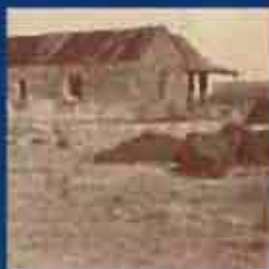




mind over matter

The Sasol Story: A half-century of technological innovation

John Collings



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Journey from the interior

This is the story of how a country at the southern end of Africa launched an industry half a century ago in defiance of expert opinion elsewhere, and lived to see its courage bear rich fruit.

The country was South Africa and the purpose of the industry was to produce petrol, diesel and industrial chemicals from coal. The company that pioneered the industry in Africa is known as Sasol.

It was a bold undertaking for several reasons.

First, though petrol, diesel and chemicals had been produced from coal in Germany, there was no evidence that it had been economic to do so. Whether it could be made competitive with crude oil-derived products remained to be seen.

Second, South Africa was still little developed industrially. There were few people living there with the scientific skills to solve whatever technical problems might arise in scaling up existing oil-from-coal plant to the size planned for South Africa.

Finally, the initial estimate of the capital cost of the project was huge by South African standards, for the country's economy was small compared with, say, Europe's industrially developed countries. Yet, as the enterprise got under way and began facing serious technical problems, that cost estimate proved

alarmingly inadequate. Sasol found itself astride a financial tiger from which it could not dismount. With millions of pounds already spent, there could be no turning back.

So it pressed on. Eventually, it overcame those technical problems and began showing a profit. When crude oil prices began to rise steeply in the first half of the 1970s, it was sufficiently confident of its technology and management skills to accept the government's proposal that it build a second oil-from-coal plant, one that would produce 10 times as much petrol as the first. And then, in the late 1970s, when the Shah of Iran fell from power and a second oil crisis exploded, it

received government approval for replicating its second plant with a third.

To finance the third plant, the company, until then a parastatal enterprise, went public. Its offer of shares in 1979 was heavily oversubscribed. Those who acquired them at that time and still hold them have seen their real (inflation-adjusted) market value and dividends rise considerably.

The main reason is that Sasol has, since the mid-1980s, been increasingly successful in improving its cost base by creating ever more value, through its huge reactors, from the gas it



Construction of Sasol's factory and employee housing – early 1950s



In 1959 Sasol's technology was demonstrated at the Rand Easter Show

Sasol is no stranger to large and complex projects. Its Secunda factory, for example, is the world's largest petrochemical complex built at one time on a single site

produces from coal; value that has lain in a growing variety of industrial chemicals. The latter now number more than 200 – notwithstanding that Sasol supplies 29 per cent of South Africa's motor fuel needs from coal – and fetch far higher prices in world markets than their value as components of petrol or diesel.

Both cost reduction and product proliferation are the result of intense and ongoing research into new technologies. It has not only produced chemicals that find loyal markets around the world. Recently, too, it has opened the way for Sasol to participate in projects for obtaining commercial value from other countries' natural gas resources. Using a technique developed by its researchers, it will feed processed gas into its reactors to yield a product that can then be turned into premium-quality diesel for sale around the world.

Sasol is no stranger to large and complex projects. Its Secunda factory, for example, is the world's largest petrochemical complex built at one time on a single site. The exploitation of natural gas by Sasol in joint ventures with other oil companies could also lead to projects of record-breaking size.

Many of Sasol's early pioneers, from senior managers to engineers and plant operators who accepted almost inhumanly long working hours and physical danger as the price of turning theory into viable reality, are no longer alive. Would that they were, for they would be proud to see how that squalling, recalcitrant infant has blossomed into a world-class enterprise, still the only one of its kind, that employs more than 31 000 people. In its most recent financial year it produced a turnover of just over R41 billion (in September 2001 about US\$4 850 million), of which R15 billion came from exports and foreign sales. On total turnover, Sasol made a 26 per cent operating profit and a record pre-tax profit of R10,5 billion – 72 per cent up on fiscal 2000 (which, in turn, had been 60 per cent higher than 1999).

How it got there, through the efforts of its people and the technologies they developed, is told in this book. So that everyone will now, for the first time, be able to understand what Sasol's remarkable achievements are really all about, we have described them in layman terms.

So, enjoy! It's a fascinating story.



Chapter 01 Pages 06 – 21 ►

Coal's promise discovered

1862

A purple dye is produced synthetically from coal, launching a new industry



1890s

The chemical industry learns how to produce chlorine from salty water



1925

Franz Fischer co-patents an oil-from-coal process which will be basic to Sasol's operations



1920s

SA scientists, among them Etienne Rousseau (below), join world research into oil-from-coal possibilities



1945

World War Two ends; a joyous future is anticipated



1948

SA gets a new government intent on industrial development



1950

Sasol is formed to produce oil and chemicals from coal



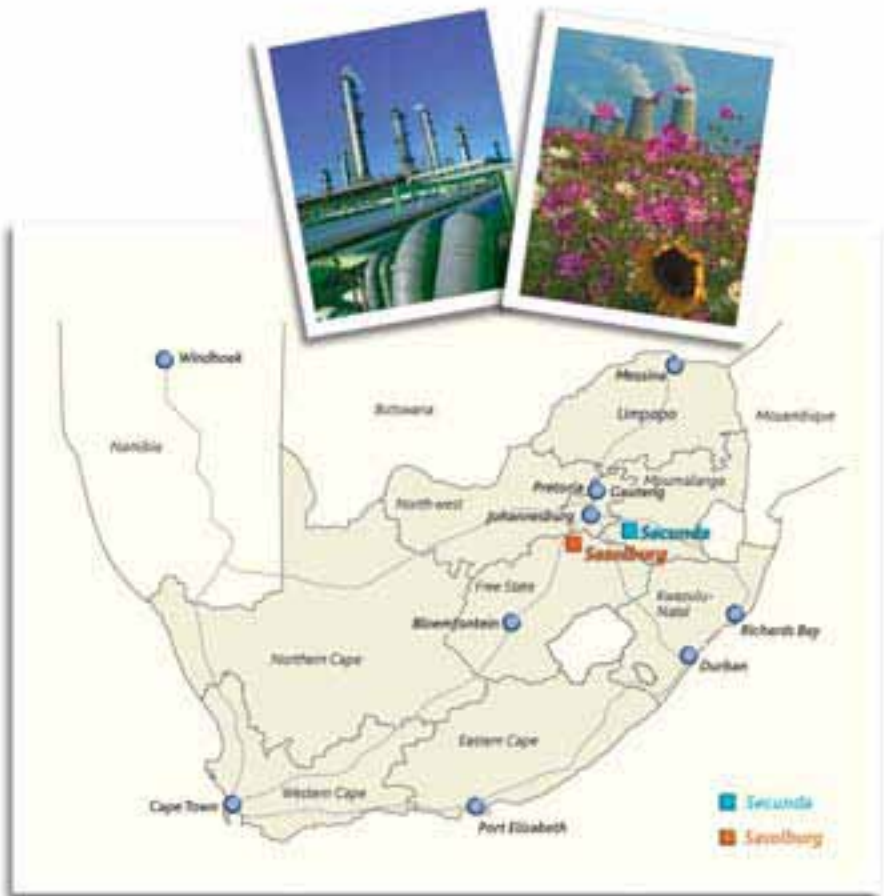
1960

By developing local engineering and fabrication skills, Sasol achieves profitability

Sasol has created two industrial sites in South Africa. The first, 80 kilometres south of Johannesburg, is called Sasolburg. The second, about 120 kilometres south-east of Johannesburg, is called Secunda.

With the fuels-producing units alone covering about 13 square kilometres, Secunda's operations are far larger than those in Sasolburg.

Both sites, however, contain industrial plants that impress non-technical visitors by their size and apparent complexity. Coal is brought on conveyor belts several kilometres long from neighbouring mines to be fed into power stations, steam generators and gasifiers. Huge cooling towers and Eiffel Tower-high smoke stacks serve the first. Steam and oxygen – the latter produced by chilling air in nearby plants to the point where it liquefies so that oxygen can be distilled from it – are fed into towering gasifiers, along with coal. Elsewhere, steam produced by chemical plant is condensed back to water in large, block-like buildings.





By 1953 Sasolburg was taking shape. Fuel production began in 1955



The Sasolburg factory today, devoted wholly to chemicals production

Gas from the gasifiers flows to other plants where it is purified of sulphur, carbon dioxide and other contaminants, then fed into Fischer-Tropsch reactors. There, in steel structures 30 or more metres high, it undergoes a process that produces what Sasol calls its 'treasure chest'. Chemical combinations between hydrogen and carbon take place that, between them, provide Sasol with its wide variety of products. This blend is then cooled and separated into its different ingredients by distillation in high columns, or through other methods. And linking all of this is a maze of pipes of various diameters.

Two ironic thoughts appear while one contemplates the size of it all. The first is that, while the design, construction and erection of the different plants clearly require high competence in engineering of various kinds, what counts above all is an understanding of what happens at the submicroscopic level. The second is that the plant, unlovely as it is to laymen's eyes, might never have been erected if Europe's middle classes, back in the 19th century, hadn't wanted to be dressed as colourfully as the rich and powerful.

Man discovered almost 10 000 years ago that you can separate some metals from the rock ore in which they reside by heating the ore with fire – smelting. They did it first with copper, because you don't need much heat to release copper from malachite, then with tin. Later they found that remelting these two soft metals together produced a far harder and more useful metal they called bronze. They didn't understand how that came about, and probably didn't care. Bronze could be honed

to a sharp edge or point, where copper couldn't – and that gave its possessor an advantage when it came to competing for turf, women or whatever.



Iron needs a far higher smelting temperature than copper (about 1 500°C against copper's 1 000°C) and that took man far longer to achieve, which explains why the Bronze Age preceded the Iron Age. Coke has been used to smelt iron ore for the past three centuries. It is produced by heating coal. A tarry liquid, as well as gas, flows from the coal, leaving behind coke, which is almost pure carbon and a highly desirable source of heat for smelting.

The gas was once used to light street lamps. For the moment, though, our interest lies with the coal tar. It contains a variety of oils that are categorised as light, middle or heavy. The last was regarded by iron and steel producers, back in the early 19th century, as nothing more than a nuisance. Chemists, however, were interested in finding out what they could transform it into, or derive from it. German chemists were particularly interested, probably because coal mining and steel production were major industries in that country.

Among them was August Hofmann who, in his late twenties, moved to London in 1845 to teach at the Royal College of Chemistry. One of his pupils there was William Perkin, who set up a laboratory at his home to find out if he could obtain quinine, even then a well-known medicine, from coal tar rather than from the more difficult to obtain bark of the cinchona tree.



William Perkin

The history of scientific discovery offers many examples of happy accident. Perkin couldn't later explain why, but one evening before leaving his laboratory he dropped a piece of silk into a tarry substance. The next morning he found it had turned purple.

*If it had turned green or brown, the excitement would have been considerable. But purple – that was like winning a major lottery! Until then, all dyes had been produced from plant juices or animal excretions and were therefore expensive. Purple was produced from the secretions of the sea snail, *Murex brandaris*, and more than 10 000 snails were needed to produce one gram of dye. That made it the most expensive of colours, and only emperors, kings, cardinals, archbishops and the wealthiest of merchants or bankers had been able to afford it.*

No longer. Chemists discovered that a particular molecule in coal tar, aniline, was the link between the tar and the dye. Soon they were using it to produce different dyes: magenta, violet imperial, Bleu de Lyon (French chemists were also busy developing synthetic dyes) and black.

While purple was the first prize – Perkin called his synthetic dye mauve – a colour known as Turkey red (scarlet) was also popular for dyeing cotton. It was derived from madder, a herbaceous plant, so was relatively costly to produce. English and German chemists (Hofmann had returned home in 1865)

The Germans beat the English to the patent office by one day, and that triggered a German synthetic dye-making industry

began trying to produce it synthetically. Though working quite separately they discovered virtually simultaneously in 1869 that the key ingredient in madder was a substance called alizarin and that they could synthesise it using an ingredient in coal tar called anthracene.

The Germans beat the English to the patent office by one day, and that triggered a German synthetic dye-making industry headed by the Bayer company and heavily supported financially by the Prussian government. By the mid-1870s Bayer was producing 100 tons of synthetic dyes annually, and German chemists were facing the next big synthetic-dye challenge, indigo blue.

It wasn't only a chemistry problem, but also a matter of getting adequate supplies of various substances, such as chlorine, caustic soda and sulphuric acid. It took 19 years of effort to solve the chlorine and sulphuric acid supply problem; the answer was to put table salt (sodium chloride)



into water and pass an electric current through the solution to split the salt crystals, thereby producing chlorine and caustic soda (a method of producing chlorine still in use among swimming pool owners).

While individual German chemists had made major contributions to their science over the previous century and more, the international lead that their country now took in producing synthetic dyes persuaded many more of them to research upgrading the gaseous by-products of coking ovens. That research produced a greater understanding of the various ways in which the two most valuable components of the gas, carbon and hydrogen, combined with each other and other substances such as oxygen and nitrogen to form different kinds of molecules, each of which had an industrial value. Over the



Studied informality characterised meetings of the Kaiser Wilhelm Institute for Coal Research

next 70 years, Germany led the world in this field, and it was from Germany that Sasol obtained the means of producing petrol, diesel, wax and other industrial chemicals from coal. It was called the Fischer-Tropsch process.



Franz Fischer



Hans Tropsch

Franz Fischer and Hans Tropsch were two chemists working at the Kaiser Wilhelm Institute for Coal Research in Mülheim, Ruhr. The Institute had been created in 1913, but the work on which Fischer and Tropsch were jointly engaged started producing results only in the 1920s. Their aim was to produce hydrocarbon molecules from which fuels and chemicals could be made, using coal-derived gas. (For the story of what atoms and molecules are, and the history of their discovery, turn to page 18).

That had, in fact, already been achieved, first in France and then in Germany. In 1902 Paul Sabatier and a colleague, using nickel and cobalt as reaction-speeding catalysts, succeeded in bringing together carbon monoxide (a compound formed from carbon and oxygen) and hydrogen under pressure to form

methane, the simplest combination of carbon and hydrogen. Ten years later he shared the Nobel Prize for Chemistry, largely because of his discovery of the catalytic power of nickel.



Friedrich Bergius

In 1914, Friedrich Bergius, a teacher at the Technische Hochschule in Hanover, built a 40-litre vessel into which he put coal that had been dissolved in recycled oil, then added hydrogen. His catalyst was iron oxide. With the vessel loaded with these three ingredients, he raised its internal temperature to well above 400°C and increased the internal pressure up to 700 atmospheres (where one atmosphere is equal to air pressure at sea level). The result was petrol, diesel and recycle oil – and, in 1931, a share of the Nobel Prize for Chemistry with Carl Bosch, who had worked on developing high-pressure vessels for the Bergius and other synthesis processes.

To build a vessel and control valves able to withstand such high pressure was, however, not easy. Fischer and Tropsch set out to devise a system that would build molecules out of hydrogen and carbon at considerably lower temperature and pressure. To achieve that required them to use a coal-derived gas rather than a heavy coal sludge and to keep the gas in contact with the catalyst for a relatively long time. So they built a reactor that contained hundreds of tubes, 10 or more metres long, and stuffed catalyst into them. Each end of the tubes was welded to a circular steel plate in which holes had been cut of the same diameter (50 millimetres) as the internal diameter of the tubes,

and each plate was welded on to the interior wall of a steel cylinder that acted as the shell of the reactor. There was enough space between the upper plate and the top of the cylinder to feed in gas, and enough below the lower plate to remove it. Water was fed into the cylinder



between the two plates to fill all the vacant space between them so that it could lower the temperature of the gas flowing down them to a level at which the desired reactions would take place. When the water became steam of too high a temperature to do its job, some of it was released through a valve and replaced with water.

Fischer and Tropsch were granted a patent on their process in 1925. Meantime, work continued on making the Bergius process more user-friendly. Both the Bergius and the Fischer-Tropsch methods were used on a considerable scale in Germany until the end of World War Two.

Because it used a higher temperature, the Bergius process produced hydrocarbon molecules of a size and shape suitable for motor and aviation fuel. The far lower temperature and pressure of the Fischer-Tropsch process produced molecules better suited to the manufacture of chemicals, detergents and wax.

During the 1920s and 1930s, English and American companies had shown interest in what German researchers were doing. The oil company Royal Dutch Shell helped finance Bergius' early work, and Standard Oil (New Jersey) also financed coal-to-gasoline research in Germany as well as in the US. In England during the 1930s, Imperial Chemical Industries used German technology to produce petrol from coal on a relatively modest scale. The interest of these companies was driven by a concern that oil reserves would soon prove insufficient to meet needs. When large new oil fields were found in Texas, Louisiana and the Middle East and the price of oil slumped, their interest in

acquiring oil far more expensively from coal evaporated. Such research as did continue after World War Two in the US never progressed from the laboratory stage to commercial production.

In South Africa there was far less complacency about obtaining reliable and affordable supplies of oil. Moreover, the country had large deposits of coal, much of which had limited commercial value because of its high ash content. If that coal could be used to produce synthetic oil, petrol and diesel fuel, it would have enormous benefits for South Africa. First, it would help further industrialise an economy that was still heavily

Having its own supply of oil would reduce South Africa's vulnerability to war and the interruptions it often brings to maritime trade

dependent on mining and agriculture. That would create more jobs for a fast-expanding population, and reduce the economy's exposure to the vagaries of the climate and international mineral markets. Second, it would reduce the import bill so that foreign exchange could be spent on plant and machinery that South Africa was not yet sophisticated enough to produce, but needed in order to grow its manufacturing capacity. Finally, having its own supply of oil would reduce South Africa's vulnerability to war and the interruptions it often brings to maritime trade.

That last point was brought home by World War Two, during which petrol had to be rationed in South Africa. But well before that war broke out in 1939, South African scientists had started

taking a close look at the possibilities of turning coal into oil. The first was a Dr PN Lategan, working for the Transvaal Coal Owners' Association in Johannesburg. In the early 1920s he wrote his doctoral thesis for the Imperial College of Science in London on The Low-Temperature Carbonisation of South African Coal. In the course of his research he visited Germany and, on his return home, tried to get some of the methods he had observed there to work. The next close investigation of the idea came from Dr F Meyer, working as technical adviser to the Department of Commerce and Industries. He wrote a White Paper for government in 1927, describing various oil-from-coal processes being used overseas and their potential for South Africa. Then in the 1930s, unreported by the press, a young student named Etienne Rousseau obtained his MSc degree from the oldest and most prestigious of the Afrikaans universities, Stellenbosch. Rousseau would become Sasol's first managing director. In retrospect, that could seem almost inevitable, for the subject of his master's thesis was The sulphur content of coals and oil shales, a highly relevant matter for anyone wanting to produce synthetic oil.

In the event, it was a private-sector mining company, Anglo-Transvaal Consolidated Investment Company (Anglovaal), that led the way in producing oil and petrol from coal. Actually, it wasn't coal that Anglovaal used, but torbanite, a shale-like mineral that, like coal, contains carbon and hydrogen. Heat it up in a large iron retort and, in the gas that is released, you will find hydrocarbon molecules of the size and shape suitable for motor fuels.

Anglovaal owned torbanite deposits east of Johannesburg, and from 1935 onwards exploited



The Satmar refinery near Johannesburg – before coal came shale

them to produce and sell motor fuel on a commercial scale under its own brand name, Satmar. While it was doing that, it also took a close look at producing oil from coal. To that end, it bought the right to use the Fischer-Tropsch process in South Africa, had Franz Fischer visit South Africa in 1937 and sent off to England and Germany samples of coal from the reserves it had bought close to its torbanite deposits, to see whether they would work in the Fischer-Tropsch process. It even had plant designs drawn and sent to engineering contractors in Britain and Europe.



Sasol's first oil – 1955

Then came World War Two.

Conducted at sea as well as on land and in the air, against merchant as well as naval vessels, it made the shipping of large steel plant from Europe to South Africa impossible. Anglovaal,

however, maintained its enthusiasm for using the Fischer-Tropsch process. One of its founders, "Slip" Menell, lived in New York during the war and during that time bought the South African rights to a method of using the Fischer-Tropsch process that had been patented by the M W Kellogg Corporation. The war ended in 1945, Anglovaal persuaded the government to create a fiscal environment in which it could profitably operate an oil-from-coal plant and in 1949 obtained an operating licence from it.

Soon after that, though, Anglovaal went cold on the idea. The South African pound was devalued in 1949, sending up the cost of imported plant and machinery – and large new gold deposits had been discovered south-west of Johannesburg in the Orange Free State, in an area where Anglovaal had earlier bought mining rights. Developing a new gold mine would consume all its capital resources, and foreign lending institutions such as America's Export-Import Bank wouldn't lend for any enterprise that did not have a loan-repayment guarantee from the borrower's government. The South African government refused to provide such a guarantee for a privately owned project. Meantime, gold, now that devaluation had raised its price in the local currency, promised to yield excellent returns.

It was clear that, if an oil-from-coal project was to get off the ground, it would be only with State-provided finance. Now it happened that in 1948 South Africa acquired a new government. Thanks to a redrawing of constituency boundaries, the incumbent United Party, though winning far more votes than the National Party, ended up with only 71 seats in Parliament against the National Party's 79. So out went a relatively liberal Cabinet headed by the 78-year-old Jan Smuts,

and in came a wholly Afrikaans cabinet, headed by Danie Malan, determined to bring about its vision for the country. That vision, which for better and for worse would be pursued with great vigour and self-confidence down the years, included a major role for the State in developing the economy.

In 1950 the government appointed a committee (Rousseau was one of its members) to investigate all aspects of producing oil from coal. The committee visited the US and Britain, and Rousseau went off alone to Germany. The upshot of these investigations was a recommendation from the committee that



Above: Sasol's first board of directors. Its members accepted a sobering challenge



Right: The Zevenfontein farm house served as Sasol's first offices

a State-owned company be formed to take over the Anglovaal venture. The plant, it recommended, should be based on the Fischer-Tropsch process, employing German reactors to produce diesel fuel, lubricants, chemicals and waxes, and the plant designed by the Kellogg Corporation to produce petrol.

Government accepted these recommendations. In September 1950, Sasol was formally incorporated as a State-owned company under the unwieldy name of the South African Coal, Oil and Gas Corporation. Its directors would be appointed either directly by the government or by the parastatal Industrial Development Corporation, through which the government would channel capital for the enterprise.

The decision to invest in an oil-from-coal project large enough to provide a meaningful degree of national self-sufficiency was extraordinarily bold. Devaluation had driven the initially estimated capital cost of £13,8 million to an eye-watering £20 million. The whole enterprise, moreover, would tax the capacity of South African project engineers as never before since it would be of an unprecedented scale. Huge items of plant would have to be fabricated overseas, shipped to South Africa, then transported over hundreds of kilometres of road to the site, south of Johannesburg, that had been chosen because of large coal reserves in the region and the nearby Vaal River, which would provide water for power generation, steam production and gas-cooling plant.

It would be no small matter, either, to accommodate the thousands of people needed to operate the plant and mine coal, and their families. To attract and retain the services at Sasolburg of highly educated and skilled people, properly built

houses, schools, shops, clinics and all the other amenities found in a well-developed community would have to be provided – and that in an environment made bleak and uncomfortable for much of the year by wind and dust.

What didn't seem to trouble Rousseau and his colleagues at the time was whether the plant would work. Yet the Kellogg reactors, which were to produce the most strategically important product, petrol, had never been built to anything approaching commercial scale. Similarly, the German coal gasifiers designed by Lurgi, while successful in Germany, would be built and operated on a far larger scale in South Africa. It could not, as design engineers well knew, be taken for granted that such a degree of scale-up would present no problems.

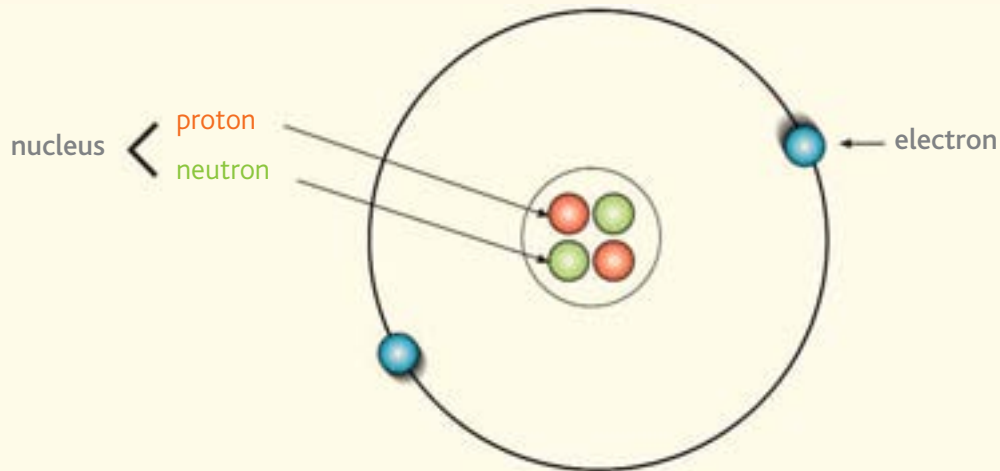
If none of this troubled Rousseau and his colleagues, it was because they were seized with a determination to make the enterprise succeed, and a conviction that whatever problems occurred could and would be solved. That determination is probably best explained by a greatly heightened, almost aggressive spirit of national independence that was promoted by the new government. In politics, it took South Africa down an increasingly lonely road as world disapproval of apartheid deepened. It also, however, demanded that South African industry develop its own skills and production capability, rather than rely on overseas experts and factories.

Industrialists responded enthusiastically; Sasol was not an isolated case of courageously taking on the unknown. What distinguished Sasol from other South African adventurers was that it set out to create an industry that existed nowhere else in the world. It would be a long and challenging haul.

Alchemy becomes chemistry

Today we know that matter is formed of atoms that combine to form molecules. We also know that nature provides 92 different elements, so called because they have been found to be the basic building blocks of matter. Among them are hydrogen, carbon, oxygen and nitrogen.

nevertheless consists of a nucleus surrounded by electrons moving around it in what some physicists have dubbed orbitals. These orbitals together cover an area that, relative to the size of the nucleus, is vast; think of a cricket ball in the middle of a cricket field.



Each element is composed of identical atoms, the composition of which is unique to that element. Too small to be seen even through the most powerful of microscopes, an atom

The most important component of the nucleus, chemically speaking, is the proton. There are as many of them in an atom as there are electrons and they are electrically attracted to



each other because electrons carry a negative charge, protons a positive one. But the protons in another atom (of the same or a different element) can attract the electrons moving furthest away from their own nucleus. That attraction binds atoms together to form a molecule. Dozens of atoms may end up joined together in this way to form a single molecule.

It took man a long time to gain that knowledge because mysticism, philosophy and religion got in the way and produced all sorts of offbeat ideas. There was, for example, the ancient Egyptian idea that the mysteries of man's existence were to be solved by astrology and numerology. That would eventually evolve into alchemy, but before that there were a couple of centuries of rational thinking in classical Greece, when a succession of Greek philosophers decided that the composition of matter could be broken down into earth, air, water and fire. "And don't forget love and hate," added the philosopher-poet Empedocles.

That wasn't a bad effort. Earth, air and water arguably represent matter's three phases, while fire represents energy, which we now know was vital for creating all the different elements out of the first and lightest of them, hydrogen. Love and hate could also be seen as a metaphor for electrical attraction and repulsion, which lie at the heart of chemistry.

Two of those ancient Greeks, Leucippos and his pupil, Democritos, had the insight to speculate that matter was composed of indivisible atoms, which they defined in terms that resemble the truth remarkably closely. It was, however, nothing more than an insight; they lacked the tools to prove it.

Unfortunately, Greek rationality was overtaken by the mumbo-jumbo of alchemy. Its inspiration was a belief that the Almighty intended the world and everything in it to evolve from the base to the pure: lead to gold, sickness to health, mortality to immortality. Achieving all of those depended on finding the



Sir Isaac Newton (1642 – 1727)

elixir or philosopher's stone, and some claimed to have done so. The prospect of being able to create gold kept many people hoping there was something in the claim. Among them were the famous 17th century English scientists, Robert Boyle and Sir Isaac Newton, both of whom were obsessed with religious speculation.

Alchemy was eventually recognised as a fraud, but it did produce one beneficial result. In trying to discover the elixir,



Among the many contenders for the title of "Father of Modern Chemistry" is Robert Boyle (January 25, 1627 – December 30, 1691)

alchemists developed some of chemistry's basic techniques, such as heating and distillation, and learned of many chemical reactions between different substances. These were observed and used by others who, dropping the Arabic prefix *al*, called themselves chemists and their area of scientific enquiry, chemistry.

They also developed their own methods for exploring the nature of matter. In 1643, for example, Evangelista Torricelli demonstrated that air has weight, and therefore exerts a



downwards pressure, by filling a tube with mercury and half-filling a bowl with it, too. Then, with the open end of the tube blocked by his thumb, he lowered that end of the tube into the mercury in the bowl and, holding the tube upright, removed his thumb. The mercury in the tube did not fully drain into the bowl but always left the same length of tube void of mercury because, he reasoned, of an unchanging pressure of air on the mercury in the bowl.

Meanwhile, though alchemists and others had been discovering dozens of new elements over the centuries, it remained to Boyle to point out that they were elements – substances, he explained, that could not be broken down into simpler substances, but could be joined together to form stable

compounds, the properties of which would depend on the number and nature of the elemental atoms they contained.



John Dalton

That is a simple statement of molecular theory. The problem for Boyle was that he could not be sure that something he thought was

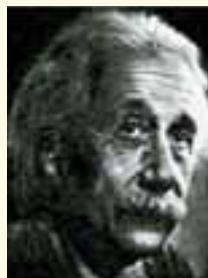


an element might not be broken down into other substances, should a technique for doing so be developed. Certainty would come only with the development of atomic theory.

Boyle published his theory on the elements in 1661, but it was not until the early 19th century that the English scientist John Dalton revived Democritus's idea of atoms, and devised a means for ascertaining their relative weights. Soon afterwards Count Amadeo Avogadro declared that atoms come together in what he dubbed molecules.

In England, Sir Humphry Davy said his laboratory experiments showed that what brought them together or separated them was to be explained by electricity (a concept that had produced the first battery in 1799). His assistant, Michael Faraday, later expanded on that observation: "The atoms in matter are in some way endowed or associated with electrical powers, to which they owe their most striking qualities, and amongst them their chemical affinity."

All of which, plus his own enormous amount of laboratory work, provided the Russian scientist Dimitri Mendeleyev in 1869 with enough data about the various physical properties and chemical behaviour of the 60-odd elements then known to divide them into a number of different categories and find the



Albert Einstein

same pattern of characteristics in each category. His analysis also enabled him to predict with remarkable success what the properties would be of as yet undiscovered elements, given each of their atomic weights.

It remained only for the French chemist, Henri-Louis Le Chatelier, to spell out in the 1880s why changes in heat and pressure would cause molecules to form and divide. His theory would obviously be of great importance to those, like Bergius, Fischer and Tropsch, trying to form molecules out of hydrogen and carbon.

Thereafter, world scientific interest was focused for several decades mainly on the nature of energy, how it existed and behaved within the atom, and the relationship between energy and matter (Einstein proved that each can change into the other). It was exciting for physicists and mathematicians, but unnecessarily rarefied stuff for those wanting to change coal into vehicle fuels and chemicals. They already had enough chemical understanding. The challenge now was to put it to work.

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Pillars, panels and probes

1950

Development of the Sigma coal mine at Sasolburg begins



1952

Sasol's first gasifier inches its way through Mozambique towards Sasolburg



Sasolburg's first gasifiers being built



1975

Coal-mine development is launched at Secunda



1991

Sigma mine's annual output reaches 7,4 million tons



1998

Sasol pioneers virtual-reality training of coal miners

Sasol's achievements begin with the efficient mining of coal; at Secunda it's on a massive scale.

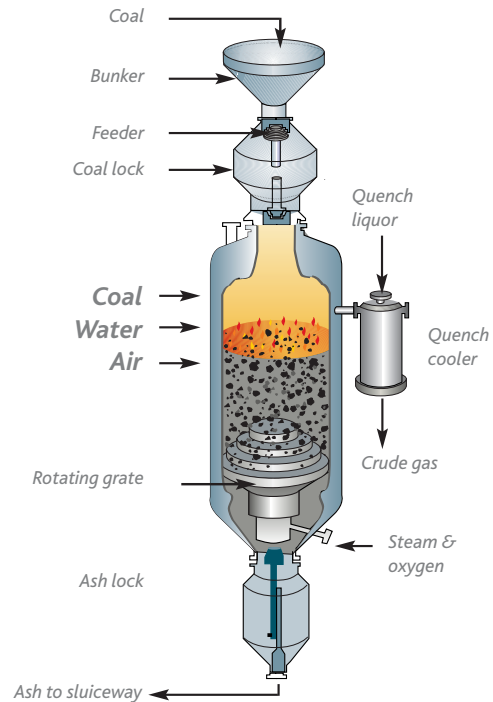


The challenge concerns not only quantity, however, but also the quality of coal needed by Sasol's huge battery of gasifiers. Explaining that requires a brief description of a gasifier – or, more accurately, of a certain kind of Lurgi gasifier.

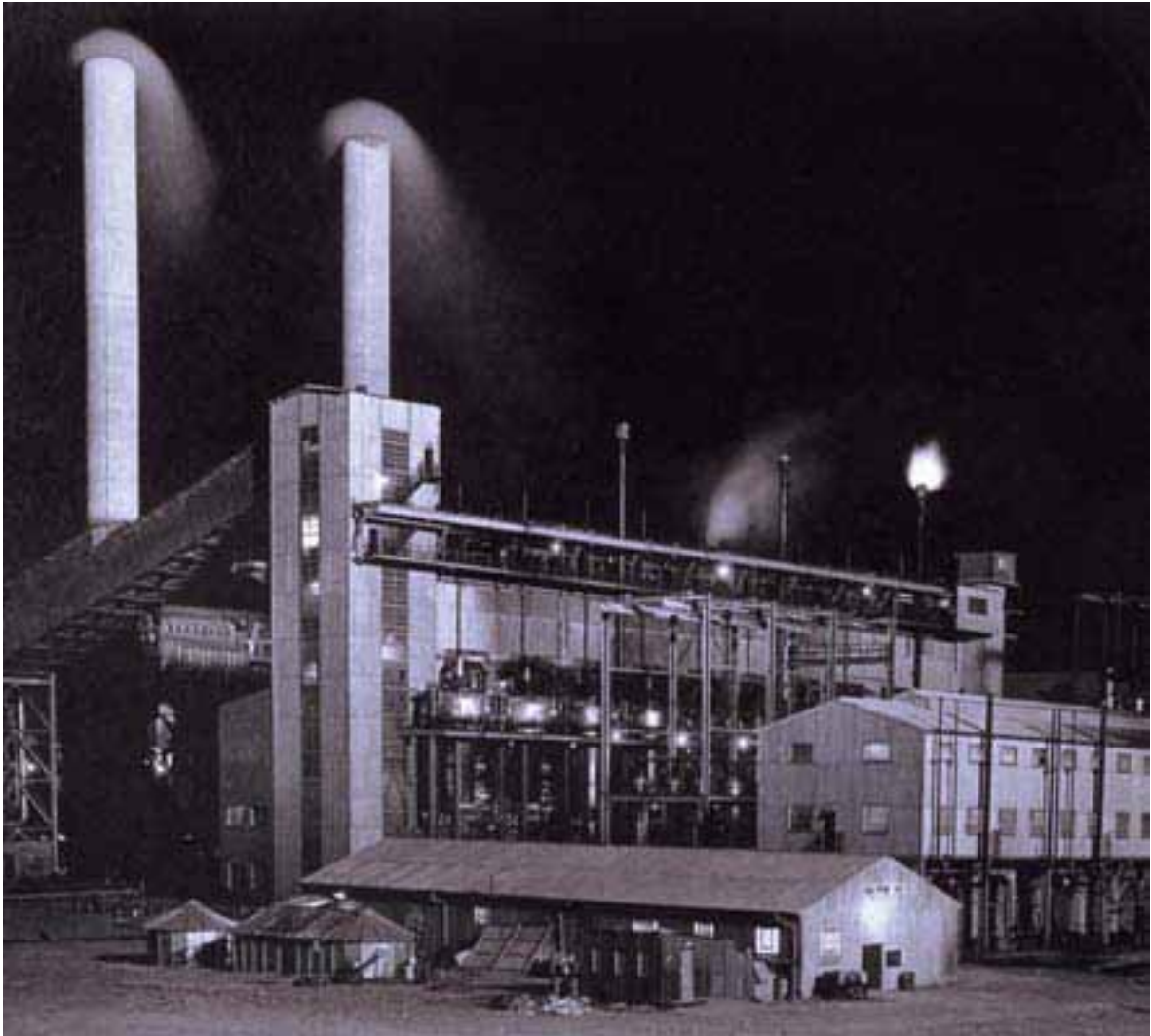
Though Sasol could have chosen from three different German gasifiers when it began planning its plant soon after 1950, it accepted a package deal from a joint venture (an Arbeitsgemeinschaft) between Ruhrchemie Aktiengesellschaft, which since 1932 had owned the rights to and developed the Fischer-Tropsch process, and Lurgi Gesellschaft für Wärmetechnik. The offer was for the designs and right to operate the Fischer-Tropsch fixed-tube reactor, with gas supplied by Lurgi-designed gasifiers. Sasol's people lost no time in dubbing the fixed-tube reactor Arge, derived from Arbeitsgemeinschaft.

A Lurgi gasifier is a colossal steel construction. Coal is fed into a compartment at its top (known as a coal lock) from a conveyor belt, eight or so tons at a time rather than continuously. Once loaded, the coal lock's lid is closed tight and a gas is fed into it before the bottom of the lock is opened to feed coal into the body of the gasifier. This strategy maintains the high pressure that has been built up by the next step: feeding high-pressure (and therefore high-temperature)

steam and oxygen into the gasifier to decompose the coal, producing what Sasol calls its raw synthesis gas, which is taken away to be cooled and further treated.



Above: Cross-section of gasifier Opposite: Sasol's first gasifiers



What's left behind is ash, accounting for close on one quarter of the 100 000 tons of coal that daily enter Secunda's 80 gasifiers. There it forms a support for the hot coal, known as the fire bed. Ash is removed from time to time, a mechanical process involving a rotating grate.

For Sasol to be economically competitive with crude oil, all stages of its operations, from coal mining onwards, must be run with great efficiency

To have all that happening in a reliable and stable fashion demands several things of the coal. First, it must come in lumps no smaller across than five millimetres and no larger than 100 millimetres. Smaller lumps, known as fines, could get carried upwards in the rising gas and would be a major hassle to remove. If they coalesced in the fire bed, they would create areas of greater resistance to the flow of gas, making operating conditions unstable. Lumps of coal larger than 100 millimetres are undesirable because they tend to roll towards the periphery of the gasifier, which also creates inconsistencies in the bed's overall resistance to gas flow. In short, particle-size distribution of the coal in the gasifier is important to the gasification process.

The quality of coal – for example, its ash and organic-matter content – can vary over a coalfield. That means the coal from the various mines within the coalfield must be carefully mixed to provide the gasifiers with an ongoing consistency of coal. Finally, stone is obviously of no value in the gasifiers, so must be kept out of them. If brought to the surface with the coal, it

could be separated out by using a coal-beneficiation technique such as dense-medium separation: coal is lighter than stone and would float in a liquid sufficiently dense to support it, but not stone. The volumes of coal mined daily at Secunda's mines are, however, so great as to render separation impracticable.

Sasol's miners must therefore be careful not to mine into the rock layers above and below the coal seam because this would contaminate the coal product with stone. In short, the demands on Sasol Mining's miners are great. But they are also onerous on those designing and operating the gasifiers. The making of fuel and other products from coal is a highly integrated process; without a steady and adequate supply of gas, all the plant downstream from the gasifiers would work below its capacity. To put it another way, though technical interest down the years has largely focused on the Fischer-Tropsch reactors, the gasifiers are the bedrock of the investment. Indeed, together with plant producing oxygen and steam for them and then the plant needed to purify the gas, they account for two-thirds of the capital cost of obtaining petrol and other products from coal. Companies producing petrol and lubricants from crude oil do not, of course, need to spend on coal mining, gasifiers, oxygen plants and so on, so their capital outlays are substantially lower. For Sasol to be economically competitive with crude oil, all stages of its operations, from coal mining onwards, must be run with great efficiency.

The usual approach to improving capital efficiency, building bigger plant to achieve economies of scale, has limited application when it comes to gasifiers because of the



mechanical engineering problems it encounters. True, the Lurgi gasifiers built for Sasol started out with a three-metre diameter and were later enlarged to four, and then five metres. The enormous improvement in gasification achieved over the decades was the result, however, not primarily of plant scale-up, but of scientists and engineers in half-a-dozen different disciplines collaborating in a spirit of experimentation and innovation that has characterised the whole range of Sasol's activities from its earliest days.

Down the years, many design changes were produced and incorporated into new gasifiers. For example, unlike the original units, the Mark Four gasifier – a four-metre-diameter model introduced in 1974 – operated without a central revolving shaft and its attendant water-cooling unit. Both had produced serious problems for maintenance engineers, but finding a way to do without them took thousands of hours of work by the engineers of Sasol and Lurgi, not to mention important inputs from operations and maintenance personnel. This multidisciplinary approach was also used eight years later when the Mark Five gasifier – five metres in diameter and, astonishingly, with almost twice the output of the Mark Four – was installed at Sasolburg. The advice of industrial engineers also saw design changes that shortened the shutdown process that precedes major plant maintenance, an important factor affecting the productivity of any industrial plant.

But it wasn't just what happened on the drawing board that advanced Sasol's gasification efficiency. Adopting experts' advice to change the materials of critically important components saw their useful life lengthened from weeks to months and even years. Coal scientists, too, modelled many of

the complex processes taking place in the gasifiers, which helped Sasol's chemical engineers to better understand coal's properties.

The most visible and dramatic improvement down the years, however, has been in how the gasifiers are controlled. In 1955 the first nine gasifiers were essentially hand-operated from 50-metre-long rooms at three levels along the side of the gasifiers. The addition of coal through the coal-lock hoppers was controlled manually, using large hydraulic devices. The flow of steam and oxygen into each gasifier was also controlled manually by turning wheels attached to large valves. Ash, too, was removed by manually operating a hydraulic unit at the base of each gasifier.

Today's gasifiers are automatically controlled by controllers and computers that require a minimum of manual intervention



The coal-supply control room at Secunda

even during times of upsets. Which means that each set of 40 gasifiers at Secunda, though producing 15 times as much gas as Sasolburg's initial nine gasifiers, employs far fewer people working in a control centre.

This process of steady improvement, which from the mid-1970s saw Sasol become a co-licensor of the Lurgi gasifier, did not go unnoticed elsewhere in the world. At that time, for example, a company in North Dakota in the US appointed Sasol as a consultant for its project to gasify lignite, a soft material derived, like coal, from plant growth and known as brown coal. About 30 000 tons of lignite were sent to South Africa from North Dakota for testing in one of Sasol's gasifiers, and to generate the right design parameters for a plant to gasify it. The plant was eventually built and commissioned with Sasol's help. By 1982 the North Dakota operation was operating 12 Lurgi gasifiers, and Lurgi was designing and building gasifiers for China, which also has large coal reserves that can be cheaply mined. In recent years, enquiries about coal gasification, with a view to producing oil from coal, have come from India, Pakistan, China, Indonesia and the US. Whether any of them will lead to Sasol-like industries remains to be seen, but it may be significant that Lurgi faces competition from several other gasifier designs. They seem, however, unable to match it for reliability.

Let us return, then, to coal mining and the particular challenges faced by Sasol Mining.

Initial annual output at Sigma, the underground mine at Sasolburg, was 2 million tons. To meet steadily expanding demand from an increasing number of above-ground plants,

coal production eventually peaked in 1991 at 7,4 million tons, leading to exhaustion of those particular underground reserves (a surface mine continues to operate) and future reliance on natural gas, piped in from Mozambique. Today, Sasol Mining extracts close on 50 million tons of coal annually, and more than 90 per cent of it comes from Secunda's four underground mines and one surface mine. The underground operations together comprise the world's largest single underground coal-mining complex.

Development in mining techniques has been no less dramatic. The traditional way of mining coal, which still prevailed in southern Africa at the middle of the 20th century, was to drill holes in the coal, using hand-held drills; pack them with explosives; detonate the charges to blast the coal; remove the



Headgear and other surface facilities at Sigma mine

coal from the face of the seam by pick-axe; manually load coal hoppers with lumps of coal; then push the hoppers along rails in the working section before attaching them to an endless-rope haulage system. This linked to an 18-degree incline shaft to the surface. Timber supports were used to hold up the roof of mined-out areas.

All of this was conducted by the light of nothing more than a small battery-powered lamp mounted on each miner's helmet. Miners walked, or rode a bicycle within the mine, to their place of work. There they faced several dangers. Methane gas, seeping from coal, could be ignited by a spark from a pick-axe or steel wheel, causing a fatal explosion. The roof of a recently mined area could collapse without warning, burying those in the vicinity.

Today, Sasol Mining extracts close on 50 million tons of coal annually

Innovations were introduced to reduce these dangers and generally improve working conditions. Electric lights were used to illuminate the incline shaft and access roadways. Rail-bound coal hoppers were replaced by pneumatic-tyred shuttle cars. Endless-rope haulage systems were superseded by conveyor systems. Blasting and pick-axes were replaced by large machines called continuous miners. Timber supports were replaced by steel bolts that penetrated a metre and more into the roof, and then were placed under tension to prevent the various layers of rock and shale from parting from each other, and therefore from collapsing.

BLADSY TWEE SASOL-NUUS, MEI 1954

Inauguration At Sigma

The setting in motion of the first section of the Sasol works — the Sigma Colliery conveyor belt from underground to the surface — was the occasion for a happy ceremony on the 8th April at the mine.

Everyone present smiled and sighed with relief that after all those months of hard work — brief, in comparison to similar development work on other coal mines — coal was at last being transported to the surface by belt.

The ceremony was marked also by the presence of all Sasol's directors who on this occasion

watched fascinated as the coal started its upward journey on the approximately 1,600 ft. conveyor belt.

A team of native miners then took over and shovelled with zest and energy. In a very short while they had the belt covered with one continuous stream of coal.

This shovelling is a temporary measure only. Later on — as soon as the mining machines have gone underground — coal will be fed on to the conveyor belt by means of the mechanical loaders.

The coal will for the present



Mr. Frans du Toit shovelling the first coal on the Sigma conveyor belt. Behind him are, left to right: Mr. Bill Watson, Mr. J. C. McIntyre, Dr. M. S. L. Dr. H. J. van Eck and Mr. O. L. Papendorff.

donned mining togs and went accompanied by the special stock pile equipment at the pithead surface crusher station and the conveyor belt are



Another world first – a curved underground conveyor at the Middelbult Colliery at Secunda

All of these improvements were used when the Sigma mine was developed in the early 1950s, except for electric illumination of incline shaft and roadways, which was installed only in the mid-1960s. Over the next decade the mine established production, productivity and safety records, and regularly broke them. When the challenge came in the mid-1970s to mine coal on a far larger scale at Secunda, and to achieve that level of output in what many would have thought an absurdly short space of time, Sasol was well prepared and took on the challenge with enormous enthusiasm. It had the know-how – and it knew the problems of mining South African coal, especially in the region that geologically encompasses both Sasolburg and Secunda.

Sasol had bought extensive coal-mining rights in the region that became Secunda; they fall within an area, running from north-east to south-west, that measures 70 kilometres north to south, and 20 kilometres east to west. Now the rush was on to ascertain what they were worth in terms of mineable coal reserves. That meant drilling thousands of vertical holes, and studying the material brought up by the drills. On that evidence depended which areas would first be mined, and therefore where the factory for producing petrol from coal should be sited to minimise coal-transportation costs.

By that time, Sasol had committed itself to huge expenditure for acquiring coal rights, for planning and building a town, and for having the factory built. No one, however, knew whether Secunda's coal would be suitable for gasification. Tests conducted on the small amount of coal available from core samples indicated it was not. With their hearts in their mouths, senior coal managers asked neighbouring collieries to provide

them with 100 tons of what seemed similar coal so that more credible testing could be carried out. The results produced huge sighs of relief.

With that concern out of the way, mine development could begin. Development of the first began in November 1975, the second in June 1976. At that stage, annual demand for coal at Secunda was forecast at 12-million tons. When it was decided in 1979 to replicate the factory,



Above: Pieter Cox (second from left) holds the very first chunk of coal from Secunda coal mines. The others are (from left) Gert Bezuidenhout, Toelie Vorster and Andrew Greeff



Left: Groundbreaking for the Secunda mining complex

that demand shot up to 27-million tons, and development of two more mines had to begin. As debottlenecking of the new plant proceeded during the early 1980s, demand for coal further increased; by the end of 1983 it was 29-million tons – a world record for speed of mine development. The level of output continued to rise, but not at the cost of declining productivity.

During the second half of the 1980s and the early 1990s, productivity of both men and machines increased by 30 per cent and 40 per cent respectively.

What made that achievement even more remarkable was that an enormous training programme had to be mounted to man the Secunda mines at the various skill levels. The Sigma mine at Sasolburg had been run too efficiently to have spare artisans and managers to send to Secunda. Nor, with the industrial and coal-mining sectors of the economy booming in



the 1970s, could they affordably be enticed away from other companies. Yet 2 400 of them were needed. A further 7 000 men were needed for training at lower levels, including the operation of sophisticated and hugely powerful continuous miners, without which Secunda could not hope to meet any of its production targets. By 1984, over R17 million had been spent on training at the Secunda mines.

The primary mining method was long-wall mining – a capital-intensive and highly productive method. Seven long-wall faces were eventually in operation before the full extent of dolerite intrusions into the coal seams could be ascertained. But more of that later.

Meanwhile, the continuous miners had needed major upgrading to cope with South African coal mining conditions at an acceptable cost. South African coal cuts harder, as miners put it, than northern-hemisphere coal because it contains more stone, and the reason for that is that much silt and grit was washed into the Karoo basin – one of South Africa's major geological features – by rivers. By contrast, northern hemisphere coal contains less inorganic material.

That difference in coal-cutting qualities would play havoc with Sasol's continuous miners at Secunda, where the coal cuts even harder than Sigma's. With its production capability wholly dependent on the continuous miners – more than five dozen would eventually be at work simultaneously on Secunda's four underground mines – Sasol Mining decided it could not rely on

the continuous miner's manufacturers to solve the problem, but must itself find the answers.

A continuous miner is a large machine, operated by one man. Imagine a rotating drum more than six metres long and not far off a metre in diameter. Around it is wound, in spiral fashion, a band of steel on which are mounted dozens of sturdy steel picks broadly resembling a bull's horns, though the picks are straight. The drum is held horizontally between the continuous miner's two steel arms, which can be raised and lowered. As it turns, the drum is pressed against the wall of the coal seam, which may be three or more metres high. The picks bite into the coal, chewing away to a depth of about 80 centimetres while the drum is

The continuous miner had to have an electric motor more powerful than any the manufacturers had yet designed

lowered down the coal face until its picks meet the floor. Disturbed coal falls on to a steel plate attached to the miner, where it is swept backwards by two mechanically controlled arms to a container at the rear of the miner. From there it is offloaded into another vehicle which takes it away to be loaded on to a conveyor belt for removal to the surface.

These continuous miners were initially designed for northern-hemisphere coal. At Secunda a set of picks would last for only 10 tons of coal compared with 100 tons in the US. Removing the coal from the seam at an economically acceptable pick wear-rate was, however, not the only challenge. The continuous

Opposite: A continuous miner at work in Secunda. Sasol's engineers had to overcome major challenges presented by South Africa's geological conditions

miner had to have an electric motor more powerful than any the manufacturers had yet designed, so that sufficient pressure could be applied to the coal through the picks. A far more powerful motor would, however, require redesigning the entire structure of the continuous miner so that it could withstand that greater pressure; an insufficiently robust machine would suffer a high rate of wear and tear, and spend too much time away from the coalface undergoing maintenance. Finally, the coal had to be cut in such a way as to avoid reducing it to the fines that are, remember, not acceptable for gasification.

These were not easy problems to solve. Trebling the voltage of the motors increased the risk of sparks igniting coal dust, so additional flameproofing had to be designed by the manufacturers. A major achievement of Sasol Mining's research and development (R&D) division was to reduce pick wear-rate and avoid producing fines by redesigning the drum and the picks, and how the picks are spaced on, and attached to, the drum. Design changes also produced a more robust machine. Finally, using a visible laser beam and an on-board programmed computer – a technique pioneered by Sasol at Secunda – the drum's elevation is controlled so as to avoid cutting into the rock above and below the seam, thereby minimising the amount of stone mixed with the mined coal.

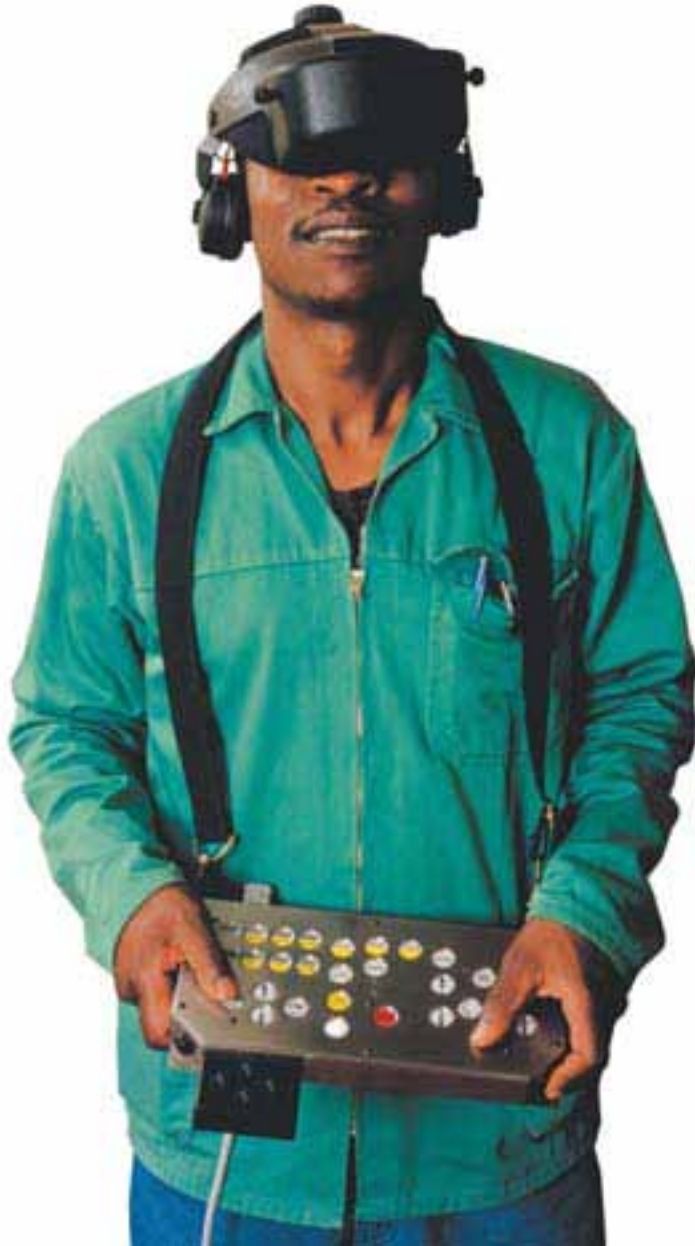
The continuous miner has, in short, been developed into a highly sophisticated, powerful machine needing a highly trained operator. But how to inculcate the required skills? You can't keep one of these behemoths as a spare, along with a couple of square kilometres of coal seam and – whoops! Let's try that up and down movement again, and this time try not to take half a metre of roof with you . . . please.

Airlines encounter essentially the same problem when training pilots. Their solution is to use virtual-reality technology in flight simulators. In 1998 Sasol Mining pioneered virtual reality's use in coal mining, specifically for the training of continuous-miner operators. While flight simulators are a mock-up of a flight deck, with a virtual-reality runway seen through the window, Sasol Mining's operators-in-training wear a head-mounted display screen and a pair of headphones, while carrying a replica of the multi-switch control panel connected to every continuous miner.

The screen is the equivalent of the flight simulator's window. The trainee sees three-dimensionally the cutting drum, the red laser beam, and the coalface as if all were truly before him. If he raises his head to look up, there is the roof; so, too, the floor. Whatever he does with the controls will, fed through an inexpensive personal computer (PC), affect what he sees and hears happening, and what the system reports to be happening: whether he is cutting into the roof or the floor – sparks fly when that happens, as they would underground – or cutting too deeply into the seam.

Virtual-reality training takes place alongside a trainer who can see, on a large screen, what the trainee sees. The trainer can, through his PC, change the situation facing the trainee, switching from one real-life mining scenario to another. In that way, operating experience is built up and, through repetition, weak areas overcome.

Opposite: Sasol developed virtual-reality training specifically for continuous-miner operators

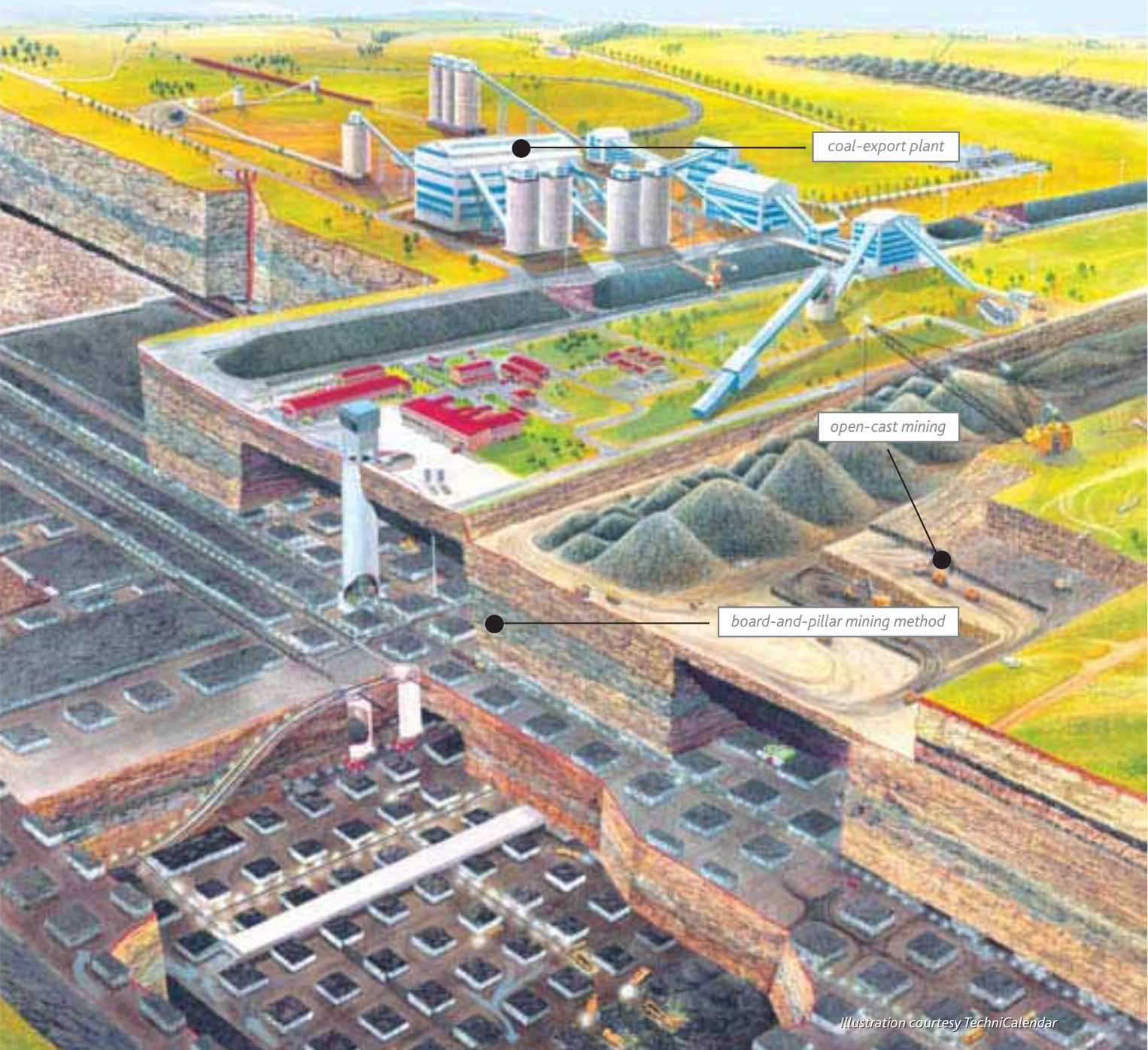


Sasol's other major technical achievement in coal mining addresses the problem of dolerite intrusions in the coal seam

It's a brilliant example of virtual reality programming, produced by a Pretoria-based company, Fifth Dimension Technologies, in collaboration with Sasol Mining. They are, unsurprisingly, looking to market it internationally.

Sasol's other major technical achievement in coal mining addresses the problem of dolerite intrusions in the coal seam. Dolerite is a very hard rock, found in coalfields and elsewhere because it was pumped there by volcanic activity. It began as magma, rock deep within the earth that was kept molten by the vast heat there. When fissures or rifts developed in the earth's crust, the magma rose through them and solidified to form dolerite deposits. Those that are mostly horizontal are known as sills, while vertical or near-vertical intrusions are called dykes. Sills can change their elevation and cut through a coal seam, displacing its horizontal plane so that the coal seam is higher on one side of the sill than on the other. Both sills and dykes are undesirable from a coal-mining point of view because, where they cut through the coal seam, they interrupt, or even terminate, mining activity.

Dolerite had been encountered at Sigma, but not often enough to be regarded as a problem. How much of it would be found at Secunda remained to be seen. Some dolerite is magnetic, which means it can be detected by magnetic survey equipment



coal-export plant

open-cast mining

board-and-pillar mining method

Opposite: The board-and-pillar mining method. Using explosives or a continuous miner, coal is mined in a criss-cross pattern of tunnels, leaving rock pillars to support the roof. Also shown is an open-cast mine and a coal-export plant.

carried in a light aircraft. Thin dolerites, however, will not be detected, though they can be troublesome enough to spoil mining economics. So aerial survey can provide only a broad impression of the presence of dolerite.

Further information will come from sinking vertical boreholes. The chances of their missing dykes, however, are considerable. And that is what happened at Secunda. The underground mines were located on the basis of information from aerial survey and vertical drilling of only one borehole per 37 hectares. Shafts were sunk and more boreholes drilled, increasing the density to one hole per 22 hectares, to help planners decide how to develop various mining sections. When the work of development got under way, these exploration techniques were shown to be inadequate for locating and sizing the number of dykes present in the area; the boreholes had missed most of them, and still missed some when the density of boreholes was increased to one every 13 hectares.

It was an alarming realisation because of the great pressure on the mines to feed sufficient coal at the lowest possible cost to the two huge oil-from-coal factories, one almost completed, construction of the other about to begin. Having to blast through dolerite to create roadways would be bad enough. To encounter it once a long-wall panel was being mined would be disastrous.

There are two basic methods of mining a coal seam. You can either remove all of it within a given area of the seam through

long-wall mining, and have the roof of the mined-out area eventually collapse. Or you can, using explosives or a continuous miner, develop a criss-cross pattern of tunnels through the coal in that area, leaving behind large pillars to

Sasol was the first company in the world to develop in-seam horizontal drilling into an effective exploration tool



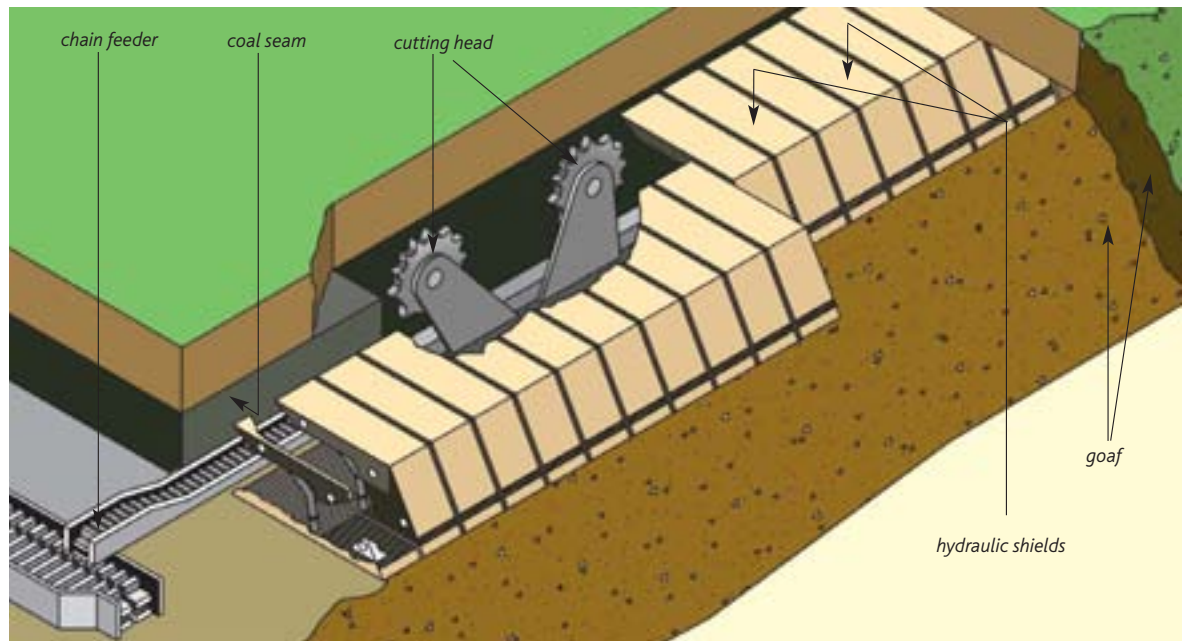
Sasol experimented with long-wall mining methods from 1967 to 1980. Shown here are hydraulic shield supports in a long-wall section

hold up the roof: the board-and-pillar method. If your only consideration is to get as long a life as possible from your coal reserves, you will choose the long-wall method.

Sasol had experience of both methods by the time it began planning the Secunda mines. It used only the board-and-pillar method when it began mining at Sigma in 1954, but launched an experimental long-wall unit there in 1967. One of its aims was to see how well available long-wall mining equipment would cope. The unit ran for close on three years, producing

645 000 tons of coal during that time. In 1975 long-wall mining was re-established at Sigma – a single unit that worked for the next 15 years, moving from one suitable part of the mine to the next. Though it encountered a few problems, it also established world production records for the technique.

It was decided to use both pillar-support and total-extraction methods at Secunda. When it came to long-wall mining, however, the major question was: where's the dolerite? Getting a correct answer was imperative because



A graphic representation of the long-wall mining process

setting up a long-wall mining operation is expensive, as the following description makes clear.

Continuous miners are used to cut two parallel tunnels, 200 metres apart and known as gate roads. Then a third tunnel is cut at the end of one roadway to join it to the other, thus forming a rectangular panel. It is in the third roadway that coal cutting takes place. It is done by a shearer, a hugely powerful machine with two rotating cutting drums that, facing the direction from which the roads have been driven, bite into the coalface then move sideways along it – along with the machine on which they are mounted – moving up and down as they do so. As the coal is removed from the face, it falls on to a conveyor, located just behind the cutting drums, and is transported to the gate road. On the other side of the conveyor are the operators, the roof above them held up by hydraulic supports. As the long-wall face advances along the panel, so do the hydraulic supports, leaving the roof behind it unsupported (miners call this area 'goaf'). Eventually that part of the roof will collapse.

The area encompassed by the three roadways is known as a panel. Because of the expense of equipping and installing a long-wall section, it is regarded as uneconomic for the panel to be less than about two kilometres long. What that means is that there must be no doleritic intrusion that will prevent long-wall mining from continuing. If one were to be encountered in board-and-pillar mining, the continuous miner could be withdrawn to a safe distance and explosives used to smash the dolerite. That is, of course, not possible with the complex installation required for long-wall mining.

How, then, to know more reliably than perpendicular drilling allows whether a proposed panel contains any dolerite dykes? From the late 1970s, Sasol began using horizontal in-seam drilling. As its name indicates, a hole is drilled horizontally into the seam for more than one kilometre ahead of present working. In fact, several holes might be drilled, each going off in a different direction so that the panel is more thoroughly explored.

The presence of dolerite is felt by a different level of resistance to the drill bit. The latter is a sophisticated piece of equipment developed by Sasol. Not only can it cut through dolerite; the cuttings it sends back show the thickness of the dyke. The cutter also provides information about the vertical positioning of the coal seam on the other side of the dolerite – that is, about how much vertical displacement has taken place. Sasol was the first company in the world to develop in-seam horizontal drilling into an effective exploration tool.

It was, of course, of no help in establishing where to locate new mines; and that, given the speed at which coal seams are mined these days, is a question that looms up with surprising rapidity. A mine is basically a set of shafts for transporting men, materials, machines, air, water and coal. There is a limit to the distance from the shafts that coal can be economically mined. When it is reached, a new set of shafts has to be created elsewhere. But – given the need to avoid dolerite – where?

Early in 1991 Sasol Mining's geologists turned to a concept that had been pioneered by oil companies. It employs a drilling rig that bores a hole from the surface in a sloping

direction, then levels out the direction of the hole, as drilling continues, until it becomes a horizontal one. Could it prove useful for coal mining?

Sasol Mining's experts worked on it for years. Eventually they designed a drilling system that would cost R9 million to build and equip. Given the millions of rands wasted by a single case of mining interrupted by dolerite intrusion and the high cost of vertical and horizontal in-seam drilling, all of which promised to be avoided or greatly reduced by the new drilling system, the latter looked likely to pay for itself several times over within a few years. The first drilling rig went into action in late 1997. It proved so successful that Sasol Mining ordered another.

The most important feature of the system is that the direction in which the drilling bit travels can be closely controlled in any direction – up, down, left, right – by the operator in his cabin on the surface. That is why it is called directional drilling. It is achieved by having a slight, adjustable bend in the motor located immediately behind the drilling bit attached to it. The angle of the bend can be changed by the operator while drilling proceeds.

The drilling bit and its associated equipment are mounted at the end of a flexible steel tube, known as a drill string, made up of 10-metre rods screwed together in an automated process by the rig alongside the operator's

cabin. Pressure is applied to the ever-lengthening string to keep the drilling bit in sufficient contact with the material ahead of it – no small challenge since the string can end up two kilometres long.

Directional drilling provides information on how far devolatilisation has occurred on either side of the dyke

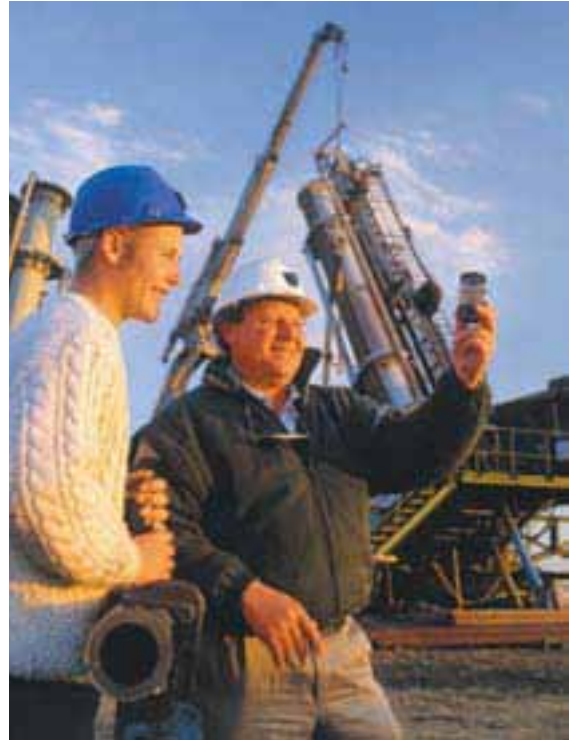
A water-based drilling fluid is constantly fed down the string to the motor where the survey instrumentation is located. The instrumentation sends information, in the form of encoded pulses, back through the liquid to the operator's computer, which decodes it.

The flexibility of the system allows the rig to be put at the centre of 1 000 hectares and, in six months of non-stop drilling, to complete a computer-controlled programme that should locate nearly all dolerite intrusions in the coal seam being explored.

Where greater resistance to the drilling bit indicates dolerite has been encountered, the string is withdrawn sufficiently for more holes to be drilled as branches curving in different directions from the first. It's rather like running your hands over an unfamiliar piece of furniture or a sculpture in pitch darkness, trying to make out its features. The information provided by those



Drill bit used for directional drilling



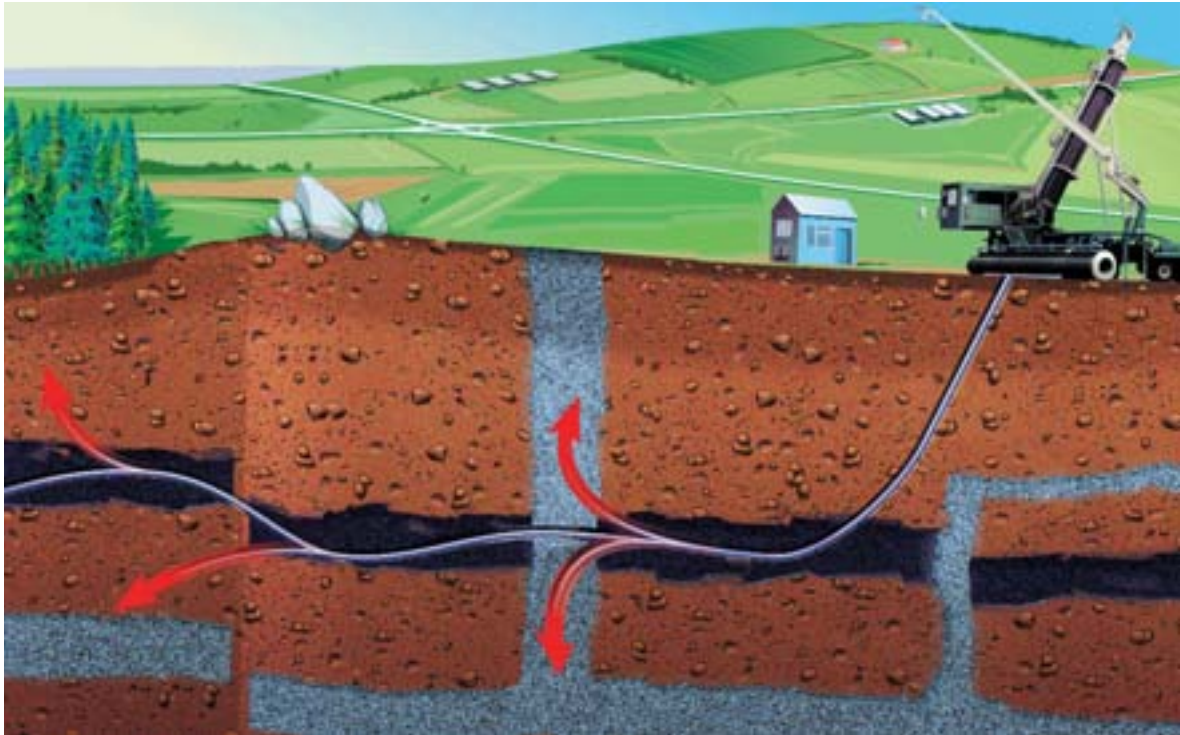
Directional drilling allows for the intensive exploration of 1 000 hectares from a single point in six months

additional holes indicates the strike (horizontal direction) of the dolerite. Further drilling will establish how much displacement of the seam has been caused by the dolerite, and how close to the dolerite it will be safe to mine.

When molten rock explodes upwards through a seam of coal, its heat devolatilises it to a variable distance on either side,

rendering the coal useless for Sasol's purpose. The immediate concern about devolatilisation, however, is that the roof above mined devolatilised coal is unstable, even with bolting, and therefore unsafe – another reason for not mining it.

Directional drilling provides information on how far devolatilisation has occurred on either side of the dyke.



The drilling bit is redirected upwards, downwards, to the left or right by the operator in his surface cabin by increasing or decreasing rotor speed

By the end of 2000, Sasol Mining's three directional drilling rigs had between them bored more than 200 kilometres. The data they provided led to optimal siting of two future mine shafts. It also had Sasol Mining wondering whether such drilling couldn't be used to drain methane from coal, thereby reducing the risk of underground explosions, as well as providing a marketable commodity.

That thought led to other ideas for exploiting the technology in non-coal activities. Diamonds, for example, were formed thousands of millions of years ago from carbon under vast temperature and pressure deep within the earth. They were later brought to the earth's surface by volcanic eruptions that formed rocky kimberlite pipes. Could directional drilling not be used to measure the diameter and cross-sectional shape of

those pipes, and what they contain, at different depths? And what about drilling pilot holes for those boring tunnels and shafts? Or drilling holes under built-up areas, highways and rivers to facilitate the installation of new services?

Sasol's enthusiasm for its newest technology has not met with indifference abroad. Interest has been shown by organisations in Australia – where fairly recent safety legislation requires the draining of methane from coal seams before mining begins – as well as in eastern Europe and China.

"We constantly pushed the boundaries. We set the pace"

In short, coal mining at Sasol has, from the earliest days, been characterised by innovation. It had to be if the factory was to receive the amount of coal it needed at a price that would enable it to compete with crude oil refiners. Imagination was directed at acquiring sufficient geological information to produce optimal mine layouts; at developing machines that would be able to cope with what could be the toughest coal-mining conditions in the world; and at creating training and incentive schemes that would enable and encourage miners to give of their best.

Sasol's present chief executive, Pieter Cox, began his career with the group at the Sigma mine and played a major role in developing the Secunda mines. "In all aspects, we constantly pushed the boundaries," he says with evident satisfaction. "We set the pace."



Sasol's Secunda collieries together comprise the world's largest underground coal-mining complex

Chapter 03 Pages 44 – 55 ►

Finally, it was courage

Fuels and chemical feedstocks were first produced by high-temperature Kellogg reactors...



...while low-temperature reactors produced wax



The Kellogg concept was eventually replaced by Sasol's own high-temperature reactors, the tops of which appear on the left

The checkered flag symbol was introduced in 1956, capturing Sasol's winning spirit

Petrol, diesel, wax and many industrial chemicals are all made from the two elements, carbon and hydrogen.

Many people find that difficult to believe because they think of carbon as a solid, in the form of charcoal or coke, and of hydrogen as a gas. How on earth can they be combined to form a liquid, let alone plastics?

The answer is that if you take, say, one atom of carbon and form it into a molecule with four hydrogen atoms, you will have a gas. Go through the same procedure, producing molecules that each contain rather more atoms of carbon and hydrogen – say 14 carbon atoms – and you will have a liquid. And how do you go about forming such molecules? Why, you feed your carbon and hydrogen atoms into a huge plant called a reactor, along with a granular, metallic catalyst serving as marriage broker, apply heat and pressure and wait for the union to take place. It will do so in the form of a gas comprised of molecules of all sorts of shapes and sizes. All you have to do after that is sort them out, for most of them have commercial value. The first step is to cool the gas so that larger molecules will form liquids which can easily be separated from those that form gases.

It sounds easy, but it isn't. Sasol's achievement down the decades has been to overcome major mechanical and chemical engineering problems so thoroughly and cost-effectively that, even when the price of crude oil sinks to low levels, coal can still compete with it as a feedstock for motor fuels and chemicals.

The process begins, chemically, with the raw synthesis gas produced by the gasifiers. It contains carbon and hydrogen atoms, but also other chemical ingredients which Sasol wouldn't want in its reactors: sulphur, ammonia, carbon dioxide, phenol. These are removed in successive stages by two processes: the one, devised by Lurgi the gasifier manufacturer, is called Rectisol; the other, known as Sulfolin, was jointly designed by Sasol and the German company Linde, which also provided Sasol's first oxygen-producing plant in Sasolburg. Sasol was the first company in the world to use both processes on a commercial scale.

Below: Rectisol gas-purification columns



The purified synthesis gas, as it is known, is fed into a reactor. Sasol began its operations using two types of reactor. The one, initially known as the Kellogg reactor but subsequently renamed Synthol, employs higher temperature than the other, known as the Arge reactor. Both, however, employ catalyst based on iron oxide. More about these remarkable things called catalysts later; for the moment, let's stay with the reactors.

Carbon atoms are friendly creatures, never happier than when sharing their electrons with four other atoms

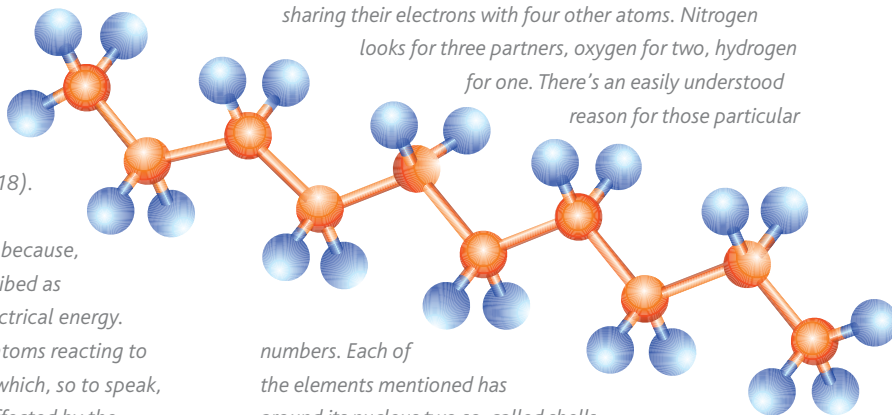
Why, first, do there have to be two different kinds, using different levels of temperature?

Think back to what an atom is (see page 18). Even without the fact that it's vanishingly small, it's difficult to think of it as matter because, although electrons and protons are described as particles, they are defined in terms of electrical energy. Indeed, chemical reaction is a matter of atoms reacting to each other's energy fields, the agents of which, so to speak, are electrons. And that reaction will be affected by the temperature and pressure of the environment in which it happens.

But what does reaction mean in practice? Quite simply, it is the acquisition by an atom of one or more electrons from another

atom. That acquisition may be friendly or hostile. In the latter case, an atom kidnaps one of the outermost electrons of another atom. That means that both of them are no longer electrically neutral (have equal numbers of electrons and protons). The kidnapper will become a negatively charged ion (because, remember, electrons carry a negative charge), the loser a positively charged ion (because protons carry a positive charge). Or, more happily, a partnership can take place: the atoms can share some of their outermost electrons. That partnership joins them together to form a molecule. If the two atoms are of different elements, the molecule is known as a compound.

Carbon atoms are friendly creatures, never happier than when sharing their electrons with four other atoms. Nitrogen looks for three partners, oxygen for two, hydrogen for one. There's an easily understood reason for those particular



numbers. Each of the elements mentioned has around its nucleus two so-called shells.

These are electric fields made up of orbitals. Think of the latter as orbits, each of them representing a pathway in which an electron can travel. One shell lies close to the nucleus, the other further away. The inner shell contains two orbitals, the outer shell eight.

That doesn't mean every orbital is occupied by an electron, but atomic happiness requires that at least the outer shell's should be. That's why carbon is always on the lookout for four electrons; it has only four electrons in its outer shell, which it is only too ready to share with other electron-needy atoms if only they will share sufficient electrons with it to fill up those four vacant orbitals.

By the same token, nitrogen has five electrons in its outer shell, oxygen six. Hydrogen has only one electron and thus only an inner shell which needs two occupied orbitals to be complete. That's why hydrogen is referred to as diatomic. In the absence of any other element, it will bond with itself, each atom sharing its one and only electron with the other.

Imagine the huge molecules that can be built up out of those four elements because of their bonding needs. It's that possibility, based on carbon's power to bond with itself and other elements, that has made life possible on earth, which is why chemistry based on carbon is called organic chemistry.

But, of course, molecular formation will take place only if the atoms are close to each other. That's where high pressure comes in; it forces the atoms in a gas together. Conversely, heat will, above a certain temperature, disincline them to remain linked together in a molecule – just like two people in bed on a hot night. Large molecules will tend to break up into smaller ones; if the temperature is sufficiently high you will have the most basic of hydrocarbon molecules, methane, which consists of one atom of carbon and four of hydrogen and, in that molecular form, is useless for producing gasoline and other petrochemicals. The art of producing molecules from carbon

and hydrogen of the kind needed to produce petrol or, say, wax therefore depends – but not solely – on using the right combination of temperature and pressure.

Synthetic oil, however, needs a quite different combination from wax. The molecules which end up as oil are smaller than those contained in wax. To produce oil, therefore, you use a higher temperature than when producing wax. The higher temperature breaks down larger molecules at the same time as smaller ones are being formed, so you end up with molecules that are either of the right size and shape for oil, or can be joined together to achieve that size. To produce wax you use only sufficient temperature to encourage the atoms to combine into molecules; no molecular break-down occurs.

Sasol's executives decided right at the beginning that the operation would use the German fixed-tube plant (described in chapter one) to produce the larger hydrocarbon molecules, and an altogether different-looking reactor that had been designed by the American company, M W Kellogg, to produce smaller molecules. Both would be fed with purified synthesis gas containing only hydrogen and carbon monoxide (a compound containing one atom of carbon and one of oxygen). Some of the hydrogen atoms would unite with the oxygen atoms to form water or water-soluble products of limited use for producing motor fuels or wax, and the rest of the hydrogen atoms would join with the carbon atoms to form hydrocarbon molecules of one size and shape or another.

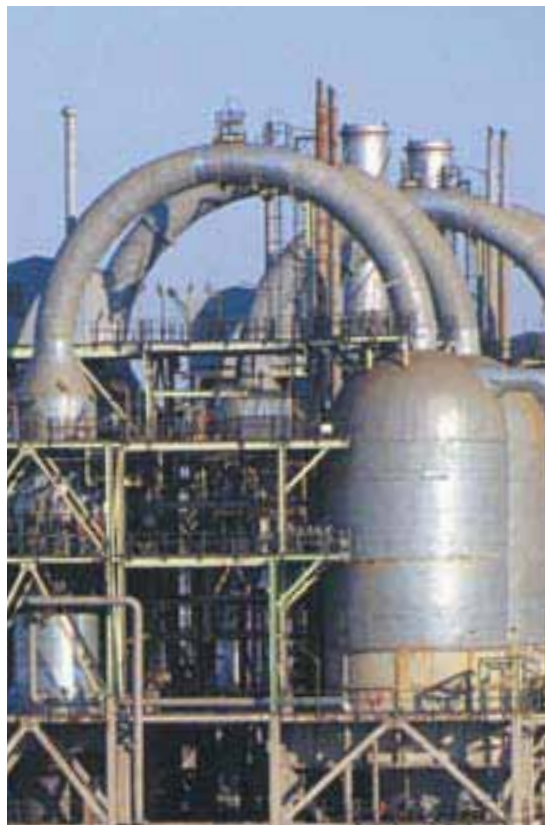
The German low-temperature ($\pm 220^{\circ}\text{C}$) reactor, known at Sasol as the Arge process (see chapter one), performed well from the start at Sasolburg. And so it should have; Germany had

operated nine of them – six in the Ruhr region alone – from the 1930s until the end of World War Two with a combined capacity of 660 000 tons a year of liquid hydrocarbons. Getting the higher temperature ($\pm 340^{\circ}\text{C}$) Kellogg reactor to work well and reliably would, however, prove deeply frustrating.

The basic problem was that the various parts of the Kellogg reactor had been badly made from sub-standard materials by overseas contractors. That was, in fact, true of all the imported plant and was probably due mainly to the loss of skilled manpower during World War Two and the strain placed on factories by burgeoning post-war demand for plant and equipment. Such poor manufacturing quality would be distressing for any plant; that it should be so for a plant the size of the Kellogg reactors at Sasolburg – not to mention the importance of petrol production for Sasol's economic viability – was downright alarming.

Kellogg's design involved feeding heated synthesis gas, under high pressure, into a pipe at the bottom of the plant. There, heated catalyst would fall into the gas through an opening in the pipe and be carried along in the gas. The formation of hydrocarbon molecules would begin immediately, further heating the gas because of the energy that such formation releases from bonding atoms.

The pipe soon curved upwards to the reaction chamber, which initially consisted of two collections of tubes assembled in the same way as they are in the Arge reactor and set one above the other. Unlike the Arge reactor's tubes, however, they were empty because the catalyst was already entrained in the gas. Surrounded by cooling oil, their purpose was to lower the



Sasol's high-temperature Circulating Fluidised Bed Synthol reactors

temperature of the gas sufficiently to prevent molecules of a useful size being broken down into methane, and also to avoid deposition of carbon on the catalyst, which would reduce the latter's effectiveness (how catalysts do their work is described in the next chapter).

Leaving the top of the reaction chamber, the pipe performed a fairly tight arc (a goose neck) that led the gas into a cyclone, a funnel-shaped steel structure that is so designed as to separate two substances of different weights from each other. The gas was led out of the plant, while the hot catalyst fell through the cyclone into a huge hopper, down which it passed into a standpipe. From there, with its rate of flow controlled by a slide valve, it fell into the path of the gas entering the plant.

All this movement happened on a huge scale. Each Kellogg reactor, for example, contained 400 tons of catalyst, half of which would, at any moment, be moving at the rate of five metres per second around



Sasol's first commercial petrol pump in nearby Parys

A little rockin' and rollin' seemed the least of the Kellogg reactor problems

the system. That movement caused the whole plant, standing 30 or more metres high, to jiggle and shake so that it had to be tied down to the ground. But a little rockin' and rollin' seemed the least of the Kellogg reactor problems – at least until it caused one of the reactors to collapse.

Sasol soon discovered that overseas manufacturers had sent work of shockingly bad quality, and had clearly not carried out adequate pre-delivery testing. Even the design of some key

components was faulty. A photographer was there to capture the moment in August 1955 when the first petrol was produced and fed into managing director Etienne Rousseau's car. It would, however, take several years more before the two Kellogg plants that were initially installed operated with passable reliability.

There were at least three major problems with the plant. The first lay with the tubes in the reaction chamber. As the gas passed through them, catalyst started to built up on the inlet of each tube, slowing the progress of the gas. That meant the gas didn't get into the tubes soon enough to be cooled down and produce the desired range of hydrocarbon molecules. At the

same time, holes began appearing in the tubes and, because the pressure of the cooling oil surrounding them was lower than that of the gas, catalyst flowed through those holes. Removing it from the oil was a major hassle.

The second problem had to do with erosion. It was found in places where the gas flowed under heightened pressure, notably in the arched pipe at the top of the plant. The solution eventually adopted came from the oil industry: lining the pipe with a putty-like ceramic material that would provide far greater resistance to erosion.

The third problem centred on the slide valve that released catalyst into the gas stream at the bottom of the standpipe. It had been designed as a bolt-on component. That meant flanges and seals, both of which were subjected to high pressure. Stressed by the constant movement of the entire plant, they often failed to contain the pressure, and the result was frightening. Hot catalyst and gas already heated to its ignition temperature would spurt through the seals into the outside air and immediately, on meeting oxygen, burst into flames. Operators would hurriedly don protective asbestos suits and masks before approaching the plant to caulk the seals – a vital preamble to shutting down the plant. But they were not always successful in stopping major fires. Over the next decade or two, Sasol would lose several of these reactors to fire.

Nor was the danger confined to the Kellogg units. Explosions and deaths occurred at gasification and units downstream from the reactors, too. "These were not toys to be played with," observes Mike Tisdall, whose father occupied senior roles at Sasol during its first 15 years. "The sirens would go off and men

at home would rush to the plant, not waiting for the telephone call summoning them. And wives whose husbands had been on shift when the explosion or fire occurred, heard the sirens and waited for the telephone call assuring them their husbands were safe. But the call might not come for hours because their husbands were too busy dealing with the emergency. So everyone shared in the anxiety."

While Sasol's men heroically battled on, opposition politicians had a field day in Parliament

Major problems were, however, eventually solved. The slide-valve, for example, was welded, rather than bolted, into place; stainless steel and refractories were used to counter corrosion and erosion. The financial cost of achieving a factory that would run reliably and achieve its various design capacities was, however, high. While Sasol's men heroically battled on, opposition politicians had a field day in Parliament.

Word must have soon reached them in Cape Town of the trouble the two Kellogg reactors were presenting: in 1956, frequent shut-downs meant they achieved only one third of their design capacity. "Sasol has already cost the State almost £40 million. Is it going to be able to provide us with control of oil for the defence of South Africa in the event of war?" demanded the United Party's Mr Mitchell of the Minister of Economic Affairs, AJ van Rhyn. Or should Parliament not, he continued, reconsider the whole project, given the recent discovery of oil in the Sahara and Angola?



When construction of Sasolburg began, none foresaw major engineering problems

Look, said the Minister, Sasol was a completely new industry; even Iscor, South Africa's first producer of steel from local iron ore, had had major teething problems despite working with well proven technology. Industrialists who had visited Sasol reckoned that what had been so far achieved was remarkable, given that it was the most difficult plant in the world to operate. If just one plant had to be shut down, the whole factory of 24 interlinked units came to a standstill – and that plant might have to be shut down for nothing more than a

faulty valve. Meanwhile, Sasol's scientists and engineers were working so hard on the problems that Etienne Rousseau feared they would break down or become ill.

He went on to describe the various sources of revenue Sasol was already enjoying. "But will Sasol ever be an economic venture?" asked another opposition MP. "We questioned the idea of investing State funds in the project when it was first put to us. We were eventually assured by your predecessor that the

project would be profitable. If that now seems unachievable, given ever-rising capital needs, let us know that Sasol will continue to operate for strategic reasons, so that we know where we stand."

Why shouldn't Sasol be profitable, retorted a National Party member, Mr Jan Haak. The £40 million the Opposition kept harping on was, in part, for expansion to the plant that had doubled its capacity from the initial 32 million gallons of petrol per year to 75 million gallons. It also included the cost of developing a residential and commercial township that would pay for itself – a cost which hadn't been built into the initial estimate. Moreover, the prices of Sasol's by-products had risen since the first calculations of its income were made.

And so it went: querulous concern from United Party members, patient explanations from the Minister of Economic Affairs about the difficulty of it all, but an assurance that in the end Sasol would provide some measure of petroleum independence and also lead to the establishment of a large chemical industry in South Africa. By March 1958 Sasol was employing £48 million of State capital, and the debate was reprised with a new Minister of Economic Affairs, Dr Nico Diederichs. The two Kellogg reactors, he reported to Parliament, were still available for only 60 per cent or so of the time, and even then produced to only half their design capacity – in short, were still delivering only one third of what had been promised. But Sasol had recently made tremendous progress in the production of both petrol and by-products and should end its current financial year showing a profit of £500 000. The overall picture, he concluded, was "very encouraging".

In the event, it was not until the following financial year that Sasol became cash positive, and not until 1960 that it made its first profit – £677 000. That landmark did not mean all its problems with the Kellogg reactors were behind it. They were still producing far less than their designed capacity. Indeed, the whole factory seemed still to have much unexploited potential, judging by the achievements that even modest investment in research and development was providing. Clearly, it would be foolish not to increase that investment substantially.



The Sasolburg plant at the end of the day on which it was commissioned

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More to catalysts than speed



Catalysts play a vital part in the Fischer-Tropsch process and Sasol learnt much about them over the years – from where to source the basic material (left), what kind of preparation they needed (construction site, centre), and how to use computer modelling in designing them (right)



1967

By now 10 000 tons of different waxes from Sasol were being shipped to two-dozen countries

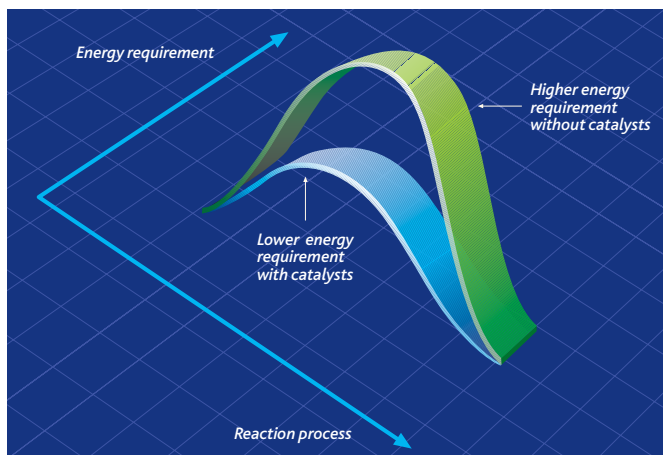
"A chemical concern which does not continually grow and improve its processes must necessarily retrogress, and for this reason research plays an important part at Sasol",

said chairman Etienne Rousseau in his address to the 1964 annual general meeting. That was why, he explained, Sasol had spent more than R800 000 during the previous year on its laboratory, about half of which went on research. To put that into perspective, the R400 000 spent on research represented an impressive five per cent of the group's pre-depreciation trading profit. It was an investment that had already produced a valuable return, especially in the field of catalysts.

The catalytic material used by Sasol looks like coarse black sand. It is made from iron oxide that is coated with other substances, referred to as promoters. The catalyst achieves two things. First, it speeds up the rate of reaction. Without a catalyst, very high temperatures would have to be employed to get a reaction between carbon and hydrogen; what's more, for reasons already mentioned such a temperature would produce only graphite (pure carbon) and methane.

Promoters can achieve two things. Aluminium oxide acts as a separator between iron-oxide crystals, preventing them from forming one large crystal. That's valuable because it vastly increases the available surface area of the catalytic crystals, which is where – for reasons that are endlessly debated by scientists – reaction between carbon and hydrogen takes place. Potassium oxide, on the other hand, provides product

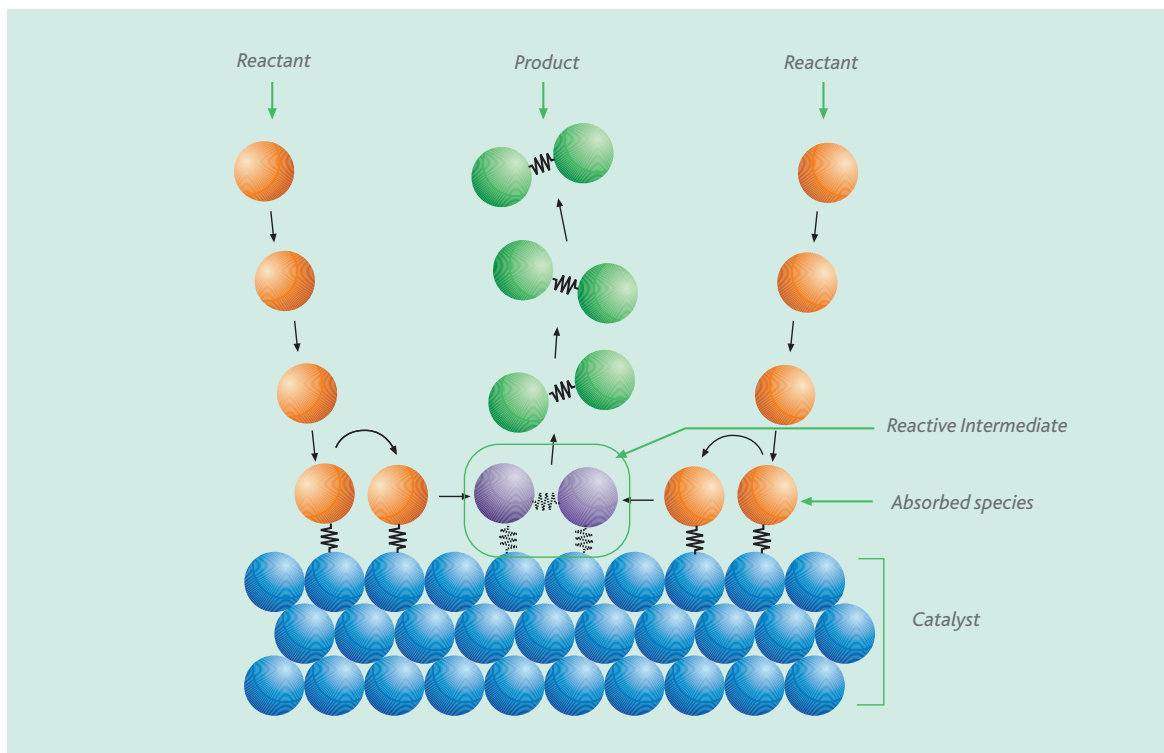
selectivity. Instead of just methane and a carbon/oxygen compound, which is what using unadorned iron oxide as a catalyst would produce, you get a sizeable proportion of



Catalysts reduce the energy needed to trigger chemical reactions

gasoline and other products. Change potassium oxide for another promoter, and other products will emerge from the reactor.

Sasol started off using catalyst for its Kellogg reactors that was imported from Pennsylvania. Nevertheless, in order to improve its own understanding of how catalysts did and could behave in



The catalytic cycle

the Fischer-Tropsch reactors, it formed its own catalyst research team in the late 1950s, headed by Mark Dry, who for several years now has been a professor at the University of Cape Town. "We have learnt about catalysts empirically, and advances continue to be empirical," he says. "To sit down and work out on paper how you are going to develop a better catalyst simply doesn't work. All advances in catalysts have been accomplished

by making the catalyst, changing the parameters and process conditions [temperature and pressure] and homing in on the better performance."

It was a laborious business. Relay teams of laboratory technicians in Sasolburg would work around the clock on miniaturised reactors, feeding purified synthesis gas into them



Electron microscopy is vital for observing how catalysts perform

and changing the composition of the catalyst and other parameters, then recording the results produced by each change at set intervals over a period of 14 days. In fact, there were two laboratory reactors at work. In the second was the catalyst being used on a commercial scale in the factory; it, too, was subjected to different operation conditions, and the results compared with whatever experimental catalyst was working in the other reactor under the same operating conditions. Jan van der Sandt was one of the technicians doing

that work. He reckons 30 years were spent refining the composition of the high-temperature catalyst, and how it should be used in the Kellogg reactors.

Major improvements were, however, made within a few years of the start of catalyst research. The first came about through Sasol's decision in 1964 to use locally available iron oxide for the Kellogg reactors, rather than import it from the US. Its source would be the Iscor steel mill in nearby Vanderbijlpark and the iron oxide would be in the form of mill scale, the foam that forms on top of molten steel and has to be removed before tapping off the steel into billets. There would be an obvious cost saving. Equally important was that the impurities in the iron oxide would remain consistent and of an acceptable kind. The properties of the imported material had not been consistent, and that had created serious problems with catalyst design and reaction outcomes since one of the tasks of catalyst design is to choose specific promoters to counteract known impurities in the iron oxide.

Catalyst made from Iscor's mill scale was an immediate success. The yield of useful products from one million cubic metres of purified synthesis gas quickly rose from 98 tons to 107 tons. Over the next five years, as Sasol's catalysis researchers learnt more about promoters, it rose to 118 tons, a 20 per cent improvement on the pre-1964 yield.

That encouraged Sasol to manufacture its own catalyst for the Arge reactors, too. It had, of course, been researching different



Catalyst research laboratory

catalysts for the low-temperature Fischer-Tropsch process – achieving considerable success, Rousseau reported in 1966. To reduce dependence on imports, he added, Sasol was building a plant to manufacture Arge catalysts. It was commissioned the following year.

All of which made good scientific as well as economic sense. In Germany, after all, the catalyst for the Arge reactors had been based on cobalt, so that's what German catalyst scientists

working with the Fisher-Tropsch process knew about. The catalyst used in Sasol's Arge reactors was, however, from the start based on iron oxide.

There was a good reason for that. Cobalt is a metal highly effective in achieving reaction, but a thousand times more expensive than iron oxide. Moreover, cobalt produces a higher proportion of methane than iron oxide does, while the latter produces a higher proportion of olefins. These are ring-shaped or straight-chain hydrocarbon molecules of a varying number of carbon atoms, two or more of which each lack a hydrogen atom. To fill up that vacant orbital they have turned to each other, creating a double instead of the usual single bond between them. It's not an ideal arrangement, however, that double bond. If another couple of atoms with unfilled outer shells came along, both carbon atoms would happily give up sharing one of their electrons with each other and use it to bond with the newcomer. That makes olefins very useful, since such bonding propensity opens the way to building larger molecules, whether hydrocarbon or including other elements. Those

larger molecules will, of course, have different chemical characteristics, and therefore industrial uses, from the two or more molecules that came together to form them.

All of which explains why an iron-based catalyst was also chosen by Kellogg for its circulating fluidised bed reactor. The high temperature of that reactor would produce mostly short-chain hydrocarbon molecules, but if they were olefins they could be joined together to produce molecules of the desired

length. And that's how it turned out. While 43 per cent of the reactor's molecules were of a size below the gasoline range of five to 11 carbon atoms, almost 60 per cent of those pint-sized molecules were olefins. The Arge reactor produced a far lower proportion of olefins, but that was no disadvantage since its lower temperature allowed large molecules to develop: molecules of 24 and more carbon atoms that produced medium and hard wax, which was the main aim of the reactor

Catalysis would soon become one of Sasol's most important research areas



and accounted for 45 per cent of its total output, while gasoline and diesel (the latter comprising molecules with 10 to 12 carbon atoms) together accounted for one third.

Catalysis would soon become one of Sasol's most important research areas, requiring the co-option of scientists working at various South African universities and at the Council for Scientific and Industrial Research in Pretoria. It showed its value not only in improved production rates and yields, but also in broadening the group's range of products. For example, the number of different types of waxes grew steadily during the 1960s until there were 23, some of them unique to Sasol.



Fischer-Tropsch hard wax flakes from the low-temperature reactor at Sasolburg

Between them they had an extraordinarily wide range of uses – "from chewing gum to floor polish," as Rousseau put it in his 1968 annual address. They were sought after not only by South African manufacturers; in fiscal 1967 more than 23 million pounds (10 500 tons) of different waxes were shipped to 23 different countries.

While the scientists in Sasol's research and development division were working on catalysts and new products, their engineering colleagues were working on how to design and fabricate plant more effectively. The need to develop Sasol's own skills in

that area had become clear as soon as the first plant arrived from overseas in the 1950s and showed serious shortcomings in design and fabrication. The need was still there in the 1960s. The painless commissioning in 1966 of two new gasifiers and associated purification units to meet demand for fuel gas from a steadily expanding industrial market (see chapter six) came about, said Rousseau, "essentially because Sasol has developed its own skills in supervising the design, construction and commissioning of the gasification plants by the contractors. By contrast, Sasol has been completely dependent on overseas technical advice and guidance when it comes to other technical plant."

A plant is worth nothing if it cannot be operated reliably

Whatever validity his second point may have had at the time, it steadily lost it down the years – at least so far as the Fischer-Tropsch reactors and their downstream units were concerned. A plant is worth nothing if it cannot be operated reliably so that its production capacity can be fully exploited. The people who can best report on that are the operators and maintenance staff. But Sasol went a step further. Its process engineers did not spend all their time in the drawing office, dreaming up new plant designs, but worked on a rotational basis in the operating units; some chose to remain in them. The benefit of that arrangement was, of course, that they could see at first hand what the problems were and devise solutions. Over the previous four years, Rousseau reported in 1967, the whole factory's productivity was increased by 10 per cent. He gave no explanation, but such improvement could be ascribed only to

the partnership between Sasol's engineers and plant operators. At any rate, it gave the group's research a legitimacy – and those conducting it an authority – that high-tech corporate research often lacks because it is not closely focused on relevant problems.

The confidence that produced caused some of Sasol's researchers to think about other ways of using the Fischer-Tropsch process; about other designs for reactors. Scientists elsewhere in the world had done the same, but none had succeeded. Sasol's scientists and engineers did, as we shall see – and the likely reason is the familiarity they developed with catalysts: with the way they behave and interact with the purified synthesis

gas. The research engineers also gained much insight through their working partnerships with operational and maintenance staff, and the resulting daily discussions.

Finally, though, Sasol's success over decades, especially in the early years, came down to passion. Everyone knew they were members of a team engaged in an exciting adventure. "There was a tremendous sense of pride in getting Sasol going, a huge sense of mission even among wives, who gave their husbands great support," says old-timer Elmore Marshall. "Outsiders commented, long before Sasol went public, that its people worked as if they owned the place. And they did – for 24 or 36 hours on the run when there was an emergency. Sasol's culture of being task-driven was created by Rousseau and his immediate colleagues, and it has remained."

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An epic in two parts

1960

The Organisation of Petroleum Exporting Countries (Opec) is formed



1968

South Africa gets an inland oil refinery, Natref. Sasol is a major shareholder with board representatives including the Iranian government



Natref today



1975

The location of Sasol's huge new factory, Secunda, is announced

1979

Construction begins of a duplicate factory (Sasol Three) at Secunda

1982

Sasol Three comes on stream

Sasol's sales turnover rose steadily during the 1960s. Profit margins, however, rose only modestly despite steady improvement in plant availability and efficiency.

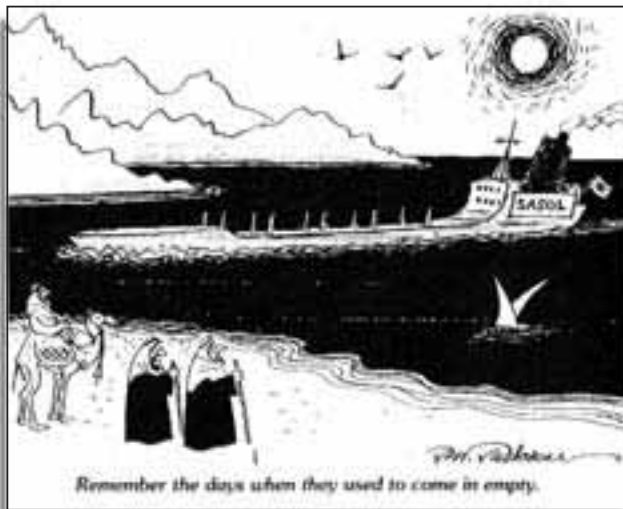
In 1960 net profit was 8,5 per cent of sales; in 1970 10,5 per cent.

The cause was apartheid on the one hand, and a booming economy on the other. Once business confidence had recovered from the shock of the Sharpeville killings and other violent demonstrations in 1960, fixed investment began to rise sharply. By 1963 the economy was growing at close to eight

per cent a year. That pace could not, however, be sustained. Various laws had confined the acquisition of industrial skills to whites; now they began to cash in, driving their wage rates ever higher. At the same time, banks began competing vigorously for customers by lending money on an unprecedented scale: discounts and advances rose from R750 million at the beginning of 1963 to R1 250 million by the end of 1964. There was an immediate surge in inflation. To counter it, the government set about discouraging credit by raising the Bank Rate to five per cent and increasing the proportion of banks' liquid assets that had to be invested in low-yielding government instruments.

So Sasol, which continued to spend on new plant to improve its existing operations and expand into additional products, was faced with rising labour and capital-good costs and higher financing charges. It could not, however, raise its prices for petrol and diesel fuel. They were inexorably tied to the international price of crude oil, and that remained virtually unchanged from what it had been when the decision was taken in 1950 to create Sasol.

There was one way to reduce operating costs, Sasol decided, and that was to trim the workforce as much as possible. In 1967 it employed 3 337 whites in the factory. By 1971 their number was down to 3 182. At the Sigma mine, their number fell from 235 to 188 over the same period. Black numbers were also steadily



A South African press cartoon of the 1970s

reduced, especially in the mine where they fell from 1 745 to 1 222 by 1974. It was a measure that, at least so far as skilled employees were concerned, would within a few years produce an unexpected cost.

The Organisation of Petroleum Exporting Countries (Opec) had been formed in 1960 to raise the price its members – all but one of them located in the Middle East – would receive for crude oil. It had, as we've seen, no success during the 1960s; many oil-producing countries had not yet joined Opec, and there was plenty of oil being produced around the world to meet demand. In the early 1970s, though, the supply/demand balance began to falter. Many countries were now enjoying rapid economic growth and needed more crude oil to fuel it. At the same time, US oil production was shrinking, its oil imports expanding. Opec introduced several price-adjusting mechanisms, the essential aim and outcome of which was to provide higher oil prices to compensate its members for inflation in countries from which they bought goods. By mid-1973 Opec had driven the oil price from about US\$1,50 in 1970 to US\$3 a barrel.

That was good news for Sasol, of course, but Etienne Rousseau warned the government in his chairman's address in late 1971 that it shouldn't lead to undue optimism about the economics of oil from coal. "The biggest problem remains the very high capital cost involved," he explained.

But then came the Yom Kippur War between Israel and its Arab neighbours in October 1973. Opec had, shortly before it, decided to raise oil prices by a further 70 per cent. Now, angered by the West's support for Israel in the war, it decided in

December to raise them yet again, this time by 130 per cent. In a couple of swift moves, it had raised the oil price to US\$12 a barrel.

The South African government had asked Sasol several times during the later 1960s and early 1970s to consider building another oil-from-coal plant, and always Sasol had refused. The price of crude oil relative to the capital cost of a new plant, it explained, would make the enterprise uneconomic. Instead, in 1969 it suggested that cheap crude oil be stockpiled in worked-out mines at Ogies, east of Johannesburg. Government agreed, and accepted Sasol's offer to administer the scheme.

When the crude oil price shot up in late 1973, Sasol was asked yet again to consider building another oil-from-coal factory. In his chairman's address of October 1972, Rousseau had observed: "The danger exists that for as long as the plants required to produce oil from coal remain of the present size and complexity, the increase in production costs resulting from the normal escalation of capital cost may well keep pace with the increases in the price of crude oil." That was tantamount to saying another factory would be economically feasible only if far larger plants could be built to yield greatly improved economies of scale in capital and operating costs.

Moreover, he added in his address a year later, there was also a good chance that further research into the design of oil-from-coal plants would reduce significantly their capital cost. It would, therefore, be unwise, he concluded, "to rush into new South African oil-from-coal plants at a time when the chances are good that such projects could be undertaken more

- 5 DEC 1974

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RAND DAILY MAIL

Giant new Sasol to be built in E Tvl

By CHRIS CAIRNCROSS
Industrial Editor

A SECOND SASOL, 10 times larger than the existing complex is to be built without delay on the Eastern Transvaal coalfields.

The Minister of Economic Affairs, Senator Horwood, said last night the Cabinet took the decision to build another Sasol on Tuesday.

The oil-from-coal complex will be built within the area bounded roughly by Indikati, Bethal, Standerton and Greylingstad, on the Transvaal highveld.

It is estimated that the plant will take about six years to build, which means it should be ready to start producing about 1981-82.

The plant, undoubtedly the biggest single industrial undertaking ever to be embarked upon in South Africa, would involve total capital investment of R3 400-million - although Senator Horwood has mentioned total capital requirements of more than R1 000-million.

Senator Horwood, speaking at the annual meeting of the Natal Chamber of Industries in Durban, said: "As soon as the oil crisis hit the world a year ago, Sasol was asked to make a comprehensive investigation of the possibility and feasibility of stepping up its oil-from-coal operations, either by expanding its present facilities or by establishing a second plant.

economically after some further research work, which is progressing well not only at Sasolburg, but also elsewhere in the world."

The South African government heard the first message and - no doubt familiar with the constant plea of all researchers for more time - ignored the second. When the Minister of Economic Affairs, Owen Horwood, announced on December 5 1974, that a second Sasol factory would be built, he revealed that it would produce more than 10 times as much petrol and petroleum products as the first factory, and would cost more than R1 billion, even before taking inevitable cost escalations into account. The cost of building the factory and developing coal mining would be met by Parliamentary appropriations, the State's Strategic Oil Fund and by export credits provided by other governments. Profits made at Sasolburg, as well as its cash flow, would be used to meet most of the cost of building a residential township for employees and their families at the new factory, as well as providing its working capital and covering the "anticipated cash shortfall during start-up and initial operation of the new factory."

Rousseau announced the location of the new factory on 31 May 1975 - Republic Day, a public holiday to celebrate South Africa's declaration of independence in 1960 from Britain's overlordship and the political pressures that accompanied it. A second Sasol factory and its neighbouring mines would be situated near Evander and Trichardt, villages in the middle of farming country 120 kilometres south-east of Johannesburg. By then Sasol had not only bought land and coal-mining rights over an area of more than 1 000 square kilometres. It had also appointed Fluor Engineers and

Constructors of Los Angeles as managing contractor. Among Fluor's strengths was its engineering design and project management expertise, particularly in large projects. It would be fully used in bringing off South Africa's – and possibly the world's – largest ever chemical-plant construction project.

The intention was to use only the high-temperature Fischer-Tropsch reactors to produce fuels and chemical co-products. Those reactors were no longer referred to as Kellogg but formally registered by Sasol under the name Synthol (a mixture of English and Afrikaans that, in shortened form,



Small sign for a huge company, signalling ...

means synthetic oil). It had, after all, been Sasol's research and development scientists and plant operators who, over 20 years, had succeeded in getting the circulating fluidised bed concept to work with acceptable reliability and productivity.



... the massive project soon to begin – Sasol Two

Where the Sasolburg factory had three Synthol reactors, the new factory – immediately dubbed Sasol Two, while the whole mining/industrial/residential development was formally named Secunda – would have eight. Each of them, too, would be three



Secunda 1975 – major skilled-job prospects for a rural area

times the size and have more than three times the production capacity of those at Sasolburg. Hence the forecast that Sasol Two would produce more than 10 times the petrol and related products that Sasolburg did.

The final cost of the factory alone would, it was announced in October 1975, be R2 503 million, allowing for an across-the-board cost escalation of eight per cent per year. That would have seemed a bold forecast to some. Specialised units would

have to be manufactured, after all, in several countries where costs might inflate more rapidly than eight per cent a year, and whose currencies might appreciate against the South African rand. More than half the total factory cost, however, would be spent in South Africa, which was by the mid-1970s experiencing something of a recession that had engineering workshops competing briskly for work.

The challenge of Sasol Two, though, was not only to set a budget, organise the financing of it and complete the project within budget. It was also to find enough skilled people to construct the factory, and then to commission and operate its plants. The scarcity of skills within the Sasol organisation had already been demonstrated when prospecting for coal in the Trichardt region intensified after the Yom Kippur War. Sasol had only three mining engineers capable of such prospecting: Paul Kruger, the group's present chairman; Pieter Cox, its present chief executive; and Japie Stone. By themselves they would not have been able to complete the job soon enough, so geologists from other organisations had to be co-opted. Together they organised the drilling of more than 2 300 exploration holes. It was a massive programme made more difficult by heavy rains that saw drilling rigs bogged down in heavy mud and by plastic casings, which were introduced when the supply of steel casings ran out, melting under the heat of drilling. Yet it was completed in six months against the five years that would normally have been allowed.

While geologists could be borrowed from other organisations, there were no people elsewhere experienced in commissioning

Opposite: Secunda's second factory (Sasol Three) under construction





Sasol Synfuels (west) today, previously known as Sasol Two

and operating oil-from-coal plants. Notwithstanding the recession, too, there remained a huge shortage of qualified artisans to work on site, assembling the factory. So Sasol took a deep breath, ransacked the Sasolburg factory for skilled white personnel, and successfully applied to the government for special permission to train people of colour as artisans. As it turned out, the depletion of Sasolburg's ranks proved painful, while trampling on the country's job-reservation laws was an unqualified success.

Producing artisans was part of the brief given to Fluor and construction companies reporting to it. Fluor built a training centre where, for example, 250 people at a time were trained as welders, 900 of whom were needed to work on prefabrication and installation of pipework. Each of them received between 350 and 450 hours of training. Artisan training continued into the 1980s, until construction of Sasol

Three, an almost exact copy of Sasol Two on an adjoining site, was completed. Over those years about 30 000 black artisans were trained. When the Secunda job was finished, they moved on into the wider economy.

Their subsequent jobs were unlikely to be as stressful as working at Secunda had been. There, the core aim was to complete the task within budget. That meant, above all, completing it within schedule because time is money, especially when interest rates are high, as they were during the high-inflation 1970s. So the initial time frame was shortened by nine months and the number of people working on site increased by thousands.

At the peak there were more than 20 000 of them and 5 000 vehicles. A reactor and its upstream and downstream units – a processing line known as a train – would be commissioned and go into full operation while construction of another train proceeded alongside it.



The rapid training of black process controllers was pioneered at Secunda

It wasn't only the tremendous amount of movement that tested the nerves of those working on site; there was also the noise. Worst of all was the purging of thousands of kilometres of piping by blowing high-pressure steam through them to remove any loose metal or other material. The noise was like Concorde taking off – deafening for anyone working on site, so it was decided to purge pipes only at night. The noise, however, prevented people living kilometres away from sleeping, so it was eventually decided to purge only for an hour or so before people arrived on site, and for a similar period after they had left the site.

Though Fluor co-ordinated the day-to-day operations of dozens of contractors, Sasol's senior men and technical and project experts played more than an overseeing role in the construction

The quality of the training was recognised by other companies adopting Sasol's training systems and programmes

of Secunda's two factories. Its senior operators examined contractors' design drawings of units to ensure they were truly operable. Buying offices were set up in Germany, England, France and Los Angeles to optimise communications with manufacturers. Working out of those offices, too, were specially trained equipment inspectors who would visit a supplier's plant and point out any defects in an ordered item so that it could be corrected before leaving the plant. Welding became an area of special expertise: Sasol's engineers specified which welding methods to use to meet the needs of different units' particular steels and operating conditions.

In-plant inspections would have paid off under any circumstances. For some items of equipment they were imperative. For example, the compression motors and circulating pumps ordered to serve Secunda's greatly scaled up process units were so large that they could not be test-run anywhere but at Secunda. To have discovered manufacturing faults only at that stage, thousands of kilometres from the supplier's plant, would have been ruinously expensive.

But once all the plant needed for a train had been assembled at Secunda, who was to commission and operate it?

Sasolburg had been trimming its workforce for years. Could it really afford to release enough people from its factory and mine to get Sasol Two and the attendant Bosjesspruit mining operation up and running, and still increase its profit sufficiently to make a significant contribution to meeting Sasol Two's costs?

It did. Year after year during the second half of the 1970s, Rousseau reported record profits.

What made it even more remarkable was that the Sasolburg plant was by now elderly and the Sigma mine was encountering unusually difficult geological conditions. More than 20 years of operating had the factory needing major refurbishment, but it was denied it; all available funds were directed at Sasol Two. Those running the factory had to improve efficiency by improving maintenance procedures and co-operation between operating and maintenance staff; those running the mine had to improve management training. They did. The loss of people to Secunda cost Sasolburg R100 million, Kruger reckons. By 1984, though, the Sasolburg factory, which had enjoyed a

R100 million renovation two years earlier, was achieving record output. Sigma, too, was setting new production, productivity and safety records.

Over at Secunda, the race was on to produce properly trained plant operators. The first thing that had to be established was how to run the various units. Sasolburg's operators knew, of course, but the procedures they carried out, modified over the years in light of their experience, had never been recorded, let alone systematised. Once that task was completed, training systems and programmes had to be designed that would produce process controllers more quickly than usual. In the event, almost 1 000 black process controllers were trained by Sasol, each in an 11-month course against the 18-24 months standard in the chemical industry. Training of senior process controllers similarly took only 19 months against the usual 36 months. The quality of the training was recognised by other companies adopting Sasol's training systems and programmes.

Construction of Sasol Two was completed in July 1980. Huge items of imported equipment, the largest a reactor weighing 330 tons, had been transported over hundreds of kilometres of road and bridges on massively long and powerful vehicles at no more than five kilometres an hour. Yet, in spite of this and other challenges and setbacks, when all the bills were in and the final cost tallied, it added up to R4 million less than the R2 503 million that had been forecast five years earlier.

While those who had brought it off could justly congratulate themselves, there was no time to rest. On January 16 1979, the Shah of Iran and his family had fled their country, and the price of crude oil shot up overnight by US\$10 a barrel, and soon

thereafter peaked at US\$40 a barrel. This sudden collapse of what had been in many ways a successful regime caught many outside the country by surprise, not least the US's Central Intelligence Agency. Under the Shah, and especially during the 1970s, Iran had seen major social, political and economic changes. They were achieved, however, at heavy cost to the Islamic clergy and large landowners who had much of their land redistributed to the workers. In 1978, the clergy and other conservative groups led popular demonstrations against Westernisation of the country's culture and mores. Martial law was imposed in September of that year, but it couldn't save the Shah.

His downfall had a special significance for Sasol. In 1966 its vice-chairman Dr Hendrick van Eck – one of the giants of South Africa's industrial development in the 20th century – had responded to government's urging Sasol to build a second oil-from-coal plant by suggesting that a crude-oil refinery be built at Sasolburg to widen the scope of the State's direct investment in motor fuel-producing plants. While the State would hold the major stake in the refinery, there should also be foreign investors who could provide not only capital, but also refinery design and operating skills, on the one hand, and an assured stream of crude oil, on the other. In August of that year, the government accepted his proposal.

But who should be the State's foreign partners? Among the oil-producing countries of the Middle East – the group closest to South Africa and therefore the cheapest from which to bring oil – Iran seemed the most likely. The Shah's efforts to develop his country economically had seen rapid growth in recent years of imports from South Africa of industrial materials such

as steel and cement. There was also an emotional tie. The Shah's father had had to flee his country in 1941 in the face of Anglo-Soviet hostility towards his support for German interests in Iran. He ended up in Johannesburg, where he died in 1944. Finally, the Shah, ever mindful of his country's over-dependence on revenue from crude oil, was keen to invest in its downstream activities, the first of which, of course, is refining.

Which oil company, then, to choose as a technical partner? Again, France stood out. In 1964, Britain's Labour government



When Sasol went public in 1979, its offer of shares was more than 31 times oversubscribed. Sasol's share issue was, at the time, the biggest in the history of the Johannesburg Stock Exchange

had announced it would prohibit armaments exports to South Africa beyond current commitments. France's president, Charles de Gaulle, stepped into the breach. Developing close ties with second-ranking countries such as Israel, Pakistan and South

Africa would give France a power base to counter that lost through its withdrawal from the North Atlantic Treaty Organisation. And the way to develop closer ties quickly with South Africa was to sell it armaments, notably military aircraft and submarines. It wouldn't hurt the entente cordiale, either, to have a French investment in refining crude oil in South Africa, since that was also regarded by the South African government as an industry of strategic importance.

A company was formed in 1968 to own and operate the planned crude-oil refinery at Sasolburg. Its official name is National Petroleum Refiners of South Africa (Pty) Ltd. Everyone, however, calls it Natref. When it was launched, Sasol held 52,5 per cent of its shares and the National Iranian Oil Company 17,5 per cent. The remaining 30 per cent was held by Total South Africa, the local subsidiary of Compagnie Française des Pétroles. For many years it had sold petrol under the Total brand name in South Africa, but had had no refinery interests there.

Most of the crude oil would come from Iran. And so it did, satisfying the refinery's 55 000 barrels-a-day capacity, until the Shah's downfall. In the chaos and violence that followed, most of the foreigners running Iran's oil industry fled and production came virtually to a halt. Not that Natref was suddenly without crude oil; Sasol had squirreled away huge quantities of it over the past 10 years and more not far away in Ogie. Still, it was a nasty surprise; one, moreover, that brought home again how politically unstable the Middle East was. Which is another way of saying that the price of crude oil was likely to stay high for the foreseeable future.

So why not build a third Sasol factory? Long before the Shah quit Teheran, Sasol had concluded that world oil prices would probably continue to rise during the 1980s. In his 1977 annual

needed commissioning. The Sasolburg factory, moreover, had been commissioned more than a quarter of a century earlier and there were few, if any, people still around in the late 1970s

who had worked at that commissioning. It's doubtful, anyway, that their experience with far smaller units would have been

Sasol Three was up to speed almost immediately

address, the new chairman, David de Villiers, said it was "widely expected". It is not surprising, therefore, that Sasol knew early in 1979 what it would probably cost to replicate Sasol Two. It came to R3 276 million, or R776 million more than had been allowed for Sasol Two because of inflation that was accompanying the current economic boom in South Africa. Sasol put the proposal to the government in January 1979 – together with one for privatising Sasol to help finance the construction of a third Sasol factory – and received its nod the following month. Four months later it had signed contracts with all major contractors and suppliers, and construction began.

It took two years less than Sasol Two had to design and build Sasol Three. And where Sasol Two was not running at full design capacity until 18 months after its last train had been commissioned, Sasol Three was up to speed almost immediately. The explanation, of course, is that Sasol and its contractors learnt much from Sasol Two that was of value for the Sasol Three project.

There was, for example, the matter of commissioning plant. It requires a set of skills quite different from those used to operate plant. Large, international chemical companies therefore have dedicated teams travelling the world to commission new plant. But Sasol was still a single-plant company until Sasol Two

of much value when commissioning Secunda's behemoths.

So those who were to operate Sasol Two's units first had to commission them. It was, not surprisingly, a long learning curve. But the experience gained was later put to work in the commissioning of Sasol Three. It was one of the few areas in which Sasol Three was allowed to draw on Sasol Two's managers, given the need for them to concentrate on getting their factory producing motor fuels, chemicals and profit as soon as possible. For the rest, Sasol Three had to recruit and train its own people, even at management level. The result, says executive director Jan Fourie, who was one of the first people recruited to Sasol Three's management cadre and eventually found himself running it, was that much new blood was introduced to Sasol Three. It came largely from the chemical industry, was young and highly enthusiastic about confronting new challenges.

All of which may help explain Sasol Three's painless commissioning and start-up, and why it was running at full capacity by virtually the same date as Sasol Two. There was, however, an important third factor. Small design faults detected by those commissioning Sasol Two's units – there were

Opposite: Sasol Synfuels (east) today, previously known as Sasol Three



eventually 103 of them – were corrected before manufacture of Sasol Three's units began. Those operating Sasol Two, however, had to wait for a complete plant shutdown for maintenance before those faults could be rectified.

Which is not to say Sasol Three did not face serious technical problems. The great height of the reactors, for example, and the vast tonnage of catalyst swirling around in each of them, saw vibrations build up that threatened metal fatigue, and even toppling of the structures. Erosion was also encountered in the goose-neck pipe carrying catalyst and gas from reaction chamber to cyclone and hopper. The same ceramic that had been used in Sasolburg's three Synthol reactors lined those at Secunda, but proved unable to cope with the far greater volumes of catalyst.

Both these problems were fairly quickly overcome. Those presented by the heat-exchange coils in the reactors took considerably longer. Each reactor had several of these coils, made of hollow steel and shaped into a serpentine form to create as much surface area as possible in the space within the reaction chamber. The idea of a serpentine heat exchanger had been pioneered in the third Synthol reactor built at Sasolburg, replacing the unsatisfactory fixed-tube exchangers. In his 1977 address, De Villiers observed that the new "heat-removal system . . . represents a substantial advance in Sasol's Synthol technology".

No doubt it did, but it still presented operators with serious problems. Each coil was slung from a concrete beam and attached to another below to keep it still in the upward torrent of gas and catalyst. That measure, however, proved inadequate,

so steel channels were created into which each end of the coil was dropped to prevent horizontal movement. The high temperature inside the reaction chamber, however, caused the coils to expand and buckle because of the space limit imposed by the steel channels. Further problems were caused by catalyst lodging in the channels. And then there were acidic compounds in the steam passing through the coils as the cooling medium, and they corroded the steel.

Greatly enlarged Synthol reactors also required downstream units to be scaled up. That, too, presented problems, especially when it came to those units reforming methane. Because it consists of molecules comprising one atom of carbon and four of hydrogen, methane doesn't react with any other compound; the carbon atom's need for bonding is already fully satisfied. So for chemical synthesis purposes – getting atoms and molecules of different compounds to join together in a myriad different combinations, each with a well-known or potential commercial value – methane is of no value; it just takes up space in the reactor, like a cuckoo in another bird's nest.

There are, however, two ways of getting value from it once you have separated it from other compounds by distillation (an easy, though not cheap, process involving chilling the soup of chemicals to, say, minus 170 degrees Celsius then raising the temperature by eight degrees, at which point methane turns from a liquid into a gas, while everything else in the soup remains liquefied). You can upgrade its heating properties by adding hydrogen and sell it to industry and households; Sasol did this from the mid-1960s, as we shall recount in chapter six. Or you can, in the presence of steam and oxygen and a catalyst, use intense heat to break the bonds between the carbon and

hydrogen atoms. You will end up with water, carbon dioxide, hydrogen and carbon monoxide. The last two gases in that mixture are, remember, the components of purified synthesis gas, so can be fed straight into a Fischer-Tropsch reactor.

The problem with a significantly enlarged methane reformer, Sasol found, was to get the flame-producing burner to last, and

US\$17 by mid-1987, following an Opec decision to curtail production for a trial period, but who knew how long that recovery would last, De Villiers asked.

It was a prescient question. By late-1988 oil was selling for little more than US\$10 a barrel and Sasol had turned to the government, asking it to meet its undertaking at the time of the

1979 public listing, that it would alter, upwards or downwards, the modest amount of tariff protection then provided should "the ratio between the rise in general cost factors and the rise in the prices of petroleum products materially deviate from the assumptions

made for the purpose of the economic evaluation of the Sasol undertaking." In other words, Sasol's shareholders, who had bought the government's 50 per cent share in Sasol Two for R2 620 million in 1984, would be compensated should a low oil price indicate they had been overcharged.

By 1986, De Villiers reported, both Secunda factories were running at five per cent more than their design capacity

the flame to cover all the area through which the methane passed. Incomplete coverage meant some unbroken carbon-hydrogen bonds – that is, incomplete reforming. The very high bond-breaking temperature also required the reformer to be lined with ceramics, which proved physically difficult.

By 1986, De Villiers reported, both Secunda factories were running at five per cent more than their design capacity. Further improvement could be expected, he implied, when debottlenecking had been completed. By that he meant that the output of any unit would, if it was insufficient to keep downstream units amply supplied with product, be increased by one means or another.

For all that, earnings per share in 1986 represented a return on net asset value of only 20 per cent, which was no more than commercial interest rates. The major reason was a collapse of the oil price from US\$28 to US\$8 a barrel. It had recovered to

It remained to be seen, though, whether the government would meet its undertaking, let alone how generously. Shouldn't Sasol take a fresh look at how it was exploiting what came out of its Synthol reactors, the new managing director, Paul Kruger, asked. Perhaps there were compounds in it that could be separated out of the fuel stream and sold for far more than petrol fetched.

The head of his research and development division shook his head discouragingly; separation was, for technical reasons, not possible. Kruger, however, insisted that it be tried yet again. Eventually, his persistence paid off. His suggestion proved to be not impossible, but inspired.

Chapter 06 Pages 78 – 95 ►

Developing with a bang

1964

Sasol enters the nitrogenous fertilizer field – a tough nut to crack



Paint and inks are among dozens of products using Sasol's solvents



1984

Sasol enters the explosives business



1996

Sasol Mining Initiators is formed



2001

Sasol announces it will market natural gas from Mozambique from 2004



Behind Paul Kruger's challenge was the need to free Sasol's profitability as far as possible from world oil prices.

The selling prices of its petrol and diesel were closely tied to them; those of its chemicals were not. World chemical prices, moreover, were higher per ton of converted synthesis gas than those of petrol and diesel because refineries needed additional expensive processes and plant to produce them from the various fractions – categories of hydrocarbon chain lengths – into which they refined crude oil.

The potential for Sasol to become, through the by-products of its various processes, a significant producer of chemical feedstocks and other products besides motor fuels had been appreciated years before its first reactors became operational at Sasolburg. Rousseau told the Johannesburg Junior Chamber of Commerce in 1951: "However important Sasol may be in South Africa's future fuel picture, I should think that for the immediate future and from the point of view of secondary industry in South Africa over the next 10 years, Sasol will be more important as a by-product and industrial raw material producer."

That view seems to have been shared by the government. From the 1960s onwards it vigorously pursued a policy of import replacement, and regarded Sasol as the most likely producer of major feedstocks around which a local chemical industry could develop. Its hopes were not disappointed. Over the following decades, Sasol recovered more and more of the compounds produced in its reactors, becoming not only the primary

producer of raw materials for South Africa's infant chemical industry, but also a significant exporter. Foreign sales would, indeed, become ever more important to the group's sales revenue. Kruger's aim was to

make chemicals the equal of motor fuels when it came to producing profit – a not unrealistic aim, especially given the rand's steady decline against major currencies from the early 1980s onwards.

The first chemical intermediates Sasol decided in the early 1960s to start selling were ammonia, styrene and butadiene. The last two are brought together to produce synthetic rubber. Sasol invested in plant to recover them and in 1964, using licensed technology, began selling them to its new neighbour, the Synthetic Rubber Company.

That year also saw it begin synthesising ammonia. A compound of nitrogen and hydrogen, it is produced in Sasol's gasifiers and has to be removed before the raw synthesis gas passes into the Fischer-Tropsch reactors. Fortunately, its nitrogen makes it a basic raw material for fertilizers.

Sasolburg initially had nine gasifiers. The amount of ammonia they would produce looked, in the early 1950s, like meeting half or more of South Africa's nitrogenous fertilizer needs. That proportion steadily shrank over the next decade as farmers came to understand the benefits of using the fertilizer. By the early 1960s it made good sense for Sasol to synthesise ammonia – using a catalytic process devised by the German chemist Fritz Haber in 1908 – to produce a range of nitrogenous fertilizers. Sasol was already producing the



Fritz Haber

nitrogen in its air-separator but, with no use yet found for it, was releasing it into the air. Hydrogen could be recovered at low cost from the purge gas emerging from its reactors.

From 1964, then, Sasol was a major supplier to wholesalers of nitrogenous fertilizers. Over the next

decade and more they proved to be tough customers, and Sasol made no profit from its fertilizer activities and plant at Sasolburg. What worried it even more was that far more

Without those vessels or a guaranteed offtake, Sasol would have to stop the whole of its Secunda operation

ammonia would be produced at Secunda when Sasol Two, and then Sasol Three, came on stream. Fertilizer companies would be able to hold Sasol to ransom in a bid to obtain ammonia products from it at rock-bottom prices. Ammonia is an extremely dangerous, rapidly suffocating gas that cannot be flared. Storing it safely, though, requires turning it into a liquid under pressure, and keeping it in expensive, high-pressure vessels. Without those vessels or a guaranteed offtake, Sasol would have to stop the whole of its Secunda operation.

In the early 1980s, therefore, it decided to avoid that dilemma by itself manufacturing and retailing fertilizers. It couldn't have chosen a worse time. Its Secunda fertilizer plant, which had been designed to produce only limestone ammonium nitrate, was commissioned in early 1984, about the same time that South Africa's worst drought in 200 years began. Soon afterwards, Sasol Fertilizers, which had been formed in the early 1980s, took the advice of fertilizer-market experts to add



With ammonia and nitrogen readily available, Sasol began fertilizer production confidently. Tough times, though, were round the corner

phosphate- and potassium-based fertilizers to the product slate. It involved major and painful modifications to the plant. Meanwhile, the drought continued. By the mid-1980s local fertilizer consumption was down from 3,5 million tons before the drought began to little more than 2 million tons.

Farmers, financially stretched to the utmost, learnt to do with far less fertilizer. When the drought was over, there was no recovery in fertilizer uptake. Sasol Fertilizers decided to export surplus production, but the prices it obtained were, despite the steadily shrinking rand, miserably unprofitable. By the end of the 1980s, in spite of achieving profitability by rationalising production facilities it had long owned at Sasolburg or had bought there and elsewhere, it was still, chairman Joe Stegmann admitted, producing an unacceptable return on capital. Nor has there been any significant improvement in the fertilizer market or Sasol Fertilizer's fortunes since then.

A far happier story, one that also began in the mid-1960s, can be told about selling methane to industrial and domestic users. Methane is produced in both the gasifiers and the reactors. It doesn't, as explained in the previous chapter, react with other molecules without expensive treatment. It is, however a useful fuel.

In August 1964, Sasol formed the South African Gas Distribution Corporation (Gascor) in equal partnership with the Industrial Development Corporation. Two years later it was piping methane-based gas to factories in neighbouring industrial areas and planning to expand its gas-production and purification capacity in response to expanding demand. Its most recently acquired customer was the Johannesburg Gas Works, which

had an extensive reticulation system for distributing to domestic consumers.

By 1971 its sales were worth R6 million, up by 50 per cent on the previous year and now accounting for more than seven per cent of Sasol's total sales. "Several mass energy consumers have changed to the specialised application of gas in the processing of metals and the manufacture of glass, ceramics and bricks," Rousseau reported.

And so it continued; the limiting factor was the ability to supply rather than customer demand. The latter was kept firm by Gascor's own fuel engineers helping industrialists, as Rousseau put it, "to find new applications to which this refined fuel is ideally suited."

By late-1972, inflation had become a serious concern for the government. So serious, in fact, that the Cabinet lost its marbles. It had fatuous posters displayed on major highways, saying "Let's do something about inflation." Equally fatuously, it asked Sasol to freeze Gascor's prices for three years. Sasol agreed, and saw Gascor's sales surge. But its profitability, Rousseau warned in late 1975, was unsatisfactory because of the price freeze. The latter was due to be lifted in early 1976. In the event, the government asked for it to be retained a little longer, Sasol complied, and profitability "continued to be disappointing".

By the second half of 1977, though, the price-freeze was over and Sasol had extended its pipeline network to Olifantsfontein, south-east of Pretoria, as well as to Springs, which lies due west of Secunda. When Sasol Two came on stream there was far

more methane-based gas available and a pipeline was built from Secunda to Springs to feed it into the network. By July 1994 the network had been extended to the industrial areas of Witbank and Middelburg – both towns due east of Pretoria and home to major industries such as Columbus Steel – which, Gascor forecast, would increase its sales by 30 per cent.

By now, Gascor had more than 800 kilometres of pipeline, 630 industrial customers and an untold number of domestic users. Yet its potential market area was still far from being fully exploited. There were, for example, Pretoria and the industrial area west of it, Rosslyn. Durban, too, remained as yet untapped, despite the parastatal Petronet having a pipeline between Secunda and Durban. An agreement was struck to convert the pipeline so that it could carry gas from Secunda. Further arrangements were made to distribute the gas throughout Durban's industrial area, south of the city, and

to carry it northwards to another burgeoning industrial centre, Richards Bay.

In fiscal 1997, gas sales almost doubled, thanks in part to strong growth in inland markets, but also because of new sales coming from the coast. By then the company was no longer named Gascor, but Sasol Gas. Most of its product was used for process-heating purposes, with slightly more than 80 per cent of it being supplied by the gasifiers at Sasolburg, and the network consisted of 1 350 kilometres of underground piping.

In late 1998 Sasol reported a planned project, to bring natural gas from northern Mozambique to Secunda



The market for industrial gas proved rewarding

The development, operation and maintenance of the network had, over three decades, served as a good apprenticeship for piping natural gas – which is largely methane – over long distances. In late 1998 Sasol reported a planned project, in partnership with the Atlantic Richfield Company of the US, to bring natural gas from northern Mozambique to Secunda through a 925 kilometre-long pipeline at a forecast cost of US\$1 billion. With sales expected to rise by more than 50 per cent between 1996 and 2001 – those in KwaZulu Natal rose by two-thirds in 1999 – Sasol Gas was on a high. Yet one concern remained: would the Minister of Finance allow depreciation charges on the Secunda-Mozambique pipeline to be offset against revenue? In his February 2000 budget speech, he declared that he would. A few months later, Sasol

Gas announced that it would begin to market gas from Mozambique in 2004.

The Gascor/Sasol Gas saga is an example of Sasol's determination to overcome technical difficulties – bad welding of many kilometres of piping by a contractor in the early years – and develop markets for new products. There are many other examples, especially in the realm of technology. One of the most easily understood concerns the struggle to convert another constituent of raw synthesis gas from a pollutant into a commercially valuable product.

Hydrogen sulphide is washed out of the gas with remarkable thoroughness by the Rectisol process. Were it not, the sulphur it contains would poison the reactors' iron oxide catalyst. What to do, though, with the hydrogen sulphide emerging from the Rectisol process? Ideally, the sulphur should be removed from the gas containing it, along with carbon dioxide, and sold to those making fertilizers, pigments, dyes, drugs, explosives and detergents. For years after Sasolburg started producing synthetic fuels, though, no one knew how to do that. The gas was therefore released into the air, smelling of rotten eggs due to the sulphur it contained, albeit it at minuscule concentrations.

Those who have had to live with the smell say they soon became unaware of it. Those living further away – the smell can travel hundreds of kilometres, given the right atmospheric conditions – are in that respect less fortunate. One of the first signs of Sasol's environmental conscience – today it informs every decision and investment it makes – appeared in the late 1960s, when it began searching for a solution to the hydrogen

sulphide problem. It came across a technology that had been recently developed by scientists working for British Gas. It was called the Stretford process, after the town, close to Manchester, where the research station was located.

To recover sulphur from hydrogen sulphide, you must turn it into a solid. To do that, you must get physical contact and chemical reaction between the sulphur and oxygen. The most feasible source of oxygen for that purpose is water, a mixture of hydrogen and oxygen.

The Stretford process involved building a concrete tower 85 metres high and filling it virtually to the brim with wooden pallets. Water fed into the top of the tower would splash against the pallets as it fell, forming millions of droplets. In other words, the surface area of water would be hugely increased, and so, therefore, would the amount of contact between it and the gas that, fed into the bottom of the tower, rose up through it. In 1973 Sasol had a Stretford tower built at Sasolburg. It struggled for years to get it to work, and in 1980 admitted defeat, though it had it dismantled only 15 or more years later.

There were several differences between the tower and its working conditions that were not present in England, where the process was successful. There were, for example, certain contaminants in the English gas that were absent in Sasolburg's since the latter had been purified by the Rectisol process. Those contaminants kept bugs away. In South Africa, bugs

Opposite: A worm's-eye view of the sulphur recovery plant at Secunda



feasted happily on the chemicals that had been added to the descending water to facilitate the reaction between sulphur and oxygen.

The English wooden pallets, too, were made from a closed-cell type of pine that grew only on the northern slopes of the Alps, and then only within a certain altitude range. The South African contractor commissioned to build the Sasolburg tower used South African pine, which is open-celled. It was soon saturated with, and the pallets eventually destroyed by, the wash chemicals. Sasol was left with a huge tower, inside which lay a pile of rotting timber.

Meanwhile, the day when Sasol Two's gasifiers would come on stream was fast approaching. There would be many more than at Sasolburg. Clearly, to vent hydrogen sulphide into Secunda's air would not be acceptable. A successful method of recovering sulphur had to be found.

Sasol collaborated with other, foreign organisations facing the same problem, but came away with no solution. Then it tried the German company, Linde, which had pioneered the Rectisol process in Sasolburg. Together they worked on the problem for years after Secunda's 80 gasifiers were commissioned. Until they produced a solution in the mid-1980s, the sulphur-containing gas had to be vented through 300-metre-high stacks (ground-standing chimneys), at which height it was hoped that the gas would be so widely dispersed and diluted that it would offend no one's nostrils. It was not a completely successful solution – one can smell hydrogen sulphide even in a ratio of only a few parts per billion.

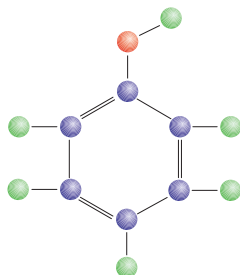
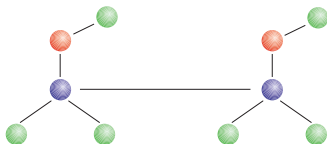
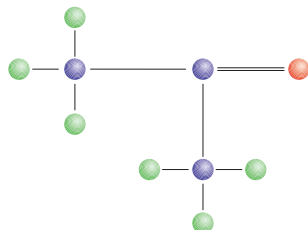
Eventually, however, Sasol's and Linde's scientists produced an answer to the two main problems: how to break up sheets of water into droplets, and which chemicals in it would best aid reaction between sulphur and oxygen. They used the concept of the Venturi tube – also used in carburettors, its narrowed neck producing the required turbulence – and a different chemical mixture. The name given to the process is Sulfolin, in recognition of Linde's contribution to its devising.



An aerial view of the sulphur recovery plant. To the right is a smokestack, with a cooling tower in the background

Three kinds of oxygenated molecules

Phenol

Alcohol
(ethylene glycol)Ketone
(acetone)

- carbon atom
- hydrogen atom
- oxygen atom
- chemical bond
- == double chemical bond

How oxygenates are used

Alcohols	Ethanol (C ₂), normal propanol (C ₃), iso propanol (C ₃), normal butanol (C ₄), iso butanol (C ₄), secondary butanol (C ₄), tertiary butanol (C ₄), normal pentanol (C ₅) etc.	Solvent use in paints and coatings, inks, adhesives, pharmaceuticals, cosmetics, toiletries etc. Intermediate chemicals for a variety of derivatives including other solvents, flavours and fragrances, plasticizers, resins and mining chemicals.
Ketones	Acetone (C ₃), methyl ethyl ketone (C ₄), methyl iso butyl ketone (C ₅)	Solvent use in paints and coatings, nail varnish remover. Intermediate chemical for manufacture of certain polymers and other chemicals.
Esters	Ethyl acetate (C ₄), propyl acetate (C ₅), butyl acetate (C ₆)	Solvent use in paints, inks, adhesives, coatings.
Acids	Acetic acid (C ₂), propionic acid (C ₃), normal butyric acid (C ₄), iso butyric acid (C ₄)	Food acidifier (vinegar). Chemical intermediate to make esters, vinyl acetate, acetic anhydride and a number of other important chemicals. Acidifier used in textiles and other processes.
Aldehydes	Acetaldehyde (C ₂), propionaldehyde (C ₃), normal butyraldehyde (C ₄) etc.	Chemical intermediates for a number of chemicals.
Ethers	Di methyl ether (C ₃), di ethyl ether (C ₄), dipropyl ether (C ₅), diisopropyl ether (C ₆) etc.	Used as solvents in a variety of applications and as propellant for some aerosols. Methyl tertiary butyl ether (MTBE) is a common fuel component used to boost octane. Some ethers also used as process solvents.

Methane, hydrogen sulphide and ammonia were problems that were eventually turned into commercial opportunities. So, too, was coal tar. It's the first product to be recovered from the gasifiers because, as the environment cools, it leads the others in turning from gas to liquid. From it Sasol derives tar pitch, which in turn is converted into valuable products such as wood-preserving creosote and calcined pitch coke.

Also contained in the synthesis gas is a group of molecules identified by their oxygen atoms. They produce a wide range of products that are categorised into seven groups. These differ from each other mostly because of the different bonds formed between one or more oxygen atoms and the carbon atoms contained in one shape or other of hydrocarbon molecule.

Sasol has, over the years, become involved in exploiting all the various types of oxygenated molecules it produces. One group goes by the name of phenol (that "ol" signifies the presence of oxygen atoms). They have come about in the following way. Instead of forming an unadorned straight chain, or one with a branch or two coming off it, carbon and hydrogen atoms have formed ring-shaped molecules. At the same time, single oxygen and hydrogen atoms have bonded together to form what are called hydroxyls. One or more hydroxyls attach themselves to a ringed molecule and voilà – you have a phenol.

There is, in fact, a whole family of them because of the permutations that can be made between the different numbers of hydroxyls attached to one or other of the various kinds of cyclic (ring-shaped) hydrocarbon molecules. Some of its members are called cresols, others xlenols. All of which explains why there are so many end-uses for phenols, cresols

and xlenols: pesticides, detergents (the first phenol, produced by a German chemist in 1834 from coal tar, was carbolic acid), resins, fungicides, polycarbonate (a strong plastic used as a glass substitute), mining chemicals, pharmaceuticals, epoxy resins, printed circuit boards, antioxidants and wood preservatives.

Alcohols are another kind of oxygenated compound. They differ from phenols in that the hydrocarbon molecules to which the hydroxyls attach themselves are straight-chained, not ring-shaped. Alcohols have many industrial uses, but the most important is as chemical intermediates. These, by simple chemical reactions with other compounds, yield other products: fats and waxes; surface active agents (surfactants) for use in detergents; compounds used as plasticisers, emulsifiers, lubricants, emollients and foaming agents.

Yet another kind of oxygenated molecule is found in acids. They have many more uses than one might suspect because there are dozens of acids, but three account for most of the total volume produced. They are acetic, adipic and phthalic acid.

Most acid produced is acetic, used to make vinegar (the Latin for which is acetum) and accounting for its pungent smell. But it is also used to make acetates. From polyvinyl acetate, popularly known as PVA, come adhesives, plastics and water-base paints. Cellulose acetate is used to make fibres, cigarette filters, plastic sheeting and film, and in the production of lacquers.

Adipic acid is not, as one would suppose, a liquid, but a white, crystalline powder that dissolves in alcohol. Though it is an approved additive, almost all of it is used to produce Nylon 66,

a durable, tough and abrasion-resistant fibre that is also easy to colour and to mould. These qualities see it used in the production of tyre cord, carpeting and other flooring fibres, and engineering plastics.

Phthalic acids are used as plasticisers for polymers, resins and fibres. Polymers, by the way, are heavy molecules formed by joining together smaller molecules. They are used to make plastics, elastomers (rubber, or a rubber-like plastic), coatings, adhesives and fibres.

The remaining groups of oxygen-bearing molecules are known as ketones, aldehydes, ethers, esters and anhydrides. Ketones are characterised by a double bond between a carbon and oxygen atom (a carbonyl); the best-known product is acetone (or propanone), used both as a solvent and as an intermediate in the production of other products such as perspex and epoxy resins. Aldehydes also have a double bond between a carbon and oxygen atom. But unlike ketones, where each of the other two carbon hooks joins it to a hydrocarbon chain, one of the hooks in an aldehyde creates a bond with just one hydrogen atom. An example of an aldehyde is formaldehyde, used for tanning, preserving and embalming, and as a constituent in some plastics. Another example is acetaldehyde, an intermediate in the production of plastics, dyes and pharmaceuticals.

Ethers are based on an oxygen atom linking two straight-chained or ring-shaped hydrocarbon molecules. It does so by bonding with two carbon atoms, replacing hydrogen atoms in the process. That leaves no hydrogen atoms available for bonding with other molecules, which makes these ethers not



Acetaldehyde, an intermediate in the production of plastics. Sasol Polymers produces the plastics used in the production of this protective footwear

very useful in the process of building compounds from different molecules. It is also highly flammable, which is why its use from 1842 as an anaesthetic in operating theatres is no longer general practice. It is, however, a good solvent for extracting certain compounds from a chemical mix. Because it is volatile, too, its presence in petrol and diesel fuel helps start vehicles in cold weather.

Esters and anhydrides also involve complicated bonding between carbon and oxygen atoms. Neither are produced by Sasol's Fischer-Tropsch process.

By 1988 Sasol was fully in the explosives business. It hadn't been easy

We have already seen how the availability of nitrogen saw Sasol enter the field of ammonia synthesis; indeed, having it at virtually no cost eventually made Sasol South Africa's only ammonia producer, since others couldn't compete. Nitrogen, though, also opens the way to producing a range of products that seem to the layman remarkable in their great differences.

Nitrogen-containing compounds fall into three groups. Those in the first are known as amines. The best known is ammonia. Another is aniline, which we saw in chapter one is an important chemical intermediate in the production of dyes.

The second group are known as nitro compounds and are characterised by the addition to hydrocarbon molecules of one or more molecules composed of one atom of nitrogen and two of oxygen. An example of this group is the explosive TNT (trinitrotoluene). The third group are known as nitriles, and their distinguishing feature is the addition to a hydrocarbon compound of a molecule comprising one atom of nitrogen and one of carbon. In this group you find acrylonitrile, used to produce tyres, plastics and clothing fibres.

Sasol became heavily involved over the years in all these areas. The fertilizer story has already been told. Sasol entered the field of explosives in the mid- 1980s when it became worried about the shrinking South African fertilizer market. What's the connection between the two products? Ammonium nitrate.



Alfred Nobel 1833-1896

Dynamite was the invention of the Swedish physicist Alfred Nobel, who patented it – calling it dynamite, after the Greek word for power – in 1867. He took nitroglycerine, an explosive compound of carbon, hydrogen, nitrogen and oxygen first produced by the Italian chemist

Scania Sobrero 21 years earlier, and made its handling far safer by mixing it with an inert porous material such as charcoal or diatomaceous earth. Nobel took dynamite's development a step further when he replaced some of the nitroglycerine with ammonium nitrate, a compound of ammonia, nitrogen and oxygen that is also used, as we've seen, in fertilizers and was therefore to be produced in Sasol's fertilizer factory at Secunda.

Thirty years before that factory opened it had been discovered, through a disaster aboard a ship carrying ammonium nitrate, that a mixture of ammonium nitrate and fine coal dust was explosive. Further investigation showed it would make better explosives than nitroglycerine. Using coal dust was clearly not practicable on an industrial scale, so it was replaced with diesel oil, its chemical equivalent that had the additional advantage of protecting ammonium nitrate from water and moisture, either of which render it useless as an explosive. The product that result was called ANFO (ammonium nitrate fuel oil).



A sequence of detonations – fine timing is key

It came out of the factory as pellets packed into polyethylene bags, or mixed with an emulsion to form a gel.

Sasol decided that, since it had all the basic ingredients at either Secunda or Sasolburg for making ANFO, it would do so. Sasol Explosives Ltd was formed in 1984, and plans approved to erect a plant at Sasolburg to produce porous ammonium nitrate (porous so that it would absorb fuel oil) and the world's biggest cartridged emulsion explosives plant at Secunda. Both plants were commissioned in late 1985; a plant producing fuel oil a year later. Meanwhile, a plant producing emulsion explosives was successfully commissioned in the Northern Cape. By 1988 Sasol was fully in the explosives business. Sasol Explosives had been renamed SMX (Sasol Mining Explosives)

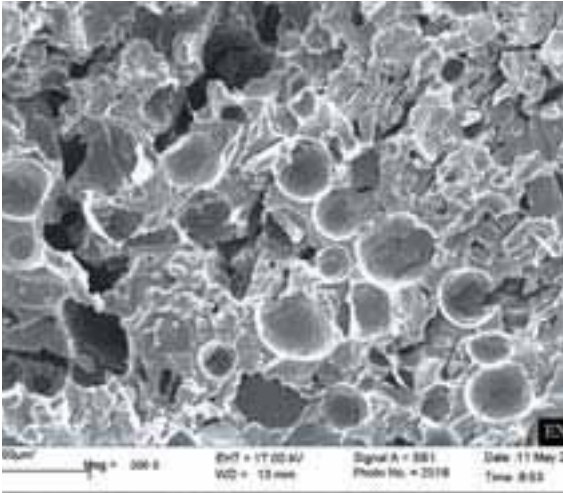


Sasol Explosives plant at Secunda

and in 1989 broke out the champagne when the accountants announced a profit.

It hadn't been easy. Though the company was licensed to use the technology of foreign patent holders, technical support from them proved inadequate. So SMX created its own research and development division, recruiting people from different industrial backgrounds and countries, as well as creating research ties within the wider Sasol group and with foreign research organisations. The 1990s saw SMX's researchers win two technological triumphs.

The first produced a considerable savings on the cost of using explosives. It was achieved by incorporating micro balloons into



EXPAN through the microscope – big bangs from tiny balloons

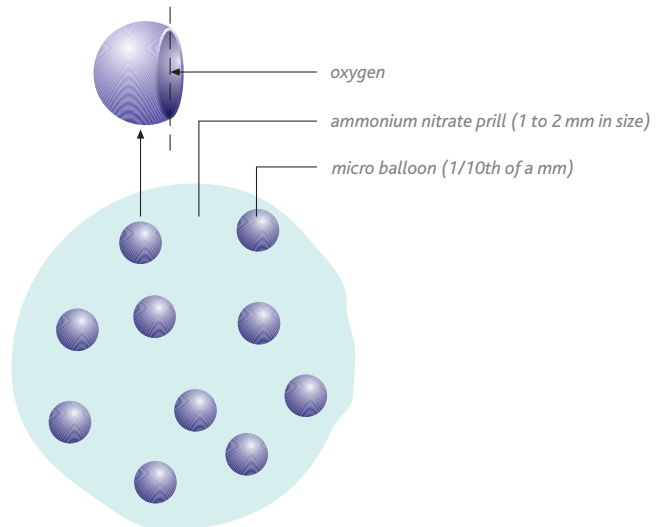
AN prills (granules or pellets), which no other explosives producer had thought of doing. It had two benefits. First, though the prills remained the same size, 10 per cent of their volume was now accounted for by the micro balloons. Since a blasting hole must be filled to a given depth with the prills, the result was a 10 per cent saving on explosives for each hole.

The second benefit was that explosives burned more completely because of the additional heat given off by the micro balloons when subjected to pressure at the beginning of the explosion. We're talking here of what physicists call *adiabatic compression*. Put a forefinger – or remember how you used to do this as a child – over the hole at the end of a fully extended bicycle pump and with your other hand push in the

handle to compress the air inside the pump. Your forefinger will feel hot because the compressed air is producing heat. When micro balloons are subjected to pressure from the beginning of an immediately adjacent explosion, the air inside them is greatly compressed and within a microsecond reaches a temperature of more than 3 000° C. That, of course, helps ignite the remaining explosives in the charge. Without micro balloons, about one-fifth of a charge remains unexploded.

Micro balloons are so small – less than one-tenth of a millimetre in diameter – they can barely be seen individually without a microscope; a handful of them looks like powder. They were being made for a decade and more before SMX ingrained them in ammonium nitrate pellets. The American

Cross-section of micro balloon

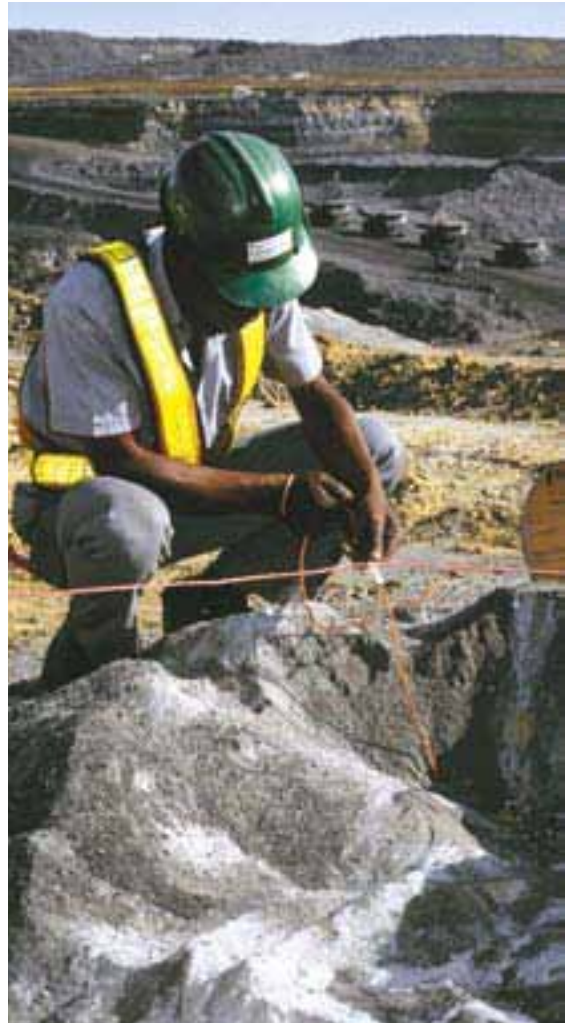


company, 3M, had been making them of glass; later, a Swedish company made them of plastic. Some companies had incorporated them into their explosives, though not into ammonium nitrate. Mostly, though, micro balloons were used mixed with inks to give an embossed effect, or to fill tennis balls (the air in the micro balloons survived blows from rackets longer than air contained only by the casing of the ball) or to bulk out plastics and putty.

SMX's technological triumph lay in working out how to ingrain them in ammonium nitrate pellets – called prills by explosives manufacturers. Prills are produced by mixing ammonium nitrate with a relatively small amount of water to produce what is known as a melt. This mixture is fed through showerheads located at the top of a tower, perhaps 80 metres high, to form droplets. As the latter fall, inside the tower, they cool and dry out to form porous prills which can later absorb diesel.

SMX's challenge was to find a way to introduce micro balloons into the melt before it went through the showerheads and started forming prills. It succeeded, and produced a prill no bigger in diameter than one or two millimetres, yet astonishingly containing 3 000 micro balloons. It calls the product EXPAN.

SMX's second triumph was to produce an advanced electronic initiator for detonating explosives. Its research into how to do that began soon after it began manufacturing explosives because of the advantage that would result from being able to offer customers not only explosives, but also the means for detonating them. But it couldn't be an initiator of the conventional kind. It had to provide the far greater timing



Preparation for blasting at an open-cast mine using explosives accessories

accuracy that electronic devices seem generally to offer: as in, for example, the electronic versus the mechanical watch.

There were compelling reasons for striving for that accuracy. The best way to remove a large amount of rock accurately and with least damage to whatever lies around it is by a number of relatively small and virtually simultaneous blasts rather than by a single enormous one. The aim, however, is not just to remove the rock, but also to break it into pieces small enough to be readily transportable. Blasters came to realise that if they charged a number of holes and detonated them in a sequence that had only microseconds between one blast and that next to it, the pieces of rock released by each explosion would, as they flew outwards, hit each other and further break them down. In the days of the Cold War, it was known as mutually assured destruction.

Detonation methods in use before electronic initiation systems were introduced could not provide sufficient timing accuracy because they all depended on small amounts of explosive material burning at a certain rate (i.e. pyrotechnics technology). But how to make an electronic device small enough to fit into the narrow confines of the hole drilled to take the main explosives charge? The traditional pyrotechnics detonator is no more than six millimetres in diameter and 30-40 millimetres long. How, too, to construct a delicate electronic initiator that would survive nearby blasts?

Rather than try to become overnight experts in electrical engineering, SMX commissioned the South African subsidiary of Britain's electronics and telecommunications giant, Plessey, to work on developing an electronic detonator. By the mid-1990s it

had come up with one that incorporated a battery. SMX decided putting a battery down a hole, then filling the rest of the hole with explosives, would be dangerous, so rejected the concept.

Instead, it decided to form a joint operation with Plessey to work solely on developing an electronic initiator. By then, two



A Sasol Mining Initiators-developed electronic initiation system

other companies unrelated to Sasol had succeeded, and their products, it was thought, might provide some clues as to the way to go. The joint operation was called Sasol Mining Initiators (SMI); it began its work in 1996, with Sasol holding 60 per cent of it. A sequence of corporate moves by Plessey and other parties saw that 60 per cent later become 80 per cent, but the

important point is that scientific skills were brought to SMI from within Plessey (now Tellumat) and Sasol.

By 1998 SMI had a product on which it could start test trials. A year or so later it was being exported, as well as sold within South Africa. Its great advantage over competing products is that the timing of each detonation – that is, the amount of delay between the first charge's detonation and that of any other charge – can be pre-programmed with great accuracy at the blasting site. Other electronic initiation systems still rely on an element of pyrotechnology.

In Sasol's 1998 annual report, shareholders were told SMX aimed to become "the world's leading explosives company." It didn't seem, to those who had been monitoring its progress, a wholly unrealistic target. About 100 000 tons of EXPAN were being exported each year to more than 50 countries, and a company, Continental Nitrogen and Resources Corporation (CNR) of Minnesota, had been licensed to produce and sell it in North America. In 1999 a plant was opened at Manitoba in Canada to produce nitric acid and ammonium nitrate. By 2000, SMX was providing six per cent of all Sasol's non-fuel revenue. (In 2001 it became Sasol Explosives again.)

For a diversification that had been launched no more than 16 years earlier, it was a remarkable achievement – almost as great a contribution as that coming from alpha olefins. Yet Sasol's technological triumphs with alpha olefins have caught the headlines, where those concerning explosives have not. Is it because explosives need too much technical explanation – or because alpha olefins are used in plastics, for which new uses seem to be found almost every year?



Initiators being assembled in Sasol Mining Initiator's Cape Town factory

Chapter 07 Pages 96 – 115 ►

Some very long chains

1860s

1839

Charles Goodyear's discovery paves the way for rubber tyres



Celluloid is invented, and used to make anything from billiard balls to false teeth



1966

South Africa's government supports the launch of a plastics industry in which Sasol will play a key role



Product development today is helped by computerised molecular modelling



Sasol starts production of polypropylene



Sasol's annual production of ethylene reaches 420 000 tons

Did you see the film, The Graduate?

The hero has just completed his four years at college and is agonising over what to do with the rest of his life. A middle-aged acquaintance tells him with great solemnity in which field he should make his career: plastics. Back in 1967, when the film was released, that advice seemed laughably crass.

Plastics were widely regarded as tacky substitutes for good, solid materials like glass, leather, wood, steel and natural fibres. The advice also seemed trite. Whatever you thought of them, plastics in the 1960s had become as commonplace as computers have today. Which is why South Africa's government decided, in the 1960s, that a local plastics industry should be launched, with Sasol providing its main raw materials or feedstocks.

The post-World War Two years had seen an explosion of demand for plastics. Before the war, today's most widely used plastics – polyethylene, polyvinyl chloride, polystyrene and polypropylene – were hardly known outside chemistry laboratories. Indeed, polypropylene was not known at all. But then, the production of materials that were wholly synthetic was barely half a century old.

They were preceded by what would eventually be termed "man-made" materials. These were produced by performing chemical wonders on natural substances. The first of them involved mixing rubber with a small amount of sulphur, which strengthened the rubber while retaining its elasticity. The surname of the man who had this inspiration in 1839, Charles Goodyear, has since been carried on millions of vehicle tyres.

His brother, Nelson, decided to push the envelope by mixing far greater proportions of sulphur with rubber. The result was a hard, black, mouldable substance he called Ebonite. He used it to make furniture; others made buttons and machinery parts from it.





After rubber came cellulose, a major component of all vegetable matter, especially of cotton. Before the

middle of the 19th century, chemists had discovered that cotton dipped in nitric acid produced an explosive material, nitrocellulose, and an even better one if sulphuric acid was mixed with the nitric acid. That led to a product called guncotton that was added to gunpowder in the 1860s. Soon after, two printers in Albany, New York, found that by dissolving nitrocellulose in camphor it became mouldable under heat and pressure. They called the result celluloid. It would eventually be used not only to replace ivory as the material for billiard balls, which had been the printers' aim, but also for making combs, brushes, photographic film, shirt collars and false teeth.



In 1892 a trio of English chemists dissolved cellulose in ammonia in which a copper salt had been dissolved. They called that solution "viscose", and the silk-like fibre they recovered from it "rayon". By 1895, the British company Courtaulds was producing rayon commercially.

Shortly before World War One broke out in 1914, two Swiss brothers, Camille and Henri Dreyfus, began producing lacquers and plastic film out of cellulose nitrate. Then they tried to produce continuous filament from it. When they eventually succeeded, they took the next train out of Basle for England. The war was still on, and they rightly reasoned there would be good money in selling their non-flammable lacquer as dope for the fabric that then covered aircraft wings. When the war was



over, they began developing the continuous filament side of the business, naming their "artificial silk" Celanese (cellulose + ease of care).

Out of cellulose, too, came a transparent film, the dream of another Swiss chemist who had been looking for a way to make natural textiles impervious to dirt and stains. He sold his patent rights to the US company, Du Pont, which marketed the film as cellophane.

Unlike these man-made materials, those termed "synthetic" result entirely from laboratory experiments in manipulating and reacting the molecules of different compounds to achieve new molecular compositions. When it comes to the plastics that resulted from these experiments, the first successes were in what are called thermosets. When the plastic resin has been put in a mould and subjected to heat, then cooled and removed from the mould, subsequent heating will not soften it, as it will with the other category, known as thermoplastics.

The first thermoset was produced early in the 20th century by Dr Leo Baekeland, a Belgian living in Yonkers, New York. It was a resin formed from phenol reacted with formaldehyde; Baekeland called it Bakelite. It was not only mouldable and



Leo Baekeland (left) led the way in developing synthetic plastics (right)

impervious to heat, but also non-absorbent and a poor conductor of electricity. These qualities would see it used eventually for a wide range of products, from moulded electrical parts and insulating varnishes to table tops, gear wheels and pump housings.

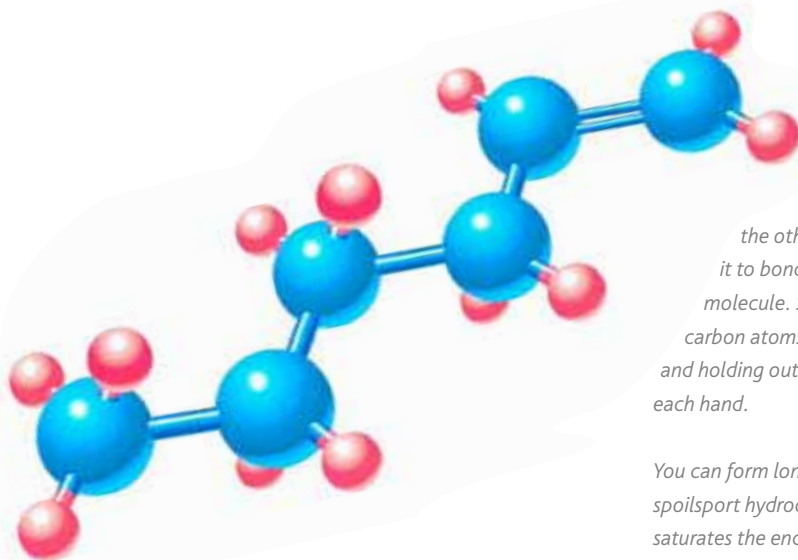
A British company, British Cyanides, decided to replace the phenol with either of two other organic compounds, urea and melamine, to make a resin that would be free of Bakelite's odour. It called the result "Beetle", changed its own name to British Cyanamid and licensed a US company, American Cyanamid Company, to produce it, too.

Thermosetting plastics offered little versatility, however, so in the early 1930s research chemists began looking more closely at what potential lay in thermoplastics. That required abandoning their scepticism towards revelations coming out of Europe.

Nineteenth-century scientists had calculated that certain natural substances were composed either of enormous molecules – starch molecules, they reckoned, had molecular weights of 40 000: that is, weighed 40 000 times as much as one hydrogen atom – or of many smaller ones that were somehow held together in clusters or networks. The latter theory was dismissed when, in the 1920s, the Swedish scientist Theodor Svedberg invented a device he called an ultracentrifuge, which could generate a centrifugal force hundreds of thousands of times greater than gravity. The machine, which helped him win a Nobel Prize for Chemistry in 1926, enabled him to determine with great precision the molecular weights of highly complex substances. Single molecules, he reported, could consist of hundreds of thousands of atoms and thus have molecular weights of 1 000 000.

At about the same time a German scientist, Professor Hermann Staudinger, proposed that molecules were held together not in blocks or networks, but formed long chains. That notion was further developed by a compatriot, Professor Herman Mark. Employed by IG Farbenindustrie as its director of research, he came to realise that major differences in polymers (many molecules joined together) would result from the degree to which their chains were branched (explanation coming up shortly). And different polymers would, of course, produce different thermoplastics.

We've seen that methane consists of one atom of carbon attached to four of hydrogen. Next comes ethane: two carbon atoms attached to each other, with each of their remaining hooks connected to a hydrogen atom – hence the chemical formula for ethane, C_2H_6 . Now, if you use a high-temperature



A graphic representation of an alpha olefin hexene molecule

You can form long, merry chains in that way until some spoilsport hydrocarbon molecule comes along and effectively saturates the end of the chain

process to sever a hydrogen atom from each of the carbon atoms – it's called dehydrogenation – you get ethylene (C_2H_4). To make use of the hooks that had connected them to those now-missing hydrogen atoms, the carbon atoms create a double-bond between themselves. The molecule, however, is called "unsaturated" because that double bond, as noted in an earlier chapter, is not a happy state of affairs; either of the carbon atoms would much rather connect with an atom in some other molecule.

Which, of course, they can quite easily if you put many ethylene molecules into a pot. The carbon atom in one ethylene molecule will remove one of its hooks from the other carbon atom in the same molecule and use it to bond with a carbon atom in another ethylene molecule. So you end up with a sort of Conga line of carbon atoms, each joined by its belt to the one in front, and holding out its arms sideways, with a hydrogen atom in each hand.

You can form long, merry chains in that way until some spoilsport hydrocarbon molecule comes along and effectively saturates the end of the chain. During the course of its growth, the chain may have developed molecular branches. That happens when a hydrogen atom at some point along the chain serves to link it with a shorter, unsaturated chain of hydrocarbons drifting around in the neighbourhood. This can happen many times along the length of the main chain.

But what has all that to do with plastics?

When you use the Fischer-Tropsch process to get hydrogen and carbon monoxide to form hydrocarbon molecules – or when you crack oil into its various fractions – you end up with molecules containing varying numbers of carbon atoms. Those that are saturated and contain three carbon atoms form propane, while four carbon atoms gets you butane. Dehydrogenate them to unsaturated molecules – also known as olefins – and you have,



respectively, propylene and butylene. All three olefins – C_3H_6 , C_4H_8 and C_4H_8 – get to be polymerised: the first two to produce plastics, C_4H_8 to produce synthetic rubber (and all of them to produce motor fuel).

That would not have been possible without the understanding gained by research scientists during the 1920s and 1930s, both of how to get molecules to form long chains, and of



different ways in which those chains can relate to each other and thereby produce products with markedly different characteristics. That knowledge was put to use during World War Two almost entirely to produce synthetic rubber and plastics for such things as aircraft windows and raincoats. Once the war was over in 1945, production facilities in Europe and the US were redirected to satisfying pent-up consumer demand for cars, refrigerators, washing machines, radios and toys.

There were no such facilities, however, in South Africa. In 1945 it was still largely a mining and agricultural country; there was little secondary industry outside of engineering shops serving the mining industry. When the National Party came to power in 1948, it set about trying to encourage the broadening of local industry, offering tariff protection, investment incentives and so on. But it was not until the mid-1960s that it had in place the beginnings of a programme for encouraging the local assembly of cars. Not until then, either, that it realised that plastics had great prospects and South Africa – like Ben in *The Graduate* – should get into them.

But where to start? Well, why not with ethylene? It was the basic building block for the biggest-selling plastic of them all, polyethylene (a name often shortened to polythene). Moreover, it was – together with benzene, which was readily available from South Africa's oil refineries – a basic component of styrene, which was used to make synthetic rubber as well as the plastic, polystyrene. Ethylene was being produced in Sasol's Synthol reactors, but not enough to meet the needs of a new plastics industry. So why not obtain it by cracking naphtha?



A fraction of crude oil, naphtha was almost being given away on world markets at the time because its straight molecular chains gave motor fuels produced from it a low octane rating. Using heat, pressure and steam, the molecules in naphtha – ranging from C_6 to C_9 – could be broken down and reformed. That would produce shorter chains, notably ethylene, and branched-chain or ring-shaped molecules containing six carbon atoms (benzene). Both types of molecule did wonders for petrol's octane rating.

Why, then, was naphtha being sold so cheaply? Because a naphtha-cracking plant was costly to build and to run because of its high power consumption. Why make that investment if naphtha's products could be obtained more cheaply from distilling crude oil?

For all that, the South African government decided to invest in naphtha cracking, and almost inevitably handed the task to Sasol. Other private-sector companies would establish plants alongside the naphtha cracker in Sasolburg to use its products. African Explosives and Chemical Industries (AECI), for example, would produce polyethylene since one of its two major shareholders was Britain's Imperial Chemical Industries (ICI), which had pioneered the polymerising of ethylene back in the 1930s. Butadiene – derived from butane – and styrene would go the Synthetic Rubber Company, controlled by Afrikaner business.

Sasol's first naphtha cracker was commissioned in 1966. It produced 80 000 tons a year of ethylene, which soon proved insufficient to meet AECI's needs. In 1969 a second naphtha cracker was installed, with a design capacity of 200 000 tons of



Another task looms for Sasol as South Africa's first naphtha cracker is built in 1969

ethylene a year. At that time naphtha crackers didn't yield more than about 10 per cent of what was put into them as ethylene, which meant Sasol's two crackers were treating 2,8 million tons of naphtha a year. They were also producing about 40 000 tons of butadiene a year. Most of the rest of the naphtha ended up as high-octane fuel components.

When Sasol Two came on stream, far more ethylene came out of it than was produced by the two naphtha crackers at

Sasolburg; a great deal more, too, than the market then required. AECl, together with another chemicals company, Sentrachem, had decided in the mid-1970s to provide some of its own plastics feedstock by making acetylene (more about that below). By the early 1980s, too, the local synthetic rubber industry was also facing extinction due to a surge – reflecting that of crude oil and naphtha – in the price of its feedstocks from Sasol, even as the market was being flooded with natural rubber from the Far East. With demand from the two companies for ethylene being met by Secunda through a pipeline that had been laid in 1980 to connect the two towns, Sasol decided its two naphtha crackers were no longer economic and in 1983 closed them down. Years later, when demand for ethylene exceeded Secunda's supply, ethane was sent through that same pipe to Sasolburg. There, in 1988, one of the naphtha crackers

By 1995 Sasol was producing 360 000 tons of ethylene a year. Today the figure stands at 420 000 tons

was modified and recommissioned to crack ethane to ethylene. By 1995 Sasol was producing 360 000 tons of ethylene a year. Today the figure stands at 420 000 tons, the increase achieved by some additions to installed capacity, as well as by plant debottlenecking.

Not all the demand in Sasolburg for ethylene came from AECl's original product, low-density polyethylene (LDPE). Some years after it began production, another company, Safripol, began making high-density polyethylene (HDPE).



Karl Ziegler

The process for producing HDPE had been pioneered in 1953 by Germany's Karl Ziegler. His technology differed from ICI's in that it did not require high pressure. That not only made it cheaper; it also produced a plastic that was significantly different in its properties from ICI's. Ziegler's HDPE was more flexible and had greater clarity than LDPE, though the latter had superior strength and was less permeable to gases.

By 1986, Sasol's olefin sales, coming mostly from ethylene, accounted for slightly more than 40 per cent of its total non-fuel sales. They enjoyed a fresh surge when Sasol decided to make both propylene and polypropylene.

Again, thanks were due ultimately to Ziegler. The pioneering work he had done in catalysis for high-density ethylene polymerisation was exploited by Italy's Giulio Natta to polymerise propylene. Ziegler had thought chain growth would not be possible for propylene, so had left that area uncovered by his patent. Natta and the company to which he was consulting, Montecatini, pounced quickly. In 1954, using catalysts very similar to Ziegler's, they produced polypropylene.



Giulio Natta

Ziegler was dreadfully miffed and refused to speak to Natta ever again, which must have produced an awkward situation when, in 1963, they had jointly to receive the Nobel Prize for Chemistry.

One has to feel sorry for Ziegler, if only because polypropylene turned out to be a remarkably versatile material. Some of it would end up as fibre with many industrial and domestic uses. It would also be blow- or injection-moulded into bottles, boxes, toys, casings for car batteries, patio furniture and so on. Part of its attraction lay in the fact that thin sheets of it could be repeatedly flexed without coming apart; instead, something like a hinge would be formed.

In the 1980s, more efficient catalysts were devised by Montedison (the former Montecatini), Japan's Mitsui and Company and Germany's BASF. By then, Ziegler was past caring – he had died in 1973 – but these advances saw production and consumption of polypropylene around the world grow even more rapidly: by 10 per cent a year, in fact – substantially higher than most developed countries' economic growth rate – with annual growth forecast to stay at five to six per cent until at least the mid- 1990s.

In 1987 Sasol reported that it was seriously considering producing propylene and polymerising it. Safripol was already producing polypropylene, its feedstock bought from local or foreign crude oil refineries. Why did Sasol want to enter the arena, too? Well, first because, with the core Secunda operations by now working efficiently, it had embarked on a beneficiation drive, seeing bigger profit margins awaiting it in plastics and other petrochemical products than that which petrol yielded.



Injection moulding offers marvellous product versatility

And to encourage beneficiation, there were those rapidly expanding world markets for polypropylene. Sasol intended to be the first South African polymer producer to establish production facilities largely aimed at the global rather than local market. Its competitive advantage would lie in the fact that propylene already existed in the stream coming from its Fischer-Tropsch reactors; all it had to do was separate them out. No costly dehydrogenation of propane would be needed.

Sasol erected a propylene polymerising plant alongside its purification plant at Secunda. Both plants came on stream in late- 1989/early- 1990 at a combined capital cost of R540 million. It also formed a new company, Sasol Polymers, to look after its propylene and polypropylene interests. Its success was rapid. By late- 1991 it had polypropylene customers in 130 countries, together taking more than 70 per cent of the plant's 120 000 tons a year output and providing



A major plant investment in Secunda (left) had Sasol soon dominating South Africa's polypropylene market and enjoying booming exports

sales revenue of R120 million. By 1993, it had captured more than half of the South African polypropylene market too, which was about 85 000 tons a year at that time.

The polymerising process Sasol chose had been developed by BASF. During the 1990s it improved its catalyst so that the rate of polymerisation rose. Sasol Polymers also made R110 million-worth of engineering changes to the plant to enable it to handle larger volumes of propylene. The latter were provided by

spending R170 million on additional purification capacity.

By the end of the decade, the polymer plant's annual output capacity had risen to 220 000 or more tons, and more than half of it was being exported.

Well before then, however, Sasol Polymers was looking about for other polymerising opportunities that would use its feedstock. Ethylene was the obvious one; Sasol was, after all, already purifying it to a high level for plastics-producing customers.

Ethylene is not the only feedstock for making plastics such as polyvinyl chloride (PVC). They can also be made from acetylene. That is produced by feeding lime, low-grade coal and anthracite into a furnace and cooking it to form a carbide slurry, which is then reacted with water to generate acetylene gas. AECI had invested heavily in such facilities at Sasolburg – where there were local supplies of coal quite independent of Sasol’s mining operations – in the mid-1970s. It was not a process that could compete economically with using ethylene as the feedstock, not at the price ethylene cost in 1985, but AECI used it to provide much of its feedstock needs well into the 1990s. Came the 1990s, though, and South Africa went through two major changes. One was political: the end of white supremacy. The other had to do with international trade and tariff barriers. Industries that had previously been heavily protected against imports by the Nationalist government, under its policy of promoting economic diversification, were suddenly exposed to the bracing wind of international competition. Some couldn’t cope. Among them were AECI’s chemical-producing activities, especially the plastics operation.

At the beginning of 1994, Sasol and AECI merged their ethylene and propylene monomer and polymer businesses into a venture called Polifin. For Sasol it meant an enlarged market for its ethylene; to AECI it offered reduced costs and expanded activities. So into Polifin went Sasol’s ethylene, propylene and polypropylene operations and AECI’s facilities for producing PVC, polyethylene, hydrochloric acid, caustic soda, and mining reagents such as sodium cyanide and calcium cyanide. Based on the value of their respective asset contributions, Sasol held

60 per cent of Polifin and AECI 40 per cent. The rationale for the joint venture was that Sasol’s ethylene would replace acetylene in return for Sasol getting access to AECI’s well-developed plastics markets.

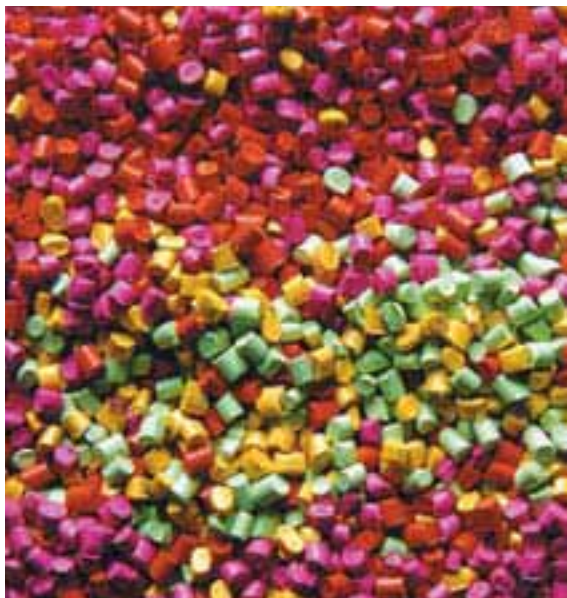
Because the intention was that both companies would be equal partners in Polifin, Sasol had accepted that it should sell a portion of its shareholding to the public as soon as Polifin was operating with sufficient credibility to make that feasible.

At the beginning of 1994, Sasol and AECI jointly formed a company they called Polifin

Despite the challenge of bringing two very different cultures together, Polifin operated well from the start, so Sasol sold 18 per cent of Polifin shares to the public, reducing its own stake to 42 per cent.

Meanwhile, Sasol and AECI continued to compete with each other in explosives and fertilizers. AECI’s overall operations weren’t doing well, however, and the dividends it was receiving from Polifin became increasingly important in keeping its ship afloat. That irked Sasol because, though AECI had much expertise in polymerisation, Sasol’s contribution to Polifin’s success – its ethylene and, no less important, its skill in operating plant at maximum efficiency – was at least as valuable. By 1999 AECI was deeply in debt. Sasol sought to take it over, but was prevented from doing so by South Africa’s Competition Board. It was, however, allowed to buy AECI’s and the public’s shares in Polifin, which happened on 1 July 1999.

The Polifin story is important for several reasons in tracing the history of Sasol's development. It saw Sasol exploit the competitive edge provided by the Fischer-Tropsch process to get further into downstream activities. It gave Sasol access to AECI's skills in promoting the use of new plastics, such as linear low-density polyethylene, in underdeveloped economies. Finally, it also saw Sasol benefiting from its meeting the challenge of bringing together people from different cultures to function efficiently in a single organisation. All of these have led to Polifin engaging in multinational ventures in Malaysia: a low-density polyethylene plant, and a 635 000 tons-a-year ethane cracker next door to it. Sasol Polymers is involved in operating



the polymer plant and selling its output in South-East Asia, and has contributed capital for the ethane cracker.

While Sasol was getting involved in polymerisation, its chemists had been looking at other ingredients in the Fischer-Tropsch product stream. Their interest focused on certain compounds that could be used to improve the properties of polyethylene or to make chemicals of value to the detergent industry. These compounds are called alpha olefins.

We have seen why ethylene and propylene are called olefins and how they will, given the right catalyst and other conditions, polymerise to form long chains. Propylene will do so because there is a double carbon-to-carbon bond at one end of the three-carbon chain. Scientists therefore call it an alpha olefin (alpha being the first letter of the Greek alphabet). All polymerisation requires alpha olefins.

You find alpha olefins right along the carbon-number sequence. If they have four, six or eight carbon atoms, they can be polymerised with polyethylene to make it clearer, stronger or more flexible. Those with 12 or more carbon atoms are the starting point for producing detergent alcohols, synthetic lubricants, lubricating oil additives and surfactants, which are substances that reduce the surface tension of liquids, and are therefore used widely in industry, from mining to textiles.

The trouble with plastics comonomers is that, like all other plastic feedstocks, they need to be extremely pure, otherwise

*Left: Colourised polyethylene pellets
Opposite: Alpha olefins distillation columns at Secunda*





they'll poison the catalyst used in polymerisation. It's no problem recovering propylene to that degree of purity. But 1-pentene (an alpha olefin with five carbon atoms), 1-hexene (six) or 1-octene (eight) are an altogether greater challenge. Here's why.

One of the basic ways of separating one liquid from another is called distillation. It works on the fact that one of them will start evaporating more rapidly at a given temperature than the other. That is because its boiling point, the temperature at which it turns from liquid to vapour, is different. A molecule's boiling point is closely related to its weight: the higher the weight, the higher the boiling point.

The oil industry and Sasol separate liquids by building distillation columns; indeed, they are one of the defining features of their sites. Imagine a mixture composed of two compounds of substantially different molecular weights. We'll call the lighter one A, the other B. The mixture is fed into the bottom of the column and heated up sufficiently to cause both liquids to evaporate completely. The resulting gaseous mixture rises under pressure. As it does so, it meets the first of a series of trays mounted, one above the other, in the column. Each tray is so designed that it can contain liquid into which the gas is led, cooling it down a little. Some of compound B is going to condense into the liquid because of this cooling, but probably none of compound A. That causes the tray of liquid to overflow. The spilt liquid is collected at the bottom of the column for reheating into a vapour.

Left: A propylene distillation column is raised into position



Meanwhile, the gaseous mixture bubbles up through the liquid and rises to the second tray, where a little more of compound B will be condensed. Given enough trays, you can get rid almost entirely of compound B. The number of trays needed to achieve that depends on how great the molecular difference is between the two compounds. To separate propylene from propane, their boiling points differing by only 5,6°C, Sasol Polymers needs a distillation column containing hundreds of them, which is why it is 104 metres high, making it at the time of its construction the highest such structure in the southern hemisphere. Physically impressive, but not involving technology that would cause any present-day chemical engineer to do a double-take.

It's quite different when separating alpha olefins containing five, six or eight carbon atoms. The challenge with them is that they come accompanied by an awful lot of siblings and cousins; the scientific word is isomers. That's because there are different places in the molecule where that carbon double-bond can locate itself. Put it in one place, and you have sister Kate; put it in another and you have cousin Charles. The more carbon atoms, the greater the number of possible isomers; indeed, it increases exponentially.

All you are interested in, however, is the alpha olefin; the isomers have properties you don't want. But all the molecules have the same weight; contain the same number of carbon and hydrogen atoms. Because of that their boiling points are impossibly close together, so trying to separate out your alpha olefins by distillation ain't going to work. Oil companies got round the problem by joining ethylene molecules together. It wasn't feasible, however, for Sasol to follow that route. To be price-competitive, it had to invest in large-capacity plant to get

economies of scale. With little local demand, however, that meant being able to sell competitively in world markets. To offset the heavy transport costs of getting its product to those distant markets, it had to exploit the fact that hexene and other alpha olefins were already in its product stream. And that meant finding a way round the close boiling point problem.

An American company, UOP, had a solution. It employs what is known as a molecular sieve: different materials to absorb different kinds of molecules. When it told Sasol what its licence fee would be, however, the South Africans threw up their hands in disbelief, vowing that they would find their own solution rather than pay such an exorbitant charge. And within a few years they did.



Product samples awaiting quality analysis at Secunda

There are differences in electrical properties between the different olefin isomers. Add a particular solvent to the mixture and you exaggerate the electrical properties of one of them. Doing so changes its boiling point, which widens the boiling point difference between it and other molecules in the mixture sufficiently to make distillation feasible. There is a range of such solvents, each changing the electrical properties of a particular isomer. You extract them one by one, which is why it is called extractive distillation.

Some of the isomers will be branched. This makes them more reactive (disposed to link up with other molecules) than straight-chain olefins. So chuck in some methanol with which they can bond. That produces a larger, heavier molecule with a higher boiling point that can be separated out by distillation. The process is called selective reaction. Sasol's scientists began

The scientists made good progress. In late 1992, chairman Joe Stegmann told shareholders a pilot plant to produce pentene and hexene had been built and successfully commissioned. Product samples had been sent to various potential customers, who had responded encouragingly. In 1994 a twin-train plant to produce 100 000 tons of pentene and/or hexene a year at Secunda was commissioned. By then, world demand for hexene was growing rapidly. To keep up with it, the Secunda plant was debottlenecked over the years, so that its eventual annual production capacity was 140 000 tons. That still wasn't enough to keep Sasol Alpha Olefins customers – most of them in North America, where the company had early on established a sales office – fully supplied. In 2000 a third train, costing almost R300 million, was commissioned to produce a further 80 000 tons a year. By then, the company had won more than 25 per cent of the world market, despite global demand growing at more than eight per cent annually.

At that time the virtues of hexene as a comonomer were just beginning to be realised around the world

researching how to use these two pre-distillation processes in the second half of the 1980s at much the same time Sasol was designing and building its propylene and polypropylene plants. At that time the virtues of hexene as a comonomer were just beginning to be realised around the world. Sasol decided therefore that its fundamental research into achieving high-purity alpha olefins would begin with hexene; with pentene, too, because it might have commercial advantages over other alpha olefins.

But what, meantime, of pentene? Sasol had hoped it would offer the properties of hexene but at a substantially lower price. It wasn't successful in that and the market preferred, anyway, to stick with hexene because using pentene would have required changing plants – and who, in all good sense, would do that when Sasol was the world's sole producer? Small amounts of pentene are nevertheless being produced; as a comonomer, it improves the clarity of polypropylene film.

Sasol's scientists turned their attention next to octene and the detergent-alcohol range of alpha olefins, C₁₂-C₁₅. The difference between hexene and octene lies not in the qualities they add to

a basic plastic polymer. Rather, it comes down to whether a manufacturer wants to use his comonomer in the gas or liquid phase: if gas, then he chooses hexene; if liquid, octene. Sasol's researchers battled, however, to find a way to separate octene, and eventually turned their attention fully to the heavier alpha olefins. The eventual end of these would be a product used by manufacturers around the world to produce surfactants that, in turn, are used in shampoos, soap powders and other detergents. Nice business; people are getting ever more obsessive about cleanliness.

But then came a call from the American plastics producer, Dow Chemical Company: "There's a shortage of octene developing. Could you produce it?"

The science of chemical engineering was by then using computer modelling. Sasol's people tapped in such data as



... made from unsaturated molecules called olefins

they had and with unlikely confidence, given their earlier frustration, replied: "We reckon so. It would be only 95 per cent pure, but the impurities in it wouldn't be of the kind to poison your polymerising catalyst."

"You've got three months to provide us with 100 litres of the stuff. Meet that deadline and your quality assurance, and we'll take 50 000 tons a year from you."

Now that amount of guaranteed offtake was enough to keep a plant of economic size fully occupied. There is, however, a big distance to be travelled between an early computer-based assessment of a project's technical viability and finding ways to produce a substantial amount of product. Covering it in only three months would be a huge challenge.



Washing powders, detergents and shampoos are all...



Sasol needed empirical data that didn't exist because what it was proposing to do to get octene had never been done before. Research in that area was, however, being done at the University of Oldenburg, and those doing it agreed to work on producing the required data. Other foreign, laboratory-scale facilities were used to produce the octene in batches. There were no laboratory facilities anywhere to test it for purity, so Sasol tested it in its own ethylene polymerising plant. It proved as good as octene produced elsewhere by oligomerising ethylene; the deadline had been met; Dow signed a supply contract.



Sasol's chief executive, Pieter Cox, receives the President's Award for Export Achievement from President Thabo Mbeki

With world demand for detergents growing, it promises to be a lucrative business for Sasol Alpha Olefins

A 50 000 tons-a-year octene plant was commissioned for Sasol Alpha Olefins at Secunda in 1999. It had taken a mere 28 months to design, build and commission a plant that cost R369 million. All of its output would go to Dow. Even before it was completed, Sasol planned to have a duplicate plant. It will come on stream in 2004.

In 1999 Sasol Alpha Olefins won the President's Award for Export Achievement. When accepting the award from South Africa's president, Thabo Mbeki, Sasol's chief executive, Pieter Cox, could have been forgiven for murmuring:

Opposite: Alpha olefins octene plant at Secunda

"You ain't see nothin' yet." On the drawing board was a second octene plant, even as design and other work continued on a detergent alcohols plant. The latter is a R1 billion project, scheduled to come on stream at Secunda in the first quarter of 2002. With world demand for detergents growing a little more quickly than the broad economy, it promises to be a lucrative business for Sasol Alpha Olefins (now part of the Sasol Olefins and Surfactants business). In mid-2000, fuel was fetching US\$220 a ton on world markets, detergent alcohols US\$1 200.

Pursuing global chemical opportunities was really paying off. International competitors weren't, however, standing by complacently watching Sasol capture ever larger market share. To meet their technological advances, especially those that reduced production costs, Sasol would have to produce more of its own.

Fortunately, it had an ace up its sleeve.

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Getting off the merry-go-round

1981

Sasol begins designing a radically different kind of Fischer-Tropsch reactor known as Sasol Advanced Synthol (SAS) using a 100 barrels-a-day pilot plant (below)



1995

The first SAS reactor comes on stream at Secunda



1996

Sasol decides to mothball its Synthol reactors



1999

Imported SAS reactors travel by road to Secunda where they soon create new production records



By the late-1960s Sasol's research engineers and plant operators had, as we've seen, overcome the main problems presented by the Synthol reactors. Nevertheless, they remained tricky as well as expensive to operate and maintain.

That seemed unavoidable, given the reactor's basic design concept of having the catalyst, entrained in rapidly moving gas, flow through large-diameter pipes from hopper to cooling section, through cyclones and back to hopper.

That approach meant, among other things, that only the catalyst that, at any moment, was in the gas between the bottom of the hopper and the cooling section was taking part in the conversion of gas into hydrocarbon molecules – and that amounted to no more than one-third of all the catalyst in the reactor. Driving the gas with sufficient pressure to entrain the catalyst also consumed a lot of electricity. And having many tons of abrasive catalyst swirling around inside the pipes meant the latter had to be lined with expensive ceramic material.

Why, asked Sasol's young research scientists in the late-1960s, had Kellogg come up with the idea of the Circulating Fluidised Bed? What was wrong with feeding gas upwards through an essentially static bed of catalyst? It wouldn't have to be under great pressure, and each particle of catalyst would move only slightly, floating in the gas that would thus make contact with each particle's entire surface area, which is where chemical reaction takes place.

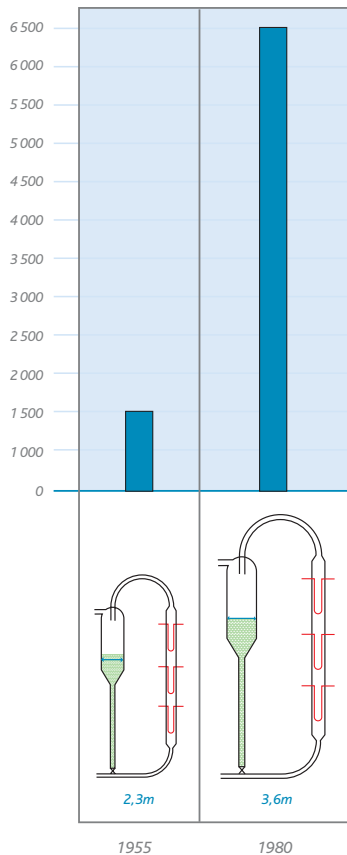
It wasn't a new idea. Indeed, it already had a name, Fixed Fluidised Bed (FFB), to distinguish it from other kinds of reactors. "Fixed" meant it didn't swirl around, as in the Synthol reactor. "Fluidised" meant its particles could move around, rather than being jammed immovably into tubes, as in the Arge reactor. "Bed" meant that, as in a coal gasifier, the solid material lay metres-thick at the bottom of a reaction vessel rather than in, say, a hopper.

It not only had a name, it also had a history – but, alas, not an encouraging one. During the 1940s, when there was worldwide concern that crude oil reserves would soon be used up, a group of Americans, headed by "Dobie" Keith of Hydrocarbon Research Inc, a company engaged in developing new refining processes, had a plant built in Brownsville, Texas, to convert natural gas into petrol using an FFB reactor. It ran into technical problems, however, and when the price of natural gas started to rise steeply and fears of oil shortages disappeared with the discovery in the late-1940s and early-1950s of huge reserves in the Middle East, the project was abandoned.

The nature of its technical problems was never revealed, but others have reckoned they stemmed from the industry's paucity of knowledge at that time about catalysts and how they

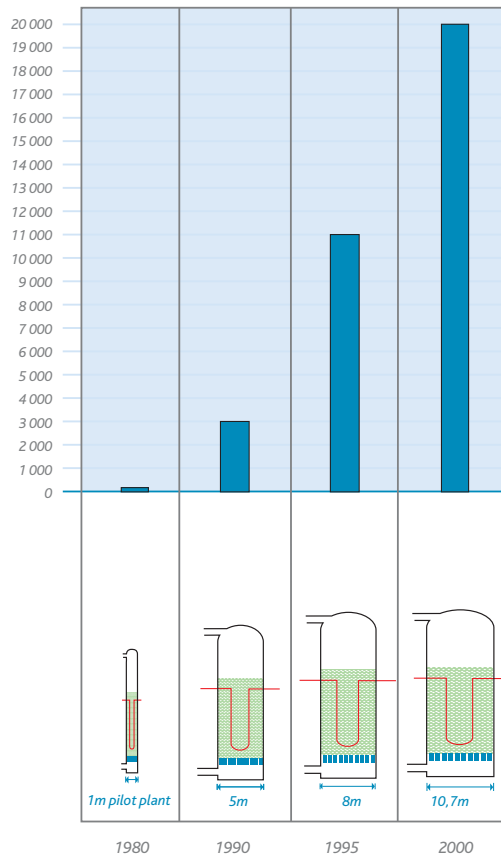
New high-temperature technology increases output hugely

Barrels per day



Circulating Fluidised Bed reactor
(relative size)

Barrels per day



Sasol Advanced Synthol (SAS) reactor
(relative size)

perform, let alone how to get them to produce only what you want. The Brownsville operators, they say, watched helplessly as the gas formed wax and carbon on the catalyst particles. The wax caused particles of catalyst to stick together, forming balls too heavy to float in the gas. Carbon also affected the bed's fluidisation properties because it is less dense (ie, it's lighter) than the catalyst, which means you need less pressure of gas to keep a cubic centimetre of carbon-coated catalyst afloat than you do for uncoated catalyst. In short, the FFB reactor produced petrol, but it was seriously unstable.

When, therefore, the American engineering consultancy M W Kellogg was asked by Sasol to design a high-temperature Fischer-Tropsch reactor, it gave the FFB concept barely a glance since overcoming the catalyst problem could take years. Instead, it came up with the idea of having the catalyst vigorously entrained in gas, so that it didn't matter if catalyst particles weren't all of the same size and density. Unfortunately, it didn't foresee the problems circulating vast amounts of the catalyst would cause, having tested the idea only at laboratory scale.

By the late-1960s, however, Sasol's scientists had done a fair amount of research on iron catalysts, and had gained quite an understanding of them and competence in designing them to produce specific ranges of hydrocarbon molecules. That knowledge, too, had been gained through experiments using fluidised beds of catalysts in laboratory equipment. It was therefore time, some of them thought, to revisit the challenge of using the FFB concept at a commercial scale.



They worked on it throughout the 1970s. Eventually, someone had the bright idea of building large perspex models of the reactor so that they could actually see what was happening to the catalyst when gas bubbled through it. The trick, they came to realise, lay not only in getting the right composition of catalyst, but also the right distribution of gas so that it was, horizontally speaking, evenly distributed throughout the catalyst. The latter rested on a thick steel plate welded into the lower part of the vessel. Holes were drilled into the plate so that gas, fed into the vessel below the plate, would move through the holes and thereafter through the catalyst.

Sasol was aiming to market a new high-temperature Fischer-Tropsch reactor internationally

Why didn't the catalyst fall through the holes? Because it would be held up by the pressure of the gas. But that begs the question of the relationship between the pressure of the gas and the size of the hole, and therefore of how many holes would be needed for a vessel of a given diameter. Too few holes would have the gas not interacting with all of the catalyst. In short, a tricky problem that was best solved by trial-and-error methods.

And that was just at the pilot plant stage. What was eventually found to work well on that scale had to be enlarged to a demonstration model, and that means a huge jump in size, from a reactor of 50 millimetres in diameter to one of about 80 centimetres. The latter, in today's money, costs about

R2 million to build, so you have to persuade the men in suits that it's worth it. And having done that, you have to get it built, which takes more than a few weeks, during which you busy yourself with other matters. Then, when the demonstration model is ready, you try it out, encounter problems, define their causes and find solutions.

All of which explains why it wasn't until 1981 that the go-ahead was given for designing an FFB demonstration reactor. It doesn't explain, though, why Sasol's management bought the idea. Within a few years, after all, Sasol would have 16 new Synthol reactors working in Secunda.

Truth is, Sasol was aiming to market a new high-temperature Fischer-Tropsch reactor internationally. Encouraging it in this was the American engineering consultancy, Badger, which had introduced Sasol to the idea of the serpentine cooling coil and had suggested, when Secunda was given the go-ahead in late-1974, that FFB reactors should be installed there. Sasol had rejected the idea because it was still way underdeveloped, but it maintained an ongoing collaboration with Badger – which would eventually be swallowed by the Boston-based Raytheon Engineers & Constructors – in designing FFB reactors and getting them to work.

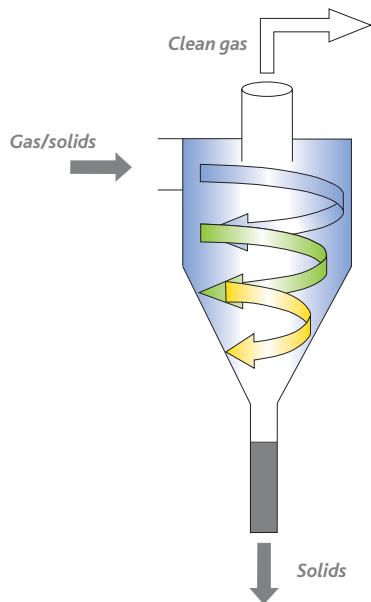
The demonstration reactor was built and commissioned in 1983. Sure enough, problems were encountered that hadn't shown up in the pilot plant: optimal gas distribution and how to remove catalyst that had travelled upwards in the gas from the bed. It took four years before the researchers felt they could confidently recommend moving to the next size of reactor, one with a diameter of five metres. They did so in 1987, won

management's approval and, together with Badger/Raytheon, set about designing the larger reactor. Installed at Sasolburg, where it could more easily than at Secunda be supplied with utilities and upstream and downstream support units, it was commissioned in May 1989.

Everyone applauded an apparently painless launch. After about three months, though, problems were picked up with the cyclones. Catalyst had blocked the pipe at the bottom of each of them, instead of falling through it, back to the bed. That was a problem that had not been anticipated, and it took the better part of a year to solve.

A cyclone is shaped like a funnel. If you feed a gas mixed with solid particles into it, at some speed and at an angle rather than straight down the middle, you create two forces. One is centrifugal, driving the relatively heavy solid particles outwards to the wall of the cyclone, where they slide downwards, then through the tube. The other force is an upwardly spiralling whirlwind in the centre of the cyclone. It carries the gas away.

Cyclones were used in the Synthol reactors. Catalyst descended through them into the hopper, while the product gas was removed for further treatment. They also had to be included in the design of the FFB reactor because some catalyst was carried upwards in its gas despite the latter travelling at a far lower speed than in the Synthol reactor. But how much catalyst was carried upwards in the fixed fluidised bed? Far less, it turned out, than had been forecast. As a result, it built up only slowly in the cyclones' downpipes, giving it time to coagulate and block them.



Sasol's process engineers decided to experiment with the design of the cyclones. One of the problems was that if they made them more efficient by increasing the velocity of the gas directed into them, the catalyst in the gas would erode the walls of the cyclones and cause holes to form in them. Eventually they hit on an acceptable compromise between how much catalyst was left in the gas – to be washed out later in gas-cooling quench towers – and how much was returned to the bed through the cyclones.

The reactor was run until 1990. By then, Sasol knew it offered great advantages over the 16 Synthol units at Secunda. Less catalyst was required to give the same hourly rate of product

because all of it was, at any moment, being used. The greater internal space of the reactor meant more cooling coils could be installed, which meant far more catalytic reaction could be controlled, leading to a surge in output capacity compared with the Synthol reactor. Because most of the catalyst, too, barely moved, it was not broken down, so didn't need replacing nearly as frequently. That virtually all the catalyst remained in the bed meant the temperature of the bed was the same throughout it. All of which meant the reactor was far easier to operate because it was more stable, and was also cheaper to run. Maintenance costs would be far lower, too, given the absence of structural movement and erosion, and longer periods between maintenance shutdowns. Sasol decided to call it the Sasol Advanced Synthol (SAS) reactor.

Still, having proved the point, there was no point in continuing to run it. To compete with the Synthol reactors, it would have to be scaled up to an eight-metre diameter. In any case, it had been recently decided that Sasolburg would, from now on, run only low-temperature Fischer-Tropsch reactors. Yet to close the SAS reactor down and leave the matter there would have been foolish. Oil companies elsewhere in the world were becoming interested in converting natural gas into motor fuels and petrochemicals. If Sasol failed to continue advancing and exploiting its technology, it would eventually cease being internationally competitive.

In 1992, Sasol decided to install at Secunda a SAS reactor with a diameter of eight metres. The only feasible location was alongside the most recently installed Synthol reactor. Upstream and downstream units serving the latter would be disconnected and reconnected to the SAS reactor.



In little more than a year, seven SAS reactors were erected at Secunda and successfully commissioned

The plant operators stood agape at this decision. That particular Synthol reactor was working more smoothly than any of the others, if only because it was the youngest. For all that, it was to be taken offline in favour of a new kind of reactor that had yet to prove it could replicate its product slate, the portions of the emerging gas accounted for by various carbon-chain lengths. That ability could not be taken for granted: for one thing, the ratio of carbon monoxide to hydrogen in Secunda's synthesis gas differed somewhat from that produced in Sasolburg, where the SAS reactor had shown its product-slate capability. Yet failure to produce the same product slate as the Synthol reactor would be disastrous because downstream units had been designed, and were operated, around it.

It turned out to be an unnecessary fear. The process engineers had done their mathematical modelling well. When the R123 million SAS reactor was commissioned in June 1995, it worked like a dream. All the operational cost savings that had been forecast in Sasolburg were achieved. Operators, too, were won over; the more stable conditions inside the SAS reactor, as well as its more automated controls, made it far easier, not to mention safer, to work with.

In March 1996, Sasol decided to replace all its Synthol reactors at Secunda with Sasol Advanced Synthol reactors. The operational efficiencies promised by the latter were too attractive to resist. Sasol's international competitiveness was, after all, heavily dependent on its ability to lower production costs. And the government had announced recently that the tariff protection the synthetic fuel industry had enjoyed for close on two decades would be reviewed in 2000.



A large section of a new SAS reactor being transported from Richards Bay, on South Africa's east coast, to the Sasol Synfuels site at Secunda. This was part of the largest superload to be conveyed on South African roads

When the R123 million SAS reactor was commissioned in June 1995, it worked like a dream

Introduced at the time Sasol was privatised in 1979 to give investors some protection against the vagaries of the oil price, it initially consisted of payments produced by imposing a levy of 2,7 cents on every litre of white products (petrol, diesel, illuminating paraffin and liquid petroleum gas) that Sasol sold to the oil companies. Ten years later, at the request of the government, a firm of auditors and the Industrial Development Corporation together designed a new approach, based on a

"floor" price for crude oil. If it fell below a certain level, Sasol would receive tariff protection, its amount worked out daily under a formula of which the main parameters were the oil price and the US dollar/rand exchange rate.

Government accepted the idea, and set the bar at US\$23. In 1993 it was lowered to US\$21,80. In 1995, following a further study by auditing and consulting firm Arthur Andersen, the

synthetic fuel industry, which now included Moss gas – an enterprise using Sasol technology to produce fuels from natural gas reserves located off the southern Cape coast – as well as Sasol, accepted a proposal from the government that the floor price be steadily lowered, year by year, down to US\$16. Arthur Andersen also recommended that the whole idea of protecting the industry be re-examined by mid-2000.

Tariff protection was important to Sasol. Over the decade 1990-1999 it would amount to R6,6 billion. Compared to the R3 billion Sasol was annually investing in plant at Secunda and Sasolburg, with all that implied for job creation, and the billions of rands-worth of foreign currency saved and earned each year by Sasol's operations, that was chicken feed. But not when compared to Sasol's pre-tax profit over the decade. It amounted to about one-quarter of that, so the prospect of tariff protection disappearing, no matter what the crude oil price was in rands, was not to be airily dismissed.

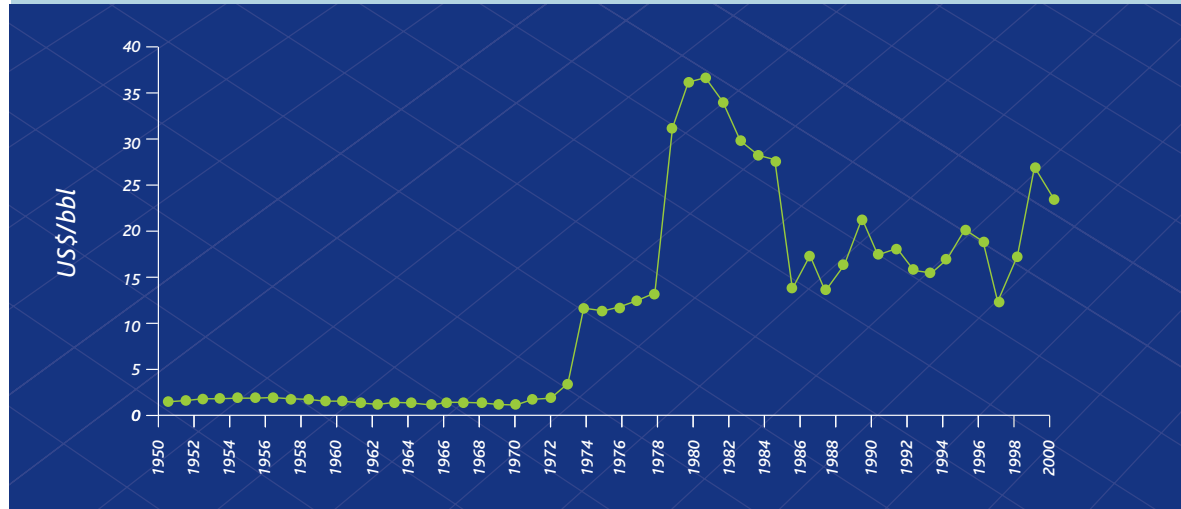
Sasol's management decided that Secunda's Fischer-Tropsch operating costs had to be drastically reduced. How much could be achieved with the Synthol reactors? Very little. They had by now been in operation for 15 years; whatever improvements could have been made to the original design and operating methodology had, it was generally agreed, already been largely achieved. But SAS reactors would be an altogether different matter.

Implementing the decision to replace all the Synthol reactors, however, would be quite a challenge. How big, for example, should the SAS reactors be? Scale-up should not present an engineering problem, given the data and lessons that had been



Assembling a SAS reactor – there was little room to move

Crude oil prices US\$/bbl



learned from the eight-metre-diameter reactor. So what about reactors 13 metres in diameter, the largest that foreign fabricators' furnace and rolling facilities would be able to handle? No — too big. South Africa's roads couldn't handle something of that size and there would be so few reactors that taking one offline for scheduled maintenance would reduce total output by far too large a percentage. Anyway, what would be the point in such a huge total reactor capacity if upstream and downstream units couldn't handle it?

Then someone observed that the intention was not to provide significantly increased capacity, but to lower running costs. So what did Secunda's present capacity convert to in terms of

the biggest SAS reactors that could be transported? If the biggest was 10,7 metres in diameter, six would be needed, three on each site. Not a good idea; the existing upstream and downstream units formed two trains on each site, each train serving four Synthol reactors. But you can't divide two by three when it comes to plant because you'd end up with a confusion of duplicated connections; and anyway, there was already an eight-metre reactor in operation. Well, asked someone, why not have four SAS reactors on each site, two of 10,7-metre

Opposite: Even allowing for perspective, the goose-necked Synthol reactors are clearly far larger than the SAS reactors seen on the left



diameter and two of eight-metre diameter, the latter having about half the catalyst and production capacity of the larger reactor? Bingo!

A Japanese consortium consisting of Hitachi Zosen Corporation and Marubeni Corporation won the contract to fabricate the required seven reactors, each in six or seven separate sections for on-site assembly. The first shipment of sections arrived in Richards Bay in late-1997, the last in February 1998. Each was then borne over 550 kilometres of national highway to Secunda. Distorting a section, the heaviest of which weighed more than 200 tons, by dropping it would have been disastrous not only for the road, but also for the construction schedule since the section would have had to be returned to Japan. So the speed at which the sections were carried was stately, ranging between five and 15 kilometres an hour, depending on



SAS reactors being fabricated in Japan

The new reactors were a joy to operate, not only because of their basic design concept, but also because of their cutting-edge controls

road conditions. The one-way trip took 10 days. The first of the new SAS reactors came on stream in September 1998, the last in February 1999. Installing them took 1,35 million man-hours, which were worked without incurring a single injury. No less pleasing, their commissioning was painless. What made both achievements remarkable was that the SAS reactors had to be installed alongside the older circulating fluid bed (CFB) Synthol reactors. That meant working in a cramped space to build the new reactors, then

uncoupling the CFB Synthol reactors and connecting the SAS units. Given the maze of pipes that surround a reactor, 36 hours had been allowed for uncoupling a CFB Synthol reactor and connecting the pipes feeding into and out of it to its

SAS neighbour. It says something for the enthusiasm and competence of Sasol's men that they, in no instance, took more than 28, and sometimes only 18 hours.

The CFB Synthol reactors had to be left in place; there wasn't room or time to dismantle them if production was to be maintained without interruption at the two sites. As it was, the 1998/99 year saw Sasol Synthetic Fuels achieve record production volumes. The SAS reactors began producing the



SAS's debut heralds greater operational efficiency

required product slate immediately to their full capacity, and downstream units had been debottlenecked to take it all.

Not surprisingly, given that the first SAS reactor had been working at Secunda since mid-1995, the operational savings provided by the seven others over the next year or so came fully up to expectations. The cost of catalyst was at least halved because far less had to be used to react a ton of purified synthesis gas. Less power was required, too, to reheat recycled gas because, owing to the greater conversion efficiency of the SAS reactor, less of it was produced. That meant the heat produced by the Fischer-Tropsch reaction, or at least that part of it that was captured by the heat-transfer coils hanging in the catalyst bed, could be used elsewhere in the plant, namely as steam to drive turbines. And the net effect of that was a

substantial reduction in the amount of electricity that had to be bought from Eskom.

Maintenance costs looked like being 85 per cent lower than those of the Synthol reactors, partly because each reactor would have to be shut down for two weeks only once every four years against the older reactor's two years. And the cherry on the top was that the new reactors were a joy to operate, not only because of their basic design concept, but also because their cutting-edge controls enabled operators to keep close to the desired product slate. All in all, the R1 billion Sasol had spent on the reactors looked well spent; it had reduced Sasol Synthetic Fuels operating costs by the equivalent of US\$1 a barrel of crude oil.

Within a year or so, Sasol decided it had to have another eight-metre SAS reactor. Using downstream units that had been mothballed when the CFB Synthol reactors were pensioned off, the reactor would be powered up to stand in for any of the other eight going offline for maintenance. In that role alone it would soon repay its R220 million capital cost since it would yield a daily operating profit of about R1 million. This time it was a Korean firm, Hyundai Heavy Industries, that got the contract. By late-March 2001 the reactor it had built was on the road from Richards Bay, soon to be followed by Korean welders who would join together the 70-millimetre-thick walls of the reactor's sections.

Meanwhile, over in Sasolburg a new kind of low-temperature Fischer-Tropsch reactor had made its debut. It, too, held enormous promise – not only for Sasol's operations there, but also for its international ambitions.

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New global prospects

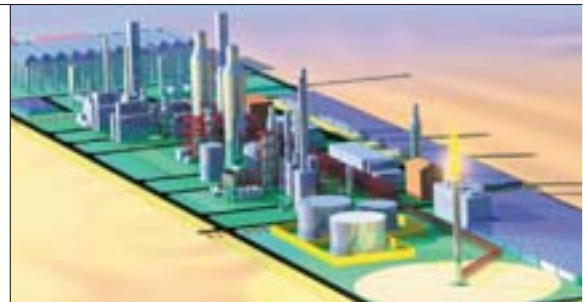
1993

Sasol builds a new kind of low-temperature Fischer-Tropsch reactor in Sasolburg, calling it the TM Slurry Phase Distillate reactor



1998

An agreement is reached with Chevron for jointly converting natural gas to liquid fuels and other products around the world, through a process dubbed GTL (gas to liquids)



2001

The target product of GTL is high-quality diesel – Sasol's trump card

Sasol and Qatar Petroleum sign an agreement for joint exploitation of natural gas reserves in the Persian Gulf

A graphic representation of the proposed Qatar GTL operation

There is an anomaly running through Sasol's history.

Though most of its investment has been in making petrol, the Fischer-Tropsch process is better suited, when it comes to the quality of motor fuels, to producing diesel. That's because most of the hydrocarbon molecules it produces are straight-chain and quick to ignite.

The propensity of diesel to ignite is indicated by its cetane number; the higher it is, the better. Petrol, on the other hand, should not ignite so easily because that can produce pre-ignition, which results in engine inefficiency and is detected by a knocking sound coming from it. The anti-knock characteristic of a petrol is indicated by its octane number. An acceptable octane number is achieved partly by boosting the proportion in the petrol mix that comprises branched or ring-shaped hydrocarbons.

The latter are obtained by subjecting straight-chain molecules to what those in the business call work-up. A better term would be work-over because it involves pretty rough treatment involving heat and a platinum catalyst. It's an expensive additional stage in producing petrol and further explains why it makes better financial sense for Sasol to use its high-temperature Fischer-Tropsch reactors to produce chemicals – especially those that will end up as plastics – rather than petrol.

By 1983, when Sasol Three came on stream, Sasol's motor fuels production was out of kilter with demand. It was producing too little diesel relative to the huge amounts of petrol coming out of the high-temperature Fischer-Tropsch reactors in Secunda. That made the local oil companies unhappy because they had to take all of Sasol's output. Sasol was able to correct the balance to some degree by using its share of the capacity of the Natref oil refinery at Sasolburg to produce mostly diesel;

The five Arge reactors had given sterling service down the years. Why not build many more?

it still, however, had to import diesel, which was clearly not acceptable in the longer term.

But how should it greatly boost its diesel production?

The five Arge reactors had given sterling service down the years. Why not build many more? Sasol's research and development engineers were handed the project.

The problem they faced was the apparent limit to the number of tubes that could economically be designed into each reactor. Those already in service each contained 2 000 tubes about 12 metres in length and 50 millimetres in diameter. The more tubes in a reactor, the less



distance there would be between them (unless the diameter of the reactor was increased proportionately, which was thought uneconomic). That meant the amount of steel holding each of them in place at either end would become insufficient – unless the thickness of the steel plates performing that function was correspondingly increased. But that also was economically unattractive because of the extremely costly forging process needed to produce plates 30 or more centimetres thick.

It was decided that 5 000 tubes per reactor would be the economic upper limit. Relative to the increased diesel production capacity Sasol needed, that wasn't much of an improvement. To provide sufficient additional diesel-producing capacity, Sasol's engineers proposed a project incorporating 76 Arge reactors. The idea was rejected as impracticable.

Clearly, an altogether different way of employing the low-temperature Fischer-Tropsch process was needed. Sasol's scientists had already been working for some years on the fixed fluidised bed concept for a high-temperature Fischer-Tropsch reactor, and laboratory-scale results were encouraging. Why not investigate the potential of a somewhat similar process, known as slurry bed?

The process is not uncommon in industry; it's used, for example, to make margarine. What made it interesting to Sasol, however, was that a group of German scientists, led by Dr Herbert Kölbel, had worked on it during the 1940s and 1950s to produce fuel from coal, and claimed success. Scientists elsewhere in the world had been unable to replicate their results. Sasol nevertheless decided to pursue its own investigations.

The process involves putting molten wax and catalyst into the bottom of a cylindrical vessel and feeding purified synthesis gas into it to form more wax. Sasol's experiments began with a reactor of no more than five centimetres in diameter that produced only one or two barrels a day (one barrel = 159 litres). That was sufficient to indicate a slurry bed would provide a reaction rate and product slate similar to those of the Arge reactor, using the same iron-based catalyst.

The next stage, which began in 1990, was carrying out the process in a pilot plant of one-metre diameter. To achieve success at that scale meant acquiring data on several key matters. The catalyst particles, for example, would be far finer than those used in the Synthol and Arge reactors; smaller, in fact, than grains of household sugar. How would they behave in the wax? Another issue arose from the fact that there would have to be such a proportion of catalyst in the mix that the latter would become like porridge. How well would the gas, fed into the bottom of the vessel, work its way through that porridge to find those tiny particles of catalyst and be converted by them into wax? A further question was how the whole mixture would flow – a complicated matter if only because there would be a gas, a liquid and a solid (that, is three different phases) interacting hydrodynamically inside a pressurised vessel. Finally, how much heat-exchange tubing to place in the bubbling mixture was a question made difficult by the porridge being three-phase; like all the other questions, it could only be answered by measuring what happened.

As Sasol's scientists sought answers to these questions, it became clear that, while the scale-up potential of the slurry bed reactor was its greatest advantage over the Arge reactor,

it had additional significant attractions. First, it would contain far fewer parts and a great deal less metal, so it would clearly cost far less to build. It would also consume less catalyst per ton of product, and less power to compress the synthesis gas. It would also be able to run for far longer periods without interruption; the Arge reactor has to be stopped every few weeks for catalyst replacement, a procedure that is carried out for the slurry bed reactor while it is operating. Finally, because the temperature of the three-phase porridge could be kept at a pretty constant temperature, which was not possible inside the

ensure it was not faced with such particles; that the catalyst did not break up while moving around the reactor or being pressed against the device.

It's the final stage of manufacturing the catalyst that mostly determines the strength of its particles. Further strength, Sasol's engineers came to realise, is provided by slowly warming up the catalyst. That slow warming was given to the catalyst by the reactor's start-up procedure. It would, of course, also be needed for replacement catalyst. Once they had appreciated

Could the catalyst problem be solved pretty soon? If it couldn't, the whole of the Sasolburg site, with R800 million recently spent on it, would become a white elephant

tubes of the Arge reactors, there was no need for a substantial safety margin when controlling the operating temperature. That meant a higher temperature could be used in the slurry bed reactor, increasing the speed of conversion.

There was, however, a major challenge still to be overcome – removing the catalyst from the wax while both were still inside the reactor. The research engineers came up with an idea for a mechanical device. When put to the test, it failed to work. It took some time for the engineers and operators to understand why.

The problem lay more with the catalyst than with the separation device. The latter would obviously not be able to work at an acceptable rate if it had to remove very small particles of catalyst from the wax. The main task, then, was to

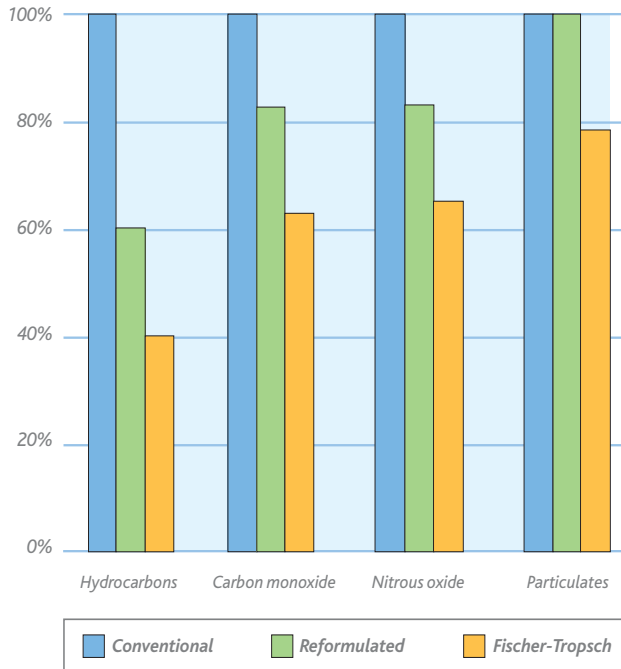
that, the engineers used mothballed Synthol catalyst-preparation equipment to do it.

While the engineers were still wrestling with the catalyst problem, Sasol's senior executives faced a tough decision. In the late-1980s it had been decided to confine the Sasolburg factory's activities to wax and petrochemicals production, and to rejuvenate the whole site by upgrading plant. The rejuvenation included two new Arge reactors, larger than those installed in the 1950s and operating at higher gas pressures. The total cost of the two reactors and their

Opposite: A graphic representation of the Sasol Slurry Phase Distillate process, which employs unique technology that will be key in producing high-quality diesel



Fischer-Tropsch diesel lowers emissions



Based on engine tests carried out by South West Research Institute, San Antonio, Texas

supporting units would run close to R1 billion. Should the plan go ahead, or should the two Arge reactors be replaced with one five-metre-diameter slurry bed reactor? If the catalyst-removal problem could be wholly overcome, the slurry bed concept would definitely be preferable, especially if the technology

could be used elsewhere in the world, furthering Sasol's globalising ambitions. But could the catalyst problem be solved pretty soon? If it couldn't, the whole of the Sasolburg site, with R800 million recently spent on it, would become a white elephant.

Sasol's general manager in charge of the research and development portfolio, Jan Fourie, decided the solution was within sight. Drawings of the new Arge reactors were put aside, and work began on designing a five-metre-diameter slurry bed reactor that would incorporate the shell of the SAS reactor pioneered a couple of years earlier and be fed by the gasifiers that had served the three retired Synthol reactors. Two years later, in May 1993, its construction was completed on schedule and without cost overruns. When it came to running it, however, there were unexpected operating problems. After two weeks or so of high anxiety, they were solved and the reactor gave no further trouble.

Its daily capacity, using an iron-based catalyst little different in composition from that used in the Arge reactors, would equal the 2 500 barrels a day still being produced by the original five Arge reactors (a sixth Arge reactor had been commissioned in 1987 with a daily production capacity of 700 barrels). What value would there be for Sasol, its scientists and engineers started asking a year or so after their slurry bed reactor had started proving itself, if they could produce one with a daily capacity of 10 000 or 15 000 barrels for use elsewhere in the world?

The answer was indisputable. Unlike diesel made from crude oil, Sasol's diesel contains almost no sulphur or aromatics

(ring-shaped molecules). The aromatics produce carcinogens in diesel exhaust fumes, while sulphur in exhaust gases not only creates environmental problems; inside engines it mixes with water to form sulphuric acid, which eats away at the steel walls of cylinders. Sasol's diesel would therefore enjoy a major advantage over other diesel as governments, especially in developed countries, imposed ever stricter environmental demands on vehicle and fuel manufacturers. It could not be made in developed countries since the only raw material they could provide for it, natural gas, would cost too much, given competing demand for it from industrial and domestic consumers. But natural gas located in remote regions with little gas demand was another matter.

There are hundreds of natural gas fields around the world. Some are closely associated with oil, and are regarded by drillers as a nuisance because gas, consisting mostly of highly inflammable methane, cannot simply be vented to the air when released by their activities. (Methane is one of the six greenhouse gases targeted under the Kyoto Protocol to promote comprehensive emissions reduction and favourable climate change). They are left with four alternatives. The first is to pipe the gas to commercial users; many gas fields, however, are too far from industrial areas to make that feasible, or local demand takes only a small proportion of the gas being released. The second option is to flare (burn) the gas; but that creates carbon dioxide, which has a greenhouse effect and is therefore environmentally unacceptable, though it is still widely practised. The third option is to pump the gas back underground to maintain the upward pressure of oil. But that's expensive, and so is the fourth option, which is to chill the gas

sufficiently to liquefy it, then carry it to distant markets in specially equipped ships as liquefied natural gas (LNG)

The Fischer-Tropsch process provides a fifth option since reforming methane into synthesis gas is, as we've seen, an integral part of the process. For many years Sasol was the only company anywhere in the world seriously exploring its potential. That began to change in the 1980s when

Unlike diesel made from crude oil, Sasol's diesel contains almost no sulphur or aromatics

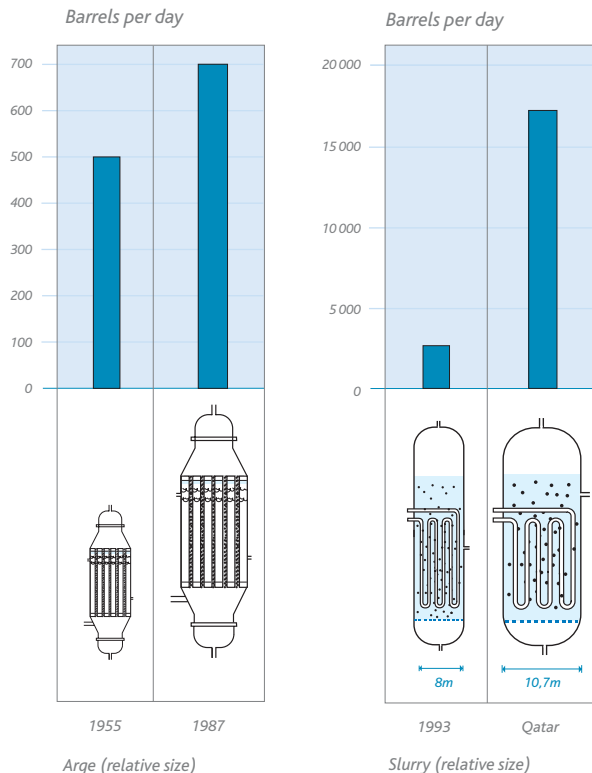
environmental concerns had governments demanding that oil producers and vehicle manufacturers clean up their act. Knowing that the major oil companies Exxon and Shell were investing in Fischer-Tropsch research, and that whoever was successful would dominate a major new industry, Sasol realised that what it needed above all else, if it was to become an international player, was a cobalt-based catalyst for its slurry bed reactor.

There were several reasons. First, Sasol's traditional iron-based catalyst is less reactive than cobalt, leading to substantial amounts of unconverted synthesis gas. That hadn't mattered in South Africa since the hydrogen in the synthesis gas could be used in making ammonia, for which there was a ready market, and the rest of the gas could be piped to industrial and domestic consumers. Those markets would not, however, be available in underdeveloped economies.

Getting prefabricated units to a remote site is also difficult in the absence of major roads, so the smaller the units the easier



Different technology and catalyst boost output hugely



Opposite: Development of the Slurry Phase Distillate reactor promised Sasol an even brighter future

their transport and installation. That works against economies of scale, however, so the units, especially the reactor, must be highly efficient in converting gas into product to maximise revenue yield from every dollar spent as capital and operating cost. Cobalt not only meets that need; it also is impervious to the water produced by the Fischer-Tropsch process. Iron-based catalyst is not, which means it must be replaced far more frequently than the cobalt-based catalyst. Finally, cobalt is physically stronger than iron, so catalyst particles made from it are less likely to break up under the stresses within the wax bed, which makes separation easier.

Cobalt catalyst had not been used in either the Arge or Synthol reactors because, apart from its high cost, its reactivity would have aggravated operating difficulties, especially temperature control. It also needs an even greater degree of gas purity, especially when it comes to sulphur, than iron catalyst does, and building a new purification plant at Sasolburg to achieve it was deemed unwarranted. Nevertheless, Sasol's researchers had acquired considerable understanding of catalyst chemistry and preparation over the years. While reactor-design work went on during the second half of the 1990s – benefiting from scale-up insights gained from the SAS experience to produce first one with a capacity of 10 000 barrels a day, then another with a 15 000-barrel capacity – various formulations of cobalt-based catalyst were tried out in the one-metre demonstration reactor. What the researchers were looking for was not only the right catalyst formula, but also an understanding of how cobalt performed. They found, for example, that where changes in operating pressure made no difference to the product slate in a low-temperature reactor using an iron-based catalyst, increasing it when a cobalt catalyst was being

used narrowed the product slate. In other words, the shotgun was replaced with a rifle.

Eventually, they produced a cobalt catalyst that satisfied them. What Sasol now needed to produce diesel from natural gas was a highly efficient technology for reforming methane – which was likely to account for about 60 per cent of the total capital investment – and another for hydrocracking wax into diesel. Sasol itself owned neither process technology. There were some pretty good technologies it could have bought off the shelf. In looking for the best, though, it had another important criterion

slurry bed reactor, it was at the leading edge of methane-reforming technology – and it was keen to partner Sasol in further development and global exploitation of the Fischer-Tropsch process. So an agreement was reached for Sasol to use the Haldor Topsøe methane-reforming technology under licence.

So, too, with hydrocracking wax into diesel fuel. There were many organisations doing it and catalysts for achieving it. But the US oil company, Chevron, appeared to be best at it – the catalyst it had developed for the purpose was in use in most oil refineries around the world – and it was also keen on forming an alliance with Sasol.

Sasol found itself discussing a joint venture with the national oil company, Qatar Petroleum

apart from efficiency. Sasol wanted to form long-term relationships with whoever's technology it used for methane reforming and hydrocracking. Those companies would therefore have to be as ambitious as it was to achieve steady improvement of what would, in order to minimise operating costs, have to be a closely integrated plant.

There were several different methods of methane reforming being used around the world. Sasol investigated them all and decided autothermal reforming, which heats the methane gas in the presence of oxygen and a catalyst, best met the needs of its slurry bed reactor. There were a number of companies offering autothermal technology. The Danish company, Haldor Topsøe, seemed to meet Sasol's needs best. The compound profile of its synthesis gas closely matched the needs of Sasol's

Even before it had produced a satisfactory cobalt catalyst, Sasol had begun assessing which regions of the world showed the most long-term potential for converting gas into diesel and other liquid hydrocarbons – a process soon dubbed gas-to-liquids, or GTL. It settled on two: Qatar in the Persian Gulf and Nigeria. Qatar is a small emirate that possesses only modest oil reserves, but huge quantities of gas – at last six per cent of the world's total estimated reserves. Nigeria, of course, has major oil and gas deposits.

Soon Sasol found itself discussing a joint venture with the national oil company, Qatar Petroleum. The latter suggested Sasol should bring in Phillips Petroleum as a third partner. By July 1997 a memorandum of understanding had been signed by the three companies to erect a 20 000 barrels-a-day GTL plant at the Ras Laffan Industrial City in north-east Qatar. Gas was



The Escravos Delta in Nigeria (left) and a graphic of the first GTL plant (right) for the Sasol/Chevron joint project there, using the Sasol Slurry Phase Distillate process

already being pumped ashore there to be liquefied and exported, so basic industrial infrastructure was in place.

the first diesel and naphtha was expected to start flowing in early 2005.

But then, as the feasibility of the project was being completed and various plant options considered, came the 1998 collapse of world oil prices. This led to substantial restructuring and a huge realignment of interests among the major oil companies, one outcome of which was that Phillips Petroleum withdrew from the GTL joint venture in Qatar. Sasol and Qatar Petroleum nevertheless proceeded with the project and in mid-2001 announced they had reached agreement to form a joint venture, with Qatar Petroleum holding 51 per cent of the project and Sasol 49 per cent. Front-end engineering design promptly began for a 34 000 barrels-a-day plant, from which

Meantime, Chevron, which by now was itself interested in converting natural gas into liquids and had become impressed with Sasol's slurry bed reactor, had suggested to Sasol that they should study the opportunities for GTL in Nigeria. Sasol agreed; Chevron, after all, had great experience in oil and gas exploration in Nigeria, as well as in dealing with its government. A study was begun in the last quarter of 1997, and an agreement to proceed with a detailed feasibility study was announced in April 1998. The agreement between the two companies was later expanded in stages into an alliance to cover GTL operations throughout the world. The first, and most



Sasol will not lack company at Ras Laffan in Qatar – an indication of the commercial prospects for natural gas

advanced project is a 34 000 barrels-a-day plant at Escravos, an oil- and gas-producing centre at the mouth of the Escravos River, which forms part of the huge Niger River delta in southern Nigeria. It's a swampy region – exactly the kind of place where you'd expect to find gas and oil – separated from the sea by sand dunes. The plant will be built on reclaimed swamp and is also planned to start producing in 2005.

Initial design work, expected to take eight months, began during the first half of 2001.

The plants in Qatar and Escravos will both consist of two 17 000 barrels-a-day GTL units, with their attendant methane-reforming and hydrocracking units so located and connected as to minimise overall energy consumption, an important factor in

In Qatar there is enough gas to supply a GTL complex of at least 10 times the capacity of the presently planned plant

achieving economic competitiveness. The Fischer-Tropsch reactors – about 35 metres high and just under 10 metres in diameter – will probably be built in Japan or Korea and shipped as single pieces because of the difficulties of assembling them on site. Handling and installing units of that size will present a challenge.

The Qatar project will cost about US\$800 million, while Escravos will take US\$1,3 billion to complete. Other projects could follow in either region or elsewhere. Capital savings would be made if further projects were added in modular fashion to the two presently planned plants since costly facilities such as offices, laboratories and workshops would already exist. How profitable the joint venture will be will depend heavily on environmental demands on oil producers, on the price of crude oil, on the cost of natural gas and on the ability of plant designers to minimise capital and operating costs. Sasol's optimism is underwritten by the Nigerian government's announcement that gas flaring will be banned from 2007. That prohibition is not surprising since there is several times more gas than oil to be handled there when pumping oil, and most of it is being flared. In Qatar, too, there is enough gas to supply a GTL complex of at least 10 times the capacity of the presently planned plant, not to mention gas fields within neighbouring territories. In other words, the potential for achieving capital and operating cost savings

through economies of scale is substantial. By the same token, for all the enthusiastic talk about monetising stranded gas fields, in many cases the opportunities for making a profit from them are slim because they are, by definition, far from developed industrial areas and not associated with oil operations. They would therefore have to be greenfield developments involving substantially higher capital, operating and, probably, product-transportation costs.

On the consumption side, meanwhile, the beginnings can be perceived among motorists of a move from petrol to diesel, a trend reflected and supported by manufacturers producing more sophisticated diesel-burning vehicles. It's caused in part by environmental concerns, and partly by a realisation that diesel is a more efficient fuel than petrol. Sasol should benefit greatly from that trend since its diesel will probably be in heavy demand as an upgrading blending stock.

Whatever financial benefits do eventually emerge from Sasol's involvement in GTL, it has already given it valuable experience in conducting negotiations around international joint ventures. These will be crucial to Sasol's efforts to globalise its production activities. The world of solitary big-hitters, whether in petroleum, pharmaceuticals or any other high-tech field, is disappearing under pressure of technology-based competition. Collaboration is becoming vital to survival.

Chapter 10 Pages 144 – 153 ►

Fuels for the future

*Over the years Sasol's fuels have been tested
in the toughest environment – motor racing*



*Sasol's synthetic jet fuel, blended with Natref's product, powers planes
leaving Johannesburg*



2001

Sasol launches DualFuel, an unleaded petrol designed for use in both leaded and unleaded engines

*Laboratory performance tests continue on Sasol's
high-quality, low-sulphur diesel*

Sasol's high-temperature Fischer-Tropsch reactors provide it, as we have seen, with a unique treasure chest of different kinds of molecules.

When it came to producing petrol and diesel fuel, however, that uniqueness was to present exciting technical challenges. So, too, did the high-altitude market into which most of Sasol's petrol is sold.

The molecular challenge became evident only during the first half of the 1980s, when Sasol Two and Sasol Three at Secunda began producing huge volumes of petrol and diesel. The products fully met international and local specifications, yet were found to be not always entirely compatible with the engines of that time. In 1986 Sasol established a special research and development unit within Sasol Technology to make its fuels always suited to market requirements and to provide a technical market-support service to customers. It soon became clear that international specifications covered too narrow a range of fuel characteristics – and that Sasol needed to learn more about the behaviour of some of the unique molecules going into its fuels.

The two main challenges were, first, to boost lubricity in Sasol's diesel fuel and, second, to improve the compatibility with aluminium carburettors of its alcohol-containing petrol. Diesel fuel derived from crude oil contains a natural lubricant that is vital for engines using it; without it, some types of their fuel pumps may quickly seize up. In the mid-1980s, however, this lubricating quality was not part of international

specifications for diesel. When a major customer complained to Sasol that using its diesel had caused a certain type of diesel pump to seize up, the new R&D unit initially supposed that the cause was the absence of sulphur in its diesel; that is,

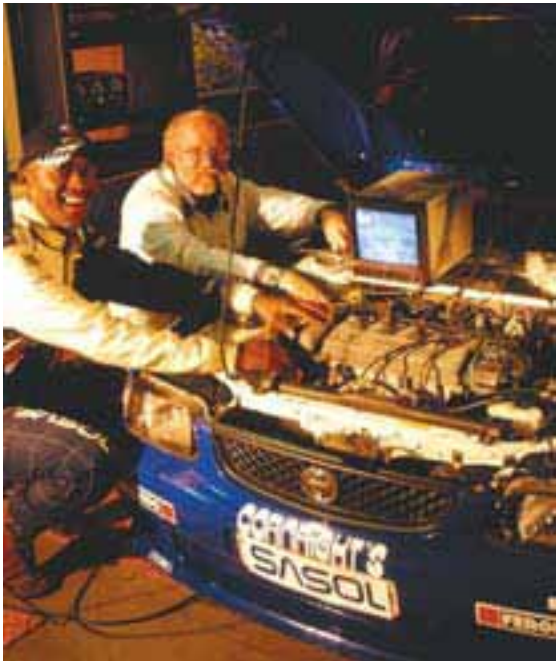
that sulphur provided the lubricant – an aspect of fuel that had been overlooked in the specifications because sulphur is present in substantial quantities in all crude oil-derived diesel. Subsequent painstaking research by the unit showed, however, that it was not sulphur itself that provided standard diesel with its lubricity, but polar molecules associated with it. Once the unit realised that, it was able to design a lubricious additive for its diesel.

The story concerning aluminium carburettors was similar. It was common and wholly acceptable practice in the first half of the 1980s for oil companies worldwide to improve the performance of their petrol by adding alcohol in the form of ethanol. Sasol decided to use other alcohols produced by its high-temperature Fischer-Tropsch reactors, as well as ethanol – molecules containing from three to six carbon atoms against ethanol's two. Doing so wouldn't flout petrol specifications, which limited the proportion of alcohol that petrol could contain but were silent on what kind of alcohols were allowed. That silence was understandable; Sasol was, and remains, the only oil company in the world producing C₃-C₆ alcohols.

Again, it took much laboratory research to identify which of Sasol's alcohols were incompatible with some types of aluminium carburettors. Once that had been achieved, Sasol

could either remove them from its petrol mixture, thereby losing two of alcohol's advantages, namely lower exhaust emissions and higher octane, or it could leave them in, but design an additive to nullify their incompatibility. It chose the latter and designed a successful additive package.

In 1991 the fuels research and development unit was removed from Sasol Technology, where work was of a longer-term nature than the unit's fast-response, customer-orientated



Sasol Oil's research and development facilities in Sasolburg

activity, and placed within the marketing company, Sasol Oil. What was becoming clear by then, though, was that the research done by the unit, wherever it was housed, benefited not only Sasol Oil's customers, but oil companies throughout the world. It was showing them not only which characteristics needed to be added to the standard list of fuel specifications, but also what those specifications should be.

Work of no less international value continues to be done by the unit in the field of low-emission fuels and those suitable for high-altitude application. Indeed, the Sasol Oil Research and Development facility at Sasolburg, one of only a few anywhere in the world devoted to high-altitude motoring problems, is highly regarded internationally.

The altitude challenge comes about thus. Air becomes less dense as altitude increases, reducing the number of oxygen atoms in a given volume of air. Those atoms are crucially important in air-and-petrol mixtures, for they cause the petrol to combust after ignition by a spark plug. The more oxygen there is, however – such as occurs when travelling to lower altitudes – the higher the pressure and the greater the likelihood that the petrol/air mixture will self-ignite prematurely. Premature ignition is detectable by an audible knocking noise in a vehicle's engine, results in inefficient use of the power produced by combustion and can also lead to engine damage. Additives mixed with the basic petrol may reduce its propensity to self-ignite; the more effective the additive is in this regard, the higher the fuel's octane rating. Sasol has therefore spent heavily over the years on researching the advantages and disadvantages of various octane-raising additives and processes. The latter change petrol's basic composition and thus, too, its octane rating.

Companies designing and manufacturing internal-combustion engines have also worked on overcoming the adverse effects of altitude. As the number of oxygen atoms in a given volume of air decreases, combustion of the hydrocarbon molecules in petrol or diesel becomes less complete. Power decreases and the fuel that remains unburnt leaves the vehicle through its exhaust pipe. The resulting economic and environmental effect can be substantial.

Engine designers use various methods to overcome this altitude-induced loss of power and combustion efficiency. One is to increase the amount of oxygen atoms in the combustion chamber by pumping air into it so as to increase its density – the turbo-charged effect. Another is to incorporate systems in the engine that more accurately measure the air flow to the engine, or the quality of the combustion, and correct fuel delivery accordingly. These are, however, sophisticated technological solutions used only in more modern, and often more expensive, cars. Their use means that these vehicles generally require a higher octane fuel at altitude than the older vehicles do.

That presents a challenge to Sasol, for its fuels market is essentially a high-altitude one. Older, less sophisticated cars still account for most of it, but they are being steadily replaced by more sophisticated vehicles requiring higher octane petrol. Most of these

modern vehicles are, however, equipped with knock sensors that detect the octane requirement and adjust ignition timing so that

the engine runs satisfactorily, though at a slight power loss on the available octane.

Meanwhile, the unit's most publicised achievement of recent years is the development of an unleaded petrol that can be safely and efficiently used not only in modern vehicles demanding unleaded petrol, but also in older models designed to run on leaded petrol. Unleaded petrol was introduced to the South African road-vehicle market in 1996. Sasol had been producing it since 1992, shortly after it became involved in Formula One motor racing, where only unleaded petrol is used. Having a testing ground for unleaded petrol was not, however, the main motive behind Sasol's involvement. Formula One cars, pushed to their physical limits on the racing circuit, represent

Unleaded petrol was introduced to the South African road-vehicle market in 1996. Sasol had been producing it since 1992

the cutting edge of all aspects of automotive technology: braking and gearbox systems, materials, engine design – and fuel formulation. Involvement in Formula One racing would therefore require Sasol Oil's R&D unit to produce a fuel that would meet demands far greater than those of road vehicles.

Those demands arise from the need for both rapid acceleration and extremely high rates of cylinder firing. The engine of a cruising saloon car is working at 3 000–4 000 revolutions a

Opposite: Fuel challenges faced on the racing circuit are unique – Sasol uses motor racing as a laboratory-on-wheels





minute (rpm). That of a Formula One car driven at full speed is working at up to 18 000 rpm, which means that each cylinder is firing 150 times a second. To design a fuel that would enable that to happen with maximum efficiency, Sasol Oil's R&D unit would have to acquire an altogether new level of understanding of the behaviour of the close on 900 different kinds of molecules contained in Sasol's petrol – behaviour that would vary in response to changes in compression ratio, engine timing, air/fuel ratio, valve configuration, the number of rpm, and so on.

Sasol's fuel performs better than crude oil-derived unleaded petrol

The unit seized the challenge with both hands. Sasol's top scientists and engineers were formed into two teams, one working on engines, the other on fuels. In a research programme of unprecedented intensity, the many different kinds of molecules were categorised into different groups. Then, using a small motorcycle engine that had been modified to replicate the characteristics of a Formula One engine, hundreds of tests were conducted on all the many different hydrocarbon groups in Sasol's fuels to determine their characteristics. That led to the construction of two mathematical models. One was for engines, to ascertain what kinds of fuel would work best in various types of engine operating under varying conditions. The other simulated the combustion of different fuels, to reveal such properties as the speed at which a fuel would burn, the way it mixed with air when drawn into the engine, its resistance to premature ignition, and so on. Several dozen different formulations

would be produced from this mathematical model for testing in the high-speed motorcycle engine. Of those, about three were tested in a laboratory-based Formula One engine at Sasolburg during a normal fuel-evaluation cycle.

As intended, all this effort produced a far greater knowledge and understanding of what was contained in Sasol's petrol. The fuel team discovered, for example, that certain molecules that had been generally regarded by the fuels industry as having little or no value were, in fact, the fastest-burning ones and therefore highly desirable for anyone trying to design a perfectly combusting petrol. Indeed, Sasol was eventually able to tailor petrol formulations to the characteristics of different racing circuits and the demands they make on cars.

Providing the motorist with a superb unleaded petrol in 1996 was therefore no problem for Sasol – provided his vehicle had been designed for unleaded petrol. Lead, in the form of a compound such as lead tetraethyl, had served two functions as a petrol additive. It raised the basic octane rating, and also served as a lubricant on exhaust-valve seats, protecting them against wear. Modern cars, designed overseas where unleaded petrol had been introduced several years earlier, compensated for the absence of lead's lubricity by protecting valve seats with hardened inserts. Older cars did not have those inserts – and in 1996 they comprised nine out of ten cars on South Africa's roads.

Sasol Oil's R&D unit therefore turned its attention once again to the racing circuit, this time to the races for modified saloon cars, many of which required leaded petrol. By late-1999 it

had designed an additive cocktail that met both octane and lubricant needs. The resulting fuel was tested on racing circuits and in Sasol's own 800-strong fleet of assorted vehicles at Secunda. Once the fuel had met Sasol's own stringent standards, it was introduced to the public in early-2001. A major advertising and promotion campaign, together with users' discovery that the fuel performs better than crude oil-derived unleaded petrol, produced a surge in Sasol's retail market share.

Winning public acceptance of a new product is, of course, as important as achieving technological breakthroughs. Fuel consumers are rightly conservative; the safety of people as well as of expensive machinery could be threatened. That is especially true for the airline industry.

Sasol has for many years been supplying most of the jet fuel taken on board at Johannesburg International Airport. It is



produced at the Natref crude-oil refinery in Sasolburg. Crude oil contains far more aromatic molecules than are produced by the Fischer-Tropsch process at Secunda. Those molecules are needed in jet fuel, but not nearly to the extent provided by crude oil. Sasol therefore reckoned a blend of synthetic jet fuel, which contains no aromatics or sulphur, and natural jet fuels would work well. It took three years of intensive work with the airline industry's major players – engine and airframe manufacturers, oil companies and regulatory authorities – to confirm that Sasol's jet fuel met and even exceeded all the quality requirements. Sasol's semi-synthetic jet fuel blend received full approval some four years ago.

Jet fuel is not the only example of the way in which Sasol Oil has been able to obtain synergistic benefits from mixing Natref and Secunda products, using a dedicated pipeline between Secunda and Sasolburg to bring them together. Secunda's diesel is excellent. Some of the other components produced at Secunda, however, cannot be used in diesel because they have too low a cetane number and too little lubricity – the latter because of the absence of the polar molecules associated with sulphur. Natref's crude oil-derived diesel, by contrast, has a higher cetane number than required and, because it contains sulphur, also provides those

lubricating polar molecules. Sasol Oil's diesel blend of 70 per cent Natref and 30 per cent Secunda components exceeds cetane requirements and has a reduced sulphur content.



The engine test cell at South African Airways. For the first time a synthetic fuel component was approved for use in jet fuel

So, too, with petrol. Some of Secunda's components that could potentially be used for petrol contain an unwanted amount of certain types of olefins, Natref's too little of them. Those olefinic components are therefore pumped from Secunda to Sasolburg, where they raise the octane number of Natref's petrol and reduce its sulphur content – a strategy with an annual pay-off worth many millions of rands. Sasol plans to transfer product from Sasolburg to Secunda, too, using spare capacity at Secunda to upgrade unwanted Natref products, then incorporate them into Secunda's synthetic fuels.

But back to jet fuel. Sasol aims to obtain approval for a wholly synthetic jet fuel. The absence of aromatics and sulphur in Sasol's synthetic jet fuel substantially reduces toxic emissions. Its effect on aircraft machinery and performance has still, however, to be fully determined. Sasol Oil's research work in this area is not motivated solely by trying to produce a successful, non-blended jet fuel at Secunda. Chevron, Sasol's international partner in gas-to-liquid projects, has a good process for separating out the range of hydrocarbon chains (C₉-C₁₂, the cut lying between petrol and diesel) used to produce jet fuel. But whether the molecular characteristics of synthetic fuel produced by Sasol's newly developed Slurry Phase Distillate (SPD) reactors will be the same as those coming out of Secunda has still to be proved. Acceptance by the airline industry of a synthetic jet fuel produced by SPD reactors cannot be taken for granted, even for use in a blend, simply because jet fuel sourced from the Secunda plant's fixed fluidised bed reactors has been approved.

Back on the ground, Sasol Oil's R&D unit is expecting the demise of the conventional internal-combustion engine during



As a prize-winning TV commercial implied in 1990 – deep reflection precedes innovation

the next two decades or so. But what will be the source of power replacing it? Already, it is common practice in Europe and elsewhere to power vehicles using methane, which is both cheaper and far less of a pollutant than petrol. But how would methane work at high altitude? Would methane-consuming engines designed for low altitudes have to be redesigned? Together with Sasol Synthetic Fuels, Sasol Oil's R&D unit has installed a high-pressure methane refuelling station at Secunda to investigate these and other questions. Some of Sasol's buses, trucks and taxis at work in Secunda fill up at it and provide research data.

Beyond methane lies hydrogen and the fuel cell. The latter is a device that converts hydrogen and oxygen into electricity to power a motor. The hydrogen can be fed into the vehicle at the start of a journey, or it can be created on board during the journey by a unit that, through reforming, produces hydrogen from sulphur- and aromatic-free petrol, diesel, or components thereof, methanol or ethanol. This conversion is carried out at lower temperatures than burning fuel in car engines, so it doesn't produce environmentally unacceptable exhaust-gas compounds. The overall system, moreover, is 50 per cent more efficient than petrol internal-combustion engines, so less fuel is needed to cover a given distance.

Billions of dollars are being spent elsewhere on developing fuel-cell vehicles. Sasol, too, is active in this area because it recognises the absolute necessity of remaining abreast of the latest developments in engine and fuel-system design. Only by doing so will it be able to continue deploying its unique range of hydrocarbon molecules, and its hard-won understanding of their nature and behaviour, to maximum advantage.

Chapter 11 Pages 154 – 163 ►

The lure of innovation

1990s

*By purifying its oxygenated products,
Sasol enters new and lucrative markets*



*Successful innovation depends on
first-mover advantage...*

1999

*A new plant for the oxygenate ethanol comes
on stream, boosting South Africa's exports*



...which means employing the best brains...

Most oxygenated molecules end up as solvents



... and allowing them to soar

Sasol's future success in forming partnerships with global companies will depend primarily on what technological achievements it can offer of international value.

Notwithstanding the long-term potential of its gas-to-liquid fuel technology, the range of Sasol's products and the competitiveness of its technologies will be prime factors in determining the rate of growth, and the stability, of its income.

That the number of its products will grow substantially over the years can almost be taken for granted. The product stream from Sasol's Fischer-Tropsch reactors contains hundreds of different chemical compounds. Only a fraction of these has as yet been recovered and turned into commercially valuable products. The potential for increasing their number is therefore great.

Exploiting these Fischer-Tropsch compounds will depend, first, on overcoming the technical problems the recovery of these compounds presents. Most of them are, singly or in combination, unique to the Fischer-Tropsch process. New techniques therefore have to be devised for recovering them from the feed stream. Devising a successful separation process invariably takes years rather than months because of the detailed analysis that must be carried out on the nature of the relevant compounds, the accompanying contaminants, and how the different components interact with each other.

Once a potential separation method has been identified theoretically on paper, the separation must be confirmed in the laboratory. How to use it on a commercial scale must then be

conceptualised and translated into engineering terms. The important point in all of this is that the product's commercial viability must be confirmed as early as possible to avoid spending too much time and money pursuing something that doesn't make business sense. If the idea still looks worth pursuing, the next step is to have the plant constructed efficiently in terms of both its initial cost and its ability to do the job in a sustainable, cost-effective way.

This sequence of activities is followed not only for isolating organic compounds from the Fischer-Tropsch oil fractions, as in the case of Sasol's alpha olefins, but also isolating oxygenated products from the Fischer-Tropsch water fraction. The development of Sasol's solvents business during the past decade usefully illustrates the challenges this can present.

From the high-temperature Fischer-Tropsch reactors come two major product streams, one oily and the other aqueous. Contained in the aqueous stream are a range of shorter-chain organic compounds (2-5 carbon atoms) containing one or two oxygen atoms in their structure and typically referred to as oxygenates. These oxygenates – including alcohols, ketones, aldehydes, acids and esters – are best suited for purposes other than making fuel or wax. Solvents and intermediates for the production of solvents dominate among the applications of these compounds.



Perfumes and cosmetics require high-purity solvents

That is remarkably fortunate for Sasol because organic solvents are used in many industries, notably those producing paint, inks, coatings, adhesives, cosmetics and pharmaceuticals. Solvents are used to dissolve other substances (solutes) without chemically changing them. This enables the solutes in inks, paints and other coatings to be spread over a surface. The solvent eventually evaporates, leaving behind only the solutes. Solvents also allow the essential oils in a perfume to be dabbed on ear lobes or wherever in financially and dermatologically acceptable concentrations. How a solvent works is that the molecules of the solute get mixed up with those of the solvent – provided the force binding the solute's molecules together has pretty much the same strength as that binding the solvent's molecules. Since the strength of the binding force can vary

greatly between different substances, there are dozens of solvents.

Sasol has, from its early days, been producing impure cuts of alcohols ranging from the shortest one, methanol, right up to hexanol with six carbon atoms. Between these two came ethanol, propanol, butanol and pentanol. The technology for separating them from water was well established; the challenge lay in separating them into pure products. For many years, Sasol's research priorities lay elsewhere. The alcohols were therefore either put into Sasol's fuel stream or sold as partly refined alcohol cuts at some discount to the pure products.

The refining problem lay in the fact that in many cases the alcohols and the typical contaminants found within these streams have a tendency to interact in such a way that an

Solvents are used to dissolve other substances (solutes) without chemically changing them

azeotrope is formed. An azeotrope, in simple terms, occurs when a mixture of a particular composition has a higher volatility (a low-boiling azeotrope) or a lower volatility (a high-boiling azeotrope) than each one of its components. In other words, a mixture of this composition cannot be separated by normal distillation.

When, in the 1980s, Sasol decided to exploit the value of its chemical treasure chest more fully, its crude alcohol products



Sasol's *n*-propanol has captured 30 per cent of the world market

came under the spotlight. Market demand was for solvents and chemical intermediates that were almost 100 per cent pure. What Sasol needed was a means of separating close-boiling or azeotropic alcohols. A process that is sometimes able to do this is known as extractive distillation. It effectively increases the differences in volatilities between different compounds by introducing an additional compound which interacts with one or more of the compounds in a manner that "modifies" its effective volatility (see page 112).

The first oxygenate for which Sasol set out to achieve a high-purity product was *n*-propanol (propyl alcohol; the *n* stands for normal, meaning a straight, unbranched carbon chain), used in antiseptics, pharmaceuticals and specialised printing inks. It spent years going through the analysis described above, and eventually found a process that looked promising. After piloting the process in the laboratory, a demonstration plant was put together in Sasolburg, built from bits of an old butadiene plant there, and yielded an acceptable product. A few years on, plans were laid for a larger commercial plant in Secunda, to yield 45 000 tons a year of *n*-propanol. Sasol's board approved the capital for the project in November 1995 and construction was completed in June 1996, which was something of a record project schedule. The first on-specification *n*-propanol product was produced less than two weeks later. Since then the plant has worked continuously and Sasol now commands a sizeable portion (about 30 per cent) of the world market for *n*-propanol.



The next alcohol on which Sasol set its purification sights was ethanol. Ethanol is used extensively in inks and paints and is the key ingredient of common or garden methylated spirits. Since ethanol also has an important market in the personal care, medical and perfume industries where product odour and colour are of great importance, the purity of ethanol has to be extremely high. As it turned out, the process Sasol had developed for purifying n-propanol was also effective in purifying ethanol and the Sasolburg n-propanol plant was subsequently converted to ethanol



Ethanol is a key ingredient in household methylated spirits

unwanted molecule in 10 000). Almost all the ethanol product from this plant is exported, finding a ready market in Europe and the US.

The two projects demonstrate not only the determination and scientific rigour with which Sasol pursues a new aim, but also Sasol's skill in managing plant construction. Both Secunda plants were built remarkably quickly; the propanol plant, indeed, in what was considered a record time.

The solvents arena also provides an example of how Sasol has used technical partnerships with major foreign concerns. The solvent in this case was ethyl acetate, an ester typically manufactured from ethanol and acetic acid. Sasol decided, however, to pursue an alternative production route, using only ethanol. To make things more interesting, it was found to be more

economic to use an impure ethanol containing five per cent iso- (branched-chain) propanol, rather than bear the cost of purifying the ethanol beforehand. Although Sasol's research and development division had made some progress in developing a suitable catalyst and reaction system to make ethyl acetate from ethanol,

it was felt that the London-based technology company of the Scandinavian engineering group, Kvaerner, had achieved greater progress in the technology. By working closely with Kvaerner in developing this process, Sasol was able to apply its experience in dealing with tricky oxygenate separations, while Kvaerner concentrated on the catalyst and reactor design.

The two projects demonstrate not only the determination and scientific rigour with which Sasol pursues a new aim, but also Sasol's skill in managing plant construction

purification. Following the success of the high-purity ethanol coming from the Sasolburg plant and pressures to remove ethanol from the fuel market, Sasol decided to expand this business. By September 1999, it had a new R140 million ethanol plant at Secunda, producing 85 000 tons a year of high-purity ethanol (99.99 per cent – that is, only one



A considerable amount of innovation was also injected into the engineering phase of the project by the Sasol and Kvaerner engineers, producing capital-cost savings, reduced energy consumption and improved maintainability and operability.

The ethyl acetate plant, which began producing satisfactorily in May 2001, represents Sasol's first technology for the manufacture, as distinct from separation, of a solvent; the underlying technology is equally owned by Sasol and Kvaerner. Sasol has some other solvent synthesis units, but their technology has been purchased.

Developing a technology that meets all the scientific criteria is, as already noted, not the whole story. The plant built around it must be able to show an acceptable return on its capital cost. Unforeseen or underestimated factors sometimes work against this, as some believe Sasol found when it decided to recover acids from the aqueous Fischer-Tropsch stream.

Many were sceptical about the proposed project's commercial viability, even if the separation problems could be overcome. Acids, after all, comprised less than two per cent of the stream – the reason why Sasol had, for many years, fed this water with its acid content to the activated sludge water treatment facilities. Two of the acids, however, have major commercial value: acetic acid (vinegar) and propionic acid, the latter used to produce a compound that prevents mould from developing

in stored wheat and bakery products. The revenue they would provide, it was decided, together with savings from a substantially reduced load on the effluent-treatment plant, could potentially justify the cost of recovering them.

The technical problems were substantial and it was only after more than 10 years of intermittent research into the problem that Sasol found a solvent – a light compound normally used as a fuel component – that seemed to have the potential to do the required acid-extraction job. But would the process to be designed around the solvent pay its way? Large volumes of solvent, relative to the amount of acid recovered, would have to be used and at least as much water would also have to be processed. This meant a large power-hungry plant and an extraction section with the world's largest-diameter packed extractor.



Opposite: Ethyl acetate plant at Secunda

Right: Propionic acid is used to produce calcium propionate, which keeps bread fresh

After validating the process in the research and development laboratories, a pilot plant was constructed in Secunda and run for several months to gather sufficient design data to design a commercial plant. However, perhaps because of capital-cost pressures on this project or perhaps because there was insufficient appreciation of the corrosion risks with such a process, the first years of operation were plagued by numerous equipment and corrosion-related problems, leading to poor online time. After much effort and financial cost, the problems seem to have been largely overcome and the plant now turns

Technology's research and development division to produce new processes and improve those already in use, but elsewhere in Sasol Technology, designing process plant and managing its construction. The dozens of awards Sasol has won over the years for its projects from South African and international professional associations testify to the excellence achieved by Sasol Technology in scientific conceptualisation and engineering design and implementation.

Sasol is prepared to take some risks that other petrochemical companies would shy away from

a profit. Lost production time, however, translates so far to a poor return on investment.

These stories are important because they illustrate qualities that have defined Sasol's culture from the start. Sasol is prepared to take some risks that other petrochemical companies would shy away from, reaches decisions comparatively quickly and attacks the technological challenges it takes on with determination, strong morale and ingenuity. When setbacks occur, it picks itself up, derives some benefit from the experience, and resumes the march.

In other words, Sasol provides its scientists and engineers not only with a steady stream of opportunity, but also with an unusual degree of freedom to innovate. As a result, it attracts and retains fine minds, working not only in Sasol

While much of the brainpower Sasol employs is located in-house and includes hundreds of people with degrees in science or engineering, it also reaches out to scientific institutions and organisations in South Africa and abroad.

For example, over the years it has developed a strong relationship with the engineering company Badger-Raytheon of the US, working with it to improve heat exchange in its Synthol reactors and to design Secunda's first fixed-fluidised-bed reactor.

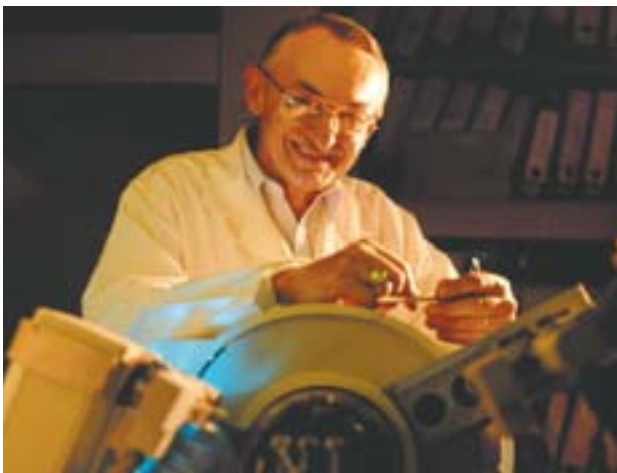
While Sasol employs about 120 scientists in Sasolburg to research catalysts, the field has become so important to Sasol that it finances additional work in it at the University of Cape Town and at Rand Afrikaans University in Johannesburg, and will extend this support to St Andrews University in Scotland. Sasol has turned to university researchers for help with other major aspects of its business, too. Potchefstroom University, for example, is working on separation technology, and there are over 50 postgraduate students at various South African universities being financed by Sasol. Altogether, these

institutions are receiving up to R10 million a year from Sasol. Fifteen foreign universities are also engaged on Sasol's behalf in various fields of research.

One of the key drivers behind Sasol's turning to others for support has to do with what business school lecturers call "first

but related tests simultaneously rather than, as previously, consecutively. Similarly, chemical reaction can now be simulated and optimised by computerised molecular modelling.

Beyond that, though, lies a need to optimise existing processes and produce new products that is fundamental to Sasol's

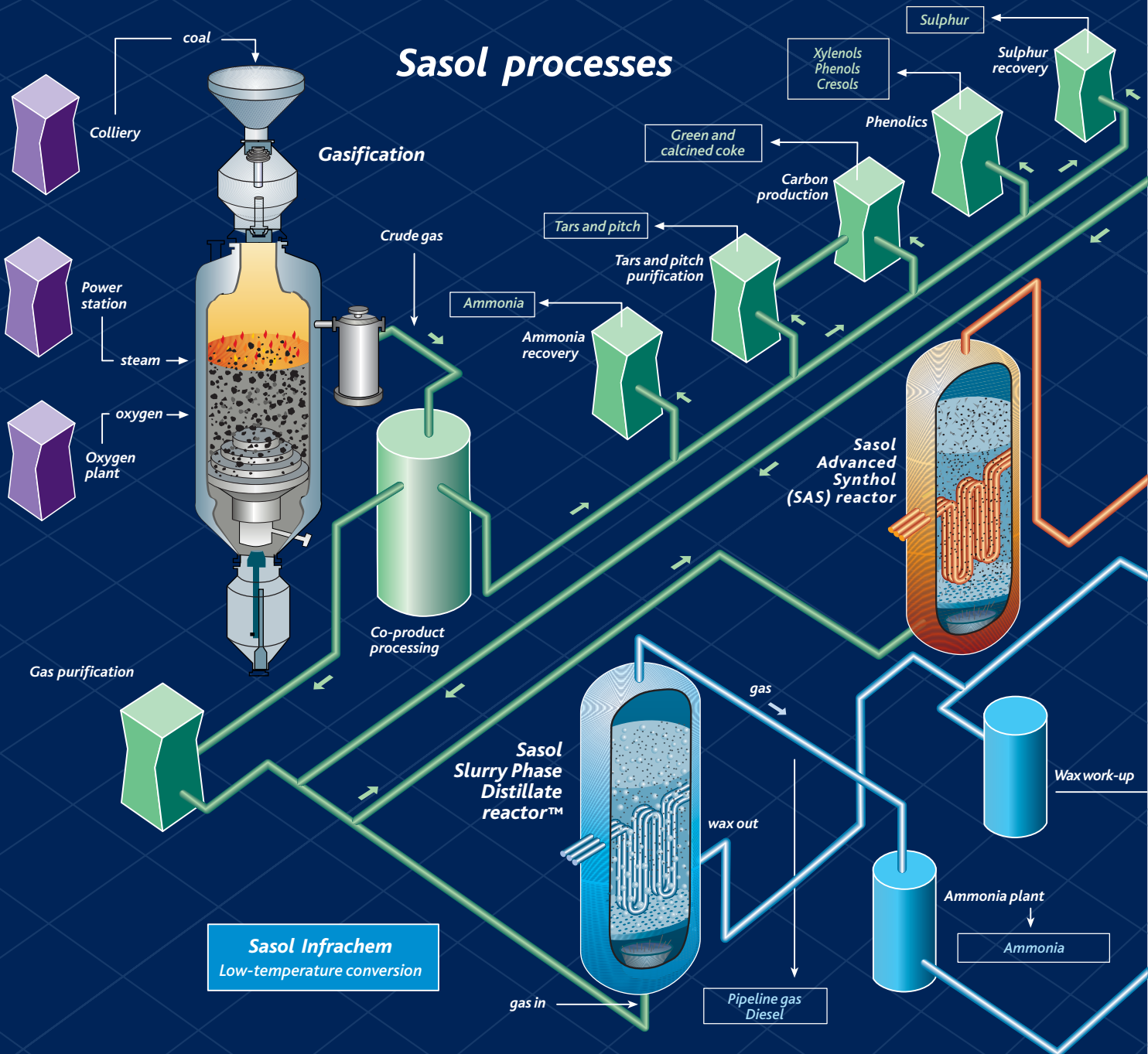


To ensure it remains in the vanguard of petrochemical technology, Sasol employs hundreds of science and engineering graduates

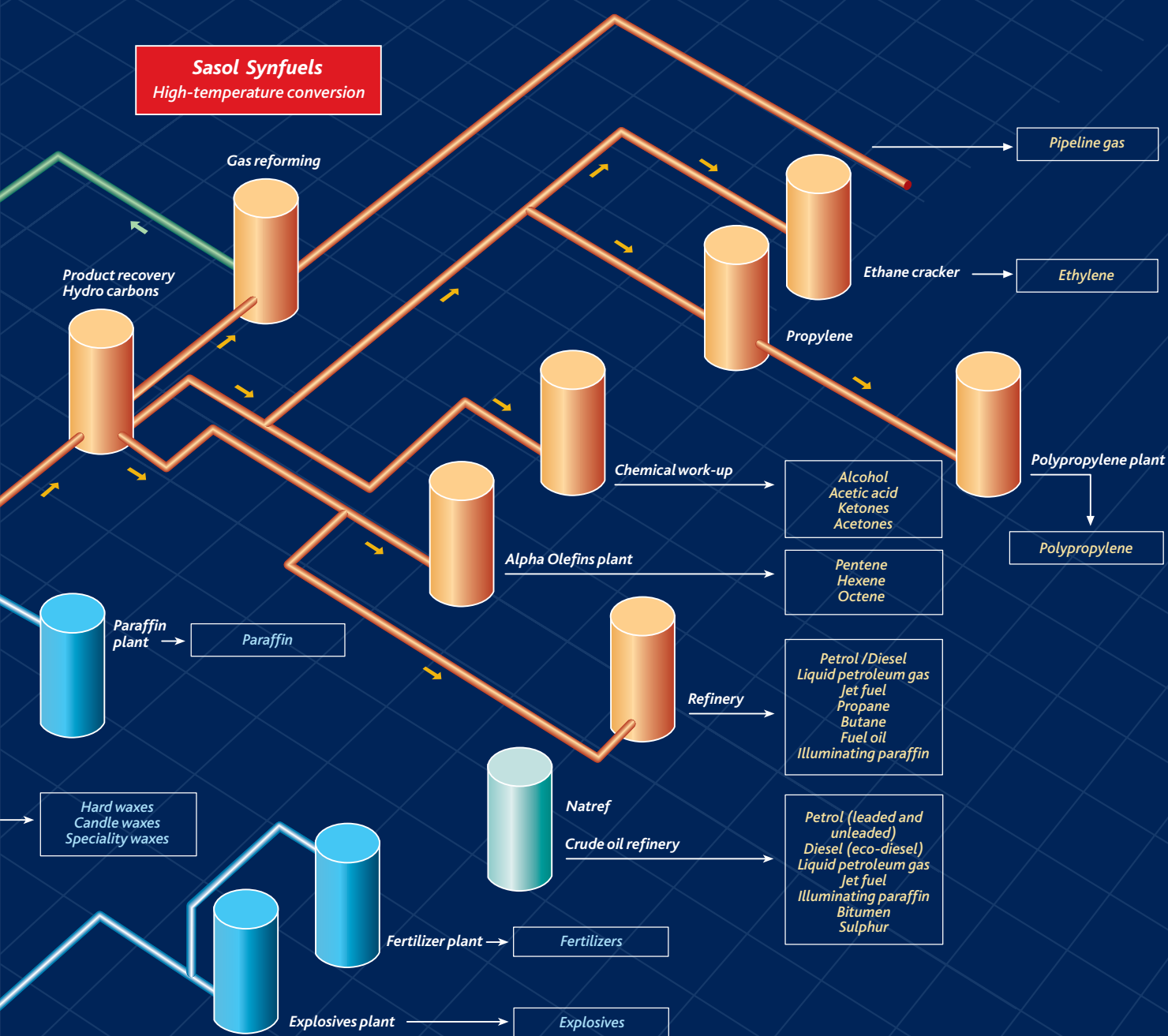
mover advantage": a company which successfully pioneers a new field of technology can develop markets and improve its technology while others are still engaged in analysing the situation. The markets Sasol addresses are becoming ever more competitive as new technology accelerates the rate at which new processes and products are introduced. For example, using very small-scale instrumentation opens the way to rapid screening and simulation: that is, to conducting many different

operations. The greater value produced from the Fischer-Tropsch treasure chest by such optimisation and innovation not only increases the profit coming out of Sasolburg and Secunda but also improves the investment appeal of gas-to-liquids sites by steadily expanding the number of their downstream products. In assessing Sasol's long-term future, those sites are arguably more likely to make Sasol a significant petrochemicals world player than products exported from South Africa.

Sasol processes



Sasol Synfuels
High-temperature conversion



GLOSSARY

A

Acetylene – A gas comprising two atoms of carbon and two of hydrogen (C_2H_2); used to create larger hydrocarbon molecules as well as in welding.

Afrikaans – One of South Africa's 11 official languages and derived largely from the Dutch spoken by South Africa's first white settlers.

Alizarin – The red colouring matter of the madder root ($C_{14}H_8O_4$).

Aluminium oxide – A compound of the elements aluminium and oxygen. It is found in nature, but can also be produced from bauxite. One of its uses is as a substrate for catalysts.

Ammonia – A compound of nitrogen and hydrogen (NH_3), its nitrogen making it useful for producing fertilizer and nitric acid (qv).

Ammonium nitrate – Ammonia with additional oxygen, nitrogen and hydrogen atoms. Also used to produce fertilizers and explosives. When heated, it yields laughing gas (nitrous oxide, N_2O).

Aniline – A colourless, oily liquid composed of ring-shaped molecules and used, among other things, for making dyes.

Anthracene – A large, ring-shaped hydrocarbon molecule (14 carbon atoms) used to produce artificial alizarin (qv).

Anthracite – The most valuable of the various varieties of coal because it contains the highest proportion of carbon.

Atom – The basic building blocks of the elements, each of which is composed of atoms unique to it.

B

Beneficiation – Using one of several available methods to remove unwanted material from a pulverised metallic ore.

Butadiene – A colourless, gaseous hydrocarbon compound that has two double bonds, making it easy to polymerise (qv). It is used to make synthetic rubber.

C

Calcined pitch coke – A high-carbon, coal-derived material produced under high temperature for use in the iron and steel industries.

Camphor – A white, waxy substance derived from the the camphor laurel bush and composed of carbon, hydrogen and oxygen atoms. Its awful smell sees it used as an insect repellent, and it is also used as a plasticiser for cellulose nitrate.

Carbide – A compound of carbon and a metallic or semi-metallic element (eg, calcium, silicon, aluminium, boron). Acetylene is produced from calcium carbide.

Carbon dioxide – A colourless gas found in very small proportions in the atmosphere, but also produced industrially. At $-78,5^{\circ}C$ it forms the refrigerant, 'dry ice'. It is also used in fire extinguishers, in fizzy drinks and in welding.

C

Carbon monoxide – A highly toxic and flammable gas formed by incompletely converting carbon to carbon dioxide through incomplete combustion of carbon-containing fuels. It is used in making many chemical products.

Catalyst – A material that accelerates or retards chemical reaction without itself being chemically affected (it may well be physically changed, though, or even destroyed).

Ceramic – A hard and durable material with a crystalline structure and high resistance to chemical corrosion and heat.

Charcoal – A porous form of carbon produced by heating wood, bone or sugar in the absence of oxygen.

Chemical reaction – The formation of new substances from one or more reactants by breaking existing electrical bonds and creating others.

Cobalt – One of the metal elements, often found in the ores of other metals, soils, plants and animals. Silvery white in appearance, but with a bluish tinge, it was for centuries used to colour ceramics and glazes blue. Today it is mostly used in metal alloys from which permanent magnets, cutting tools and heating elements are produced.

Commission (plant) – To begin operating a new plant or item of equipment.

Comonomer – An unsaturated molecule that joins with another, of a different kind but also unsaturated; the partnership then polymerises (qv).

Copper salt – Copper carbonate, a molecule containing carbon, hydrogen and oxygen atoms as well as copper.

Corrosion – The slow destruction of metal by chemical reaction; for example, iron or steel can rust away through their reaction with oxygen contained in air or water.

Cyclone – A device for separating two substances of different densities.

D

Debottlenecking – Removing the cause of a slowdown in a multi-stage production process.

Devolatilise – To remove hydrogen- and oxygen-rich gases from coal in its underground seam by subjecting it to heat, such as that produced by volcanic eruption.

Diatomaceous earth – A powder composed of the silica-containing skeletal remains of unicellular algae abundant in plankton.

Distillation – To separate liquid substances of different densities and therefore different boiling points. Carefully judged heating evaporates only the lighter substance; cooling the resulting gas condenses it back to a liquid. The alternative is to heat the entire mixture sufficiently for all its components to turn into gases. They will cool and return to their liquid form at different temperatures.

E

Economies of scale – The unit-cost benefits that result from charging fixed expenses (eg, administration and marketing staff or maintenance workshops) to as many producing units as they can service.

Entrained – Caught up in, and taken along by, a moving stream of air or water.

F

Filament – A long, thread-like structure.

Forge – To shape metal by heating and hammering it.

Formaldehyde – A compound of carbon, hydrogen and oxygen that produces a colourless, pungent liquid still used in the plastics industry and elsewhere.

Fraction – A range of hydrocarbon molecules, defined by the number of carbon atoms they contain.

Front-end engineering design – Conceptualising and beginning the design of a plant.

H

Heat exchanger – A metal device that stands between two fluid (liquid or gas) substances, absorbing heat from the hotter and transferring it to the cooler of them. The latter is replaced, as it heats up, with its cooler version.

Hexene – A six-carbon, unsaturated straight-chain hydrocarbon molecule.

Hopper – A container that tapers downwards sufficiently to direct its contents into a far smaller vessel.

Hydrocracking – A catalytic process that uses hydrogen to crack (break) heavy hydrocarbon molecules into lighter ones and thereby produce, for example, diesel from wax.

I

Intermediate – In the multi-stage petrochemical industry, a chemical substance produced at one stage for use in the following stage.

Iron oxide – A molecular compound of the two elements, iron and oxygen, and familiar to everyone as rusted iron.

Isotope – The atoms of an element, while always having the same number of protons in their nuclei, can differ in the number of neutrons their nuclei contain. That doesn't affect their chemical properties because their electrical characteristics remain the same since neutrons have no electrical charge.

L

Limestone – A sedimentary rock composed mostly of calcium (the shell remains of marine animals), carbon and oxygen. One of its industrial uses is as an agricultural fertilizer, especially when mixed with ammonium nitrate, which is rich in nitrogen.

M

Melamine – A colourless, crystalline substance with a ring-shaped molecular structure. The material popularly known as melamine is a resin formed by reacting chemical melamine with formaldehyde (qv).

Metal fatigue – Weakening of metal structures or machinery parts by repeated stress or loading, so that previously tolerable strain creates a fracture.

Methane – The simplest of the hydrocarbon molecules, consisting of one carbon and four hydrogen atoms. That makes it highly flammable, but also inert (it doesn't react with other atoms or molecules because it is electrically self-sufficient).

Molecule – Atoms of one or more compounds held together by electrical forces. Helium is an exception: one atom of it also counts as a molecule.

N

Naphtha – A fraction of crude oil, its molecules containing 6-9 carbon atoms. Comprising both straight-chain and ring-shaped molecules, it needs multi-stage processing to improve its octane rating by converting straight-chain to ring-shaped molecules.

Nickel – One of the transition-metal elements used as a catalyst, in alloys and in nickel-cadmium batteries.

Nitric acid – A powerfully oxidising acid produced from ammonia and used in the preparation of a wide variety of industrial products, including explosives and fertilizers.

O

Olefin – A straight-chained unsaturated hydrocarbon molecule. When the double-bond occurs between the first and second carbon atoms in the chain, the olefin is known as an alpha olefin.

Oligomerise – To join a few unsaturated hydrocarbon molecules together to form a larger molecule.

On-specification – An adjective describing plant, machinery or other products that have been manufactured to required specifications.

Oxygenate – To add oxygen to a gas or liquid.

P

Pentene – An unsaturated hydrocarbon molecule with five carbon atoms.

Phase – The physical state of a substance: solid, liquid or gaseous.

Phenol – A weak acid composed of ring-shaped hydrocarbon molecules to each of which one or more oxygen atoms are attached. Dissolve phenol in water and you get the disinfectant, carbolic acid. Phenol is also used in the plastics industry.

Phosphate – Any of more than 200 different compounds derived from phosphoric acid and ultimately from the element, phosphorus. Widely used as a fertilizer.

Plasticiser – A compound that, added to another, enables it to be moulded.

Perspex® – A light, transparent and thermoplastic material used in lenses, packaging, aircraft windows, etc.

Polar – Describes molecules in which an electrical tug-of-war has taken place between the atoms of different elements – the rope is composed of electrons – and one side has won. Knowing which substances contain polar molecules (eg, water) gives important information about their chemical properties.

Polyethylene – Polymerised ethylene (two carbon, four hydrogen atoms) molecules. It can be composed of straight-chain molecules, which provides a dense material known as high density polyethylene, or of branched-chain molecules that yield a product called low density polyethylene.

Polymerise – To join molecules of the same substance together to form larger molecules.

Polypropylene – Polymerised propylene (three carbon, six hydrogen atoms) molecules.

Polystyrene – Polymerised styrene (see below).

Polyvinyl chloride – A resin produced by first reacting ethylene with the element chlorine to produce ethylene chloride, then using a catalyst to convert ethylene chloride to vinyl chloride, which is then polymerised using another catalyst.

- P** ***Potassium** – One of the elemental metals. Because it is highly electropositive – it gives away electrons – it readily forms compounds with other elements. It's an important ingredient in agricultural fertilizers.*
***Potassium oxide** – A compound of potassium and oxygen used to improve the performance of iron oxide catalysts.*
***Purge gas** – Usually steam, used to clean out reactors and their associated piping.*
- R** ***Reactor** – Industrial plant to provide the physical conditions required for specific chemical reactions to take place.*
***Reform** – To use heat, pressure or a catalyst, or a combination of them, to destroy existing molecules and create different ones.*
- S** ***Slurry** – A liquid substance containing solid particles.*
***Styrene** – A liquid composed of large hydrocarbon molecules partly composed of ring-shaped molecules. The latter cause a light and rigid material to result when styrene is polymerised.*
***Sulphur** – One of the elements. Found by itself in 'free' deposits, but also, because it's highly reactive, as a constituent of the compounds forming crude oil, natural gas and coal, and of those formed with metals such as iron, copper and zinc. Widely used as a basic chemical commodity, it's one of the ingredients for making sulphuric acid, matches, fireworks and gunpowder; also used to vulcanise (strengthen) rubber.*
***Sulphuric acid** – A major industrial chemical product resulting from a multi-phase process that begins with burning sulphur in air and ends by forming molecules comprising one atom of sulphur joined to two of hydrogen and four of oxygen (H_2SO_4) – a strong, viscous (semi-liquid) acid used in a huge range of industrial processes, such as making agricultural fertilizer, high-octane petrol, explosives and rayon, and in pickling steel (removing a scale of iron oxide crystals from the surface of hot-rolled steel before cold-forming it).*
- T** ***Train** – A sequence of processing units, each of them performing a different job to arrive at the final product.*
***Turbine** – A rotating engine or motor that has finlike blades. A stream of water, steam or gas hits the blades at an angle, thereby turning the engine which transmits the mechanical energy it has received to a generator that converts it to electrical power.*
- U** ***Urea** – A crystalline material containing nitrogen that makes it valuable as an agricultural fertilizer.*

Acknowledgements

Such were the vagaries, absurdities and derelictions of England's education system in the middle of the last century that I left school with no knowledge whatsoever of physics and chemistry. My ignorance was in no way diminished until I set about researching this book, a task for which I was singularly ill-equipped, yet felt drawn to as if supernaturally guided.

My gratitude towards the dozens of Sasol scientists, engineers, miners and plant managers and operators whom I consulted is therefore boundless. I shall not name them – they know who they are and, as individuals, shun the spotlight – but merely record that not one of them showed me anything but kindness and patience when explaining the fundamentals of what they had been up to over the years. There is, however, one person whom I must name because I turned to him often: John Marriott, Sasol's official spokesman on technical matters. He never failed to provide a clear and simple explanation of technical challenges Sasol had once faced, and of how it had met them.

Reading books and technical papers was also an important aspect of my research, and thanks must therefore go to Sasol's head librarian in Johannesburg, Christine Pretorius, and her colleagues. They never hesitated to use their deep knowledge of what is a complex group of companies and the impressive technical resources at their command to suggest and provide documents that would give me some understanding of this or that matter before I set out on my interviewing. Books that were not available in Sasol's own libraries, yet seemed likely to aid my broader knowledge and understanding of science and technology, were quickly obtained from other libraries throughout South Africa.

Finally, I must remark on the quite extraordinary friendliness of all those whom I encountered at Sasol. It can only be explained, I reckon, by their feeling happy and fulfilled in their jobs. It certainly made my time with them unusually pleasant.

John Collings

Peer appreciation

Over the years Sasol has received dozens of awards from various South African and International professional bodies for its achievements in the fields of geology and mine planning, process design and innovation, project engineering and management; and chemicals research and innovation.

In May 2001, for example, its success over the decades in advancing commercial Fischer-Tropsch technology, unlocking new opportunities in the field of chemicals and chemical by-products and helping to promote science and technology through Sasol SciFest and other initiatives was recognised with the 2000 National Science and Technology Forum's corporate award for outstanding contribution in the fields of science, technology and engineering.

The South African Institute of Chemical Engineering has recognised Sasol's innovative work on several occasions – for co-developing with Linde a unique azeotropic distillation process for removing oxygenates from a C₈ broad cut; for producing acrylamide in a catalytic distillation column, and project managing a distillation tower featuring the world's largest partitioned column with trays; and for its low-steam