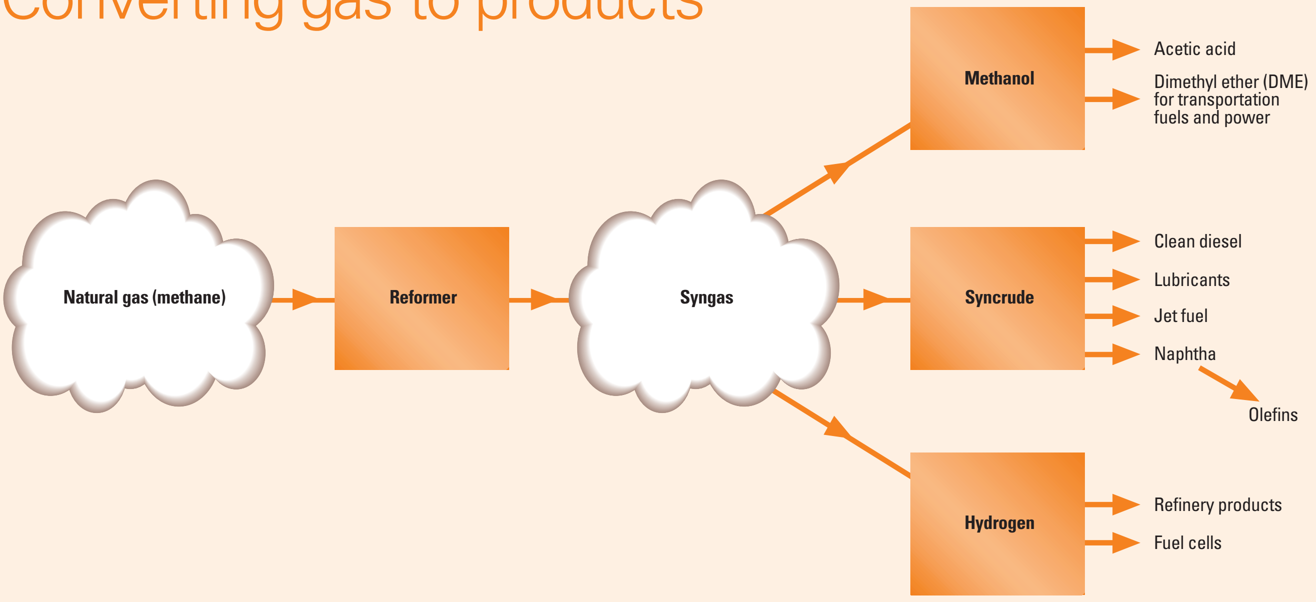
In other locations, production of oil can be constrained by associated gas which is often produced at the same time. This gas has to be either reinjected into the reservoir – an operation often with finite limits – or flared, an environmentally unacceptable solution. GTL could be applied to convert the associated gas into liquid products.

On a broader front, the technology could play a part in meeting the growing demand for cleaner fuels and cheaper chemical feedstocks, and may begin to take on a more strategic role as gas-rich nations increasingly seek ways to diversify their product portfolios and make maximum use of their natural resources.

Compact cost cutter

With such widespread interest in GTL, it is no surprise that several competing process

Converting gas to products



technologies exist for converting methane into liquids, some of which have already led to small scale production. All of these follow the same basic three-stage process (see panel on page 20).

In the first stage, known as reforming, methane is reacted with steam or oxygen to produce 'syngas', a mixture of carbon monoxide and hydrogen. The syngas is then converted into long-chain waxy paraffins in the Fischer-Tropsch process. In the third stage the paraffins are upgraded using hydrogen to produce synthetic crude oil. This 'syncrude' can then be refined to give products such as high-energy, clean diesel fuel, free from sulphur and aromatics, ultimately resulting in reduced atmospheric emissions from vehicle engines.

So what is different about BP's approach to making syncrude that will give the company a competitive advantage?

'In conventional GTL plants, about 60% of the capital cost lies in the first stage, the reformer making syngas,' explains Font Freide. 'The breakthrough we have achieved is to reduce the size of this stage significantly. Compared with a conventional steam reformer, our compact reformer has a footprint one quarter of the size, and weighs 75% less.'

The size reduction has a direct effect on the overall cost of building the plant. To date, the GTL plants which have been built have struggled to get construction costs down to economic levels, achieving at best a figure of $25,000 per barrel per day (bpd) of liquids production, and frequently much higher. The step change accruing from BP's compact reformer will bring costs down to $20,000 per bpd or lower, giving GTL production a more attractive price tag where opportunities exist to exploit the advantages of the technology.

The key to reducing the size of the reformer lies in managing the heat of reaction inside the vessel – considerable heat energy is required to break or 'reform' the highly stable molecules of methane to make syngas. Conventional steam reforming, a widely used process in refineries and chemical plants, takes place at 800-900ºC and pressures of 10-40 bar. Methane and steam are passed through catalyst-filled tubes located in a gas-fired furnace. Normal practice avoids flame impingement on the steel tubes to prevent overheating and burn-out, dictating the spacing of tubes and the overall size of the reformer.

'If you are able to remove heat from the tubes fast enough, you can bring the components closer together, shrinking the size of the entire furnace,' says Font Freide. 'This requires very careful balancing of the feed gases and fuel gas to achieve such advanced heat integration. In the early days we melted a few tubes, but now we have it right.'

The now-patented compact reformer idea originated at BP's former research centre in Warrensville, Ohio, in 1989. Single tube tests began then, followed by a large pilot plant. In 1996 BP entered into a development

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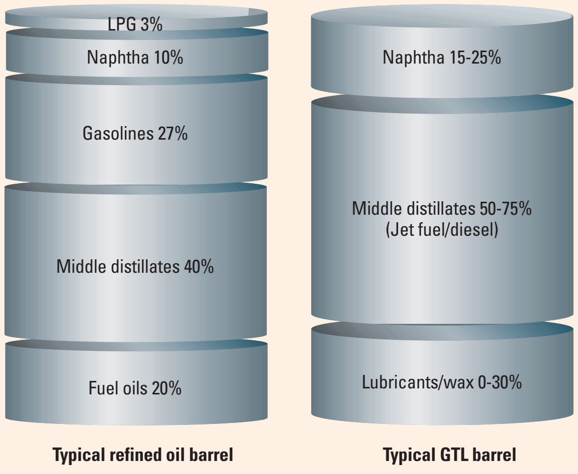
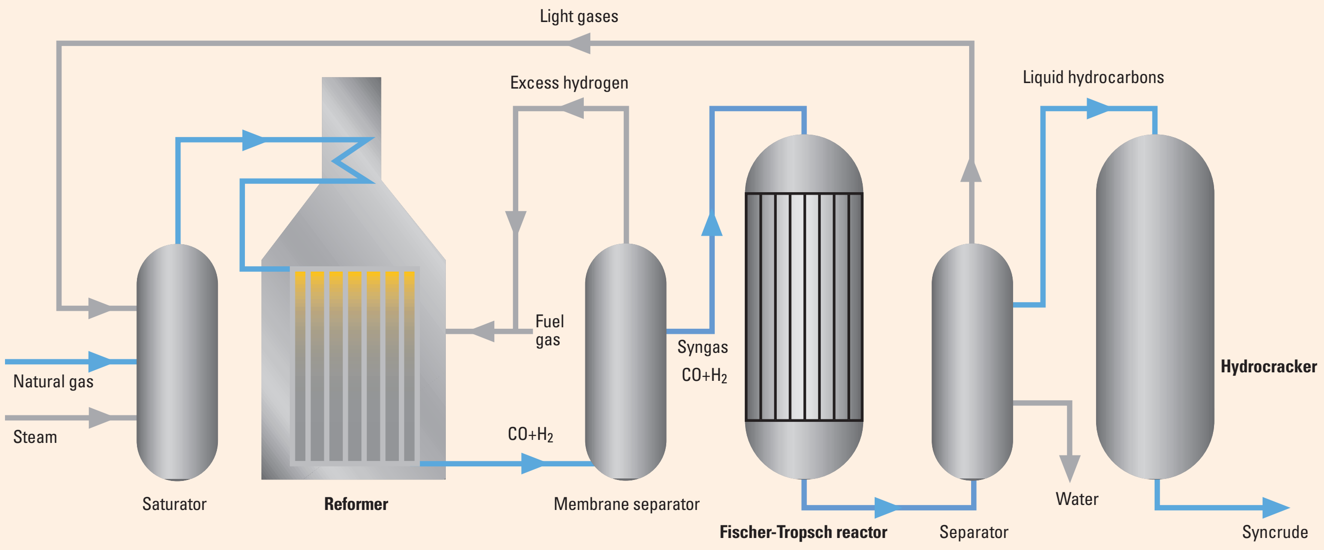
'Syncrude' compared with normal crude oil

Products obtained from refining a barrel of syncrude (far right) differ from those generated in conventional refining of crude oil. (The figures shown are percentages by volume)



BP's gas-to-liquids process



>> and licence agreement with Davy Process Technology in the UK (formerly Kvaerner Process Technology), recognised leaders in syngas reformer design. BP and Davy have since worked as a team to develop the overall GTL process (see diagram above), with Davy now holding the rights to market the technology worldwide.

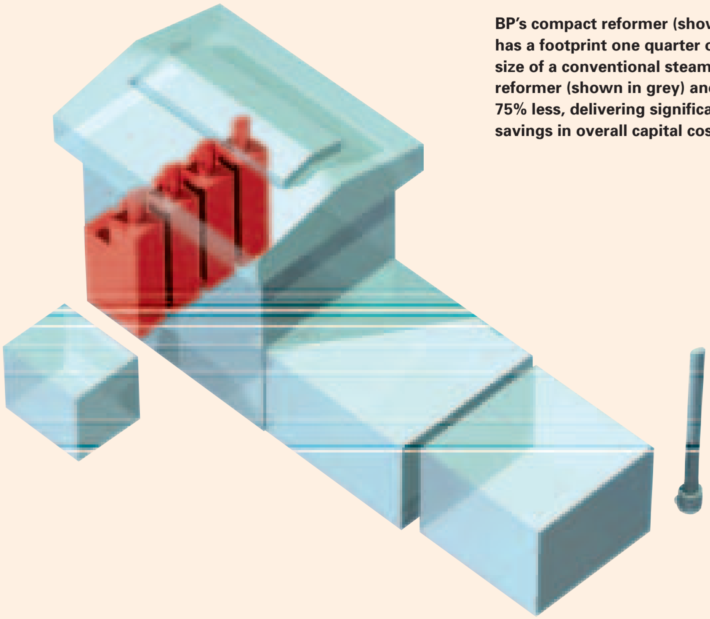
The advantages of the compact reformer reach beyond its smaller size and cost. The process operates with increased thermal efficiency due to a large internal heat recycle, approaching 90% efficiency compared with conventional reformers around 60-70%; and as steam is used rather than oxygen to convert the methane, a costly oxygen-generating plant is not required.

The design is based on standard modules which can be used in multiples to deliver commercial scale plants. This modular approach also presents opportunities for factory-built mass production of units which can be transported to remote sites – or even offshore – resulting in reduced costs and schedule in on-site construction compared with conventional steam reformers which are large and therefore built entirely *in situ*.

By no means all of the development programme, estimated to have cost over $300 million spread over the timeframe, has focused on the reformer. For the Fischer-Tropsch syngas conversion stage, BP began investigating new catalysts almost 20 years ago, resulting in pilot plant trials at the company's chemical complex at Hull in the UK in the late 1980s, and subsequent integration into the US pilot plant to prove the first two process stages together. The outcome of the work is a proprietary high-activity cobalt-based catalyst, developed by BP, which again is used in a tubular fixed bed through which the syngas is passed.

The waxy paraffins produced by the Fischer-Tropsch process are in liquid form as they exit the reactor, and contain long-chain molecules, perhaps with up to 100 carbon atoms linked together. In the subsequent hydrotreating stage, a process commonly employed in refineries, the long chains are reduced in length by adding more hydrogen to break the carbon-to-carbon bonds. The result is syncrude, a pipeline-stable liquid which when further refined produces colourless liquids, for example high-grade diesel, kerosene and naphtha.

'Normally about 65-70% of the carbon you start with in the methane supply ends up in the liquids,' Font Freide points out. 'This is because you must burn some of the methane as fuel to provide the process heat, and all GTL processes do this. But we think we can see ways to push carbon conversion up to 80%.'



BP's compact reformer (shown in red) has a footprint one quarter of the size of a conventional steam reformer (shown in grey) and weighs 75% less, delivering significant savings in overall capital cost

Testing times

The Nikiski test facility is designed to take up to 3 million cubic feet per day of natural gas from a nearby pipeline supply and convert this into 300 bpd of syncrude.

Nikiski will demonstrate BP's new compact steam reforming technology

'Demonstration plants are usually built at existing facilities, but we have had the added challenges of constructing new technology on a remote greenfield site in a harsh climate,' observes Len Seymour, BP's team leader at Nikiski. 'It's also a large plant by normal demonstration standards, similar to a small chemical plant or refinery. There were plenty of logistics challenges bringing large plant and equipment to Nikiski from all over the USA and Canada, and mainly in winter – we had tents over the ground to thaw it out for the foundations. But the key point is we have achieved a self-contained plant here, in one of the toughest regions of the world, and believe we could do it anywhere.'

At peak of construction, around 350 people were at work on the project, some 90% of them being Alaskans. In normal operation the plant will require a crew of only 20. The geographic location adds some additional design requirements to the plant, not least of which is allowance for seismic loading to withstand Alaska's occasional but sometimes significant earthquakes, and the winterisation of an outdoor facility for the extreme cold.

Great attention has been paid to the environmental aspects of the 23-acre site and the plant's operation – extensive environmental studies were carried out with several permits having to be granted before the plant could go ahead.

The breakthrough lies in significantly reducing the size and cost of the reformer

The highly integrated process reduces carbon dioxide emissions by channelling excess hydrogen produced in the plant to fuel the reformer, limiting the volume of incoming methane being burned. The excess hydrogen is obtained from the syngas mixture by membrane separation. Although water is produced in the Fischer-Tropsch converter, around 97% of this is recycled to generate steam for the plant, the remainder being trucked away for treatment and disposal. When excess gas has to be burned off, for example during startup operations, it is done in a low ground flare rather than in a high stack – this is a smokeless technique which shows no flame.

BP's plant commissioning manager Steve Fortune has been with the GTL development programme through the pilot plant phase and led the engineering design of the demonstration plant carried out by Kvaerner (now Aker Kvaerner) in Houston. He is enthusiastic about the GTL technology at Nikiski.

'The reformer module we are testing is a full-scale module of the size you would employ in a commercial plant, hence this is a large scale demonstration, calculated to reduce the technology risk in moving up to a full commercial plant. It was fantastic when we fired up the plant for the first time and it worked. Now we have to work through our test programme step by step to prove the key technologies involved and what they are capable of.'

The test campaign could last for 12 to 18 months, says Fortune. 'The real challenge is to understand the dynamics of the overall process. We have intensified the main reaction in the reformer, which means the process responds to changes faster. The target is to achieve 'tramlines' on our outputs – steady state parameter readouts for the individual stages, and across the entire plant, for a period of months. This will give us the benchmark data to design commercial scale plants producing thousands of barrels of liquids a day.'

Maximising methane

While Nikiski is the focus of BP's current activity in GTL technology, it is not the company's only involvement. In Hull, further development work has been under way on the Fischer-Tropsch conversion process, which could be tried out on the large scale at Nikiski in due course, although BP is revealing little about the nature of the work at present for proprietary reasons. The company is also funding two long-term university research programmes. One of these is based in

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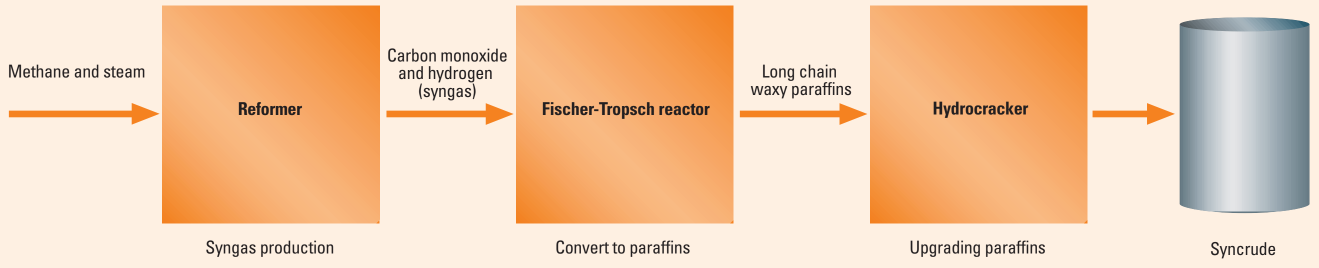
Converting gas to liquids



At the heart of most processes for converting methane gas into liquid fuels is the reaction discovered in the 1920s by the German chemists Hans Fischer and Franz Tropsch. They found that by using a catalyst under the right conditions of temperature and pressure, a mixture of carbon monoxide and hydrogen – known as synthesis gas or syngas – can be converted into waxy paraffins.

To first obtain the syngas, natural gas, or a gassified hydrocarbon source such as coal, tar or oil, is reacted with steam or oxygen/air. To end up with liquid fuels, the long chain waxy paraffins from the Fischer-Tropsch (FT) process must be treated with hydrogen to break them down into middle distillates such as diesel, kerosene and naphtha. The resulting products are of high purity, and being free from sulphur, heavy metals and aromatic compounds, they are commercially and environmentally attractive.

Research into the three-stage GTL process has been ongoing for the past 50 years, with several companies pursuing variations on the basic theme to develop proprietary processes, some with operating plant experience. Prominent among these are:

- Mossgas in South Africa uses Sasol proprietary technology to produce around 25,000 bpd of liquid fuels from natural gas.
- Sasol in South Africa has been producing liquid fuels from coal-derived syngas since 1955, based on a fluidised bed FT process. Sasol has recently teamed up with ChevronTexaco in a global joint venture to build GTL plants, which employ Haldor Topsøe autothermal reforming technology using oxygen for the reforming stage.
- Shell operates a 12,500 bpd GTL plant in Bintulu, Malaysia, using oxygen to reform natural gas and a fixed bed FT reactor.
- ExxonMobil holds several patents in GTL technology, with fluidised bed processes for both reforming and FT stages. The company has a 200 bpd pilot plant in Baton Rouge, Louisiana.
- Conoco Phillips has a 400 bpd pilot plant under construction in Ponca City, Oklahoma, based on oxygen reforming and a fluidised bed FT process.
- Other companies involved in GTL process development include ENI/IFP, Rentech, Statoil, Synfuels, Syntroleum and Williams.

While current world output of liquids from GTL plants is quite small, some projections indicate that GTL production could climb to 1-2 million bpd by 2015. GTL plants have been proposed for Nigeria and Qatar, and several locations yet to be named.

>> the USA working with the California Institute of Technology in Pasadena and the University of California at Berkeley – recognised worldwide for innovative research in catalysis and process engineering – to advance the frontiers of gas conversion research. The other initiative is part of the clean energy research programme funded by BP in China and is being carried out by the Chinese Academy of Sciences and Tsinghua University. An early project is centred on the direct conversion of methane to hydrogen and aromatics.

'Converting methane to chemicals is an area of strategic interest for BP,' says group strategy development manager, Jonathan Evans. 'In the compact reformer we have the means to produce syngas, a first step in the manufacture of commodity chemicals such as methanol, ammonia and acetic acid.

'Other constituents of natural gas – ethane and propane – can be directly converted to ethylene or propylene through auto thermal cracking, a partial combustion catalytic process which generates its own heat of reaction to crack the gas molecules. This offers substantial synergies in a gas-to-products portfolio. There are many ways in which we could leverage our gas conversion know-how.'

The Nikiski facility is designed to convert up to 3 million cubic feet of gas per day into syncrude

While there may not be an immediate commercial opportunity to apply BP's GTL technology to the company's global gas reserves as a standalone process to monetise gas, there are possibilities for it to be integrated with other operations, for example in new oil producing locations lacking gas infrastructure, or in association with liquefied natural gas (LNG) plants – the LNG process basically extracts heat while GTL needs heat, giving scope for heat integration.

Chris Mottershead, BP's technology vice president for the gas, power and renewables business stream, summarises the outlook for GTL.

'GTL is an important contingent technology for BP. While we already have routes to monetise all our own gas at present, this might not always be so. We do believe there are places around the world where the technology will become economic to apply, and we are working hard to ensure it is BP's technology that people choose. Our strategy is to drive down the cost of GTL, making it more affordable for everyone, while retaining the option to use it on our own gas in future.'

When BP's GTL process is applied commercially, the modern-day alchemists in Alaska will have the satisfaction of knowing their magic really does work in making more of methane. ■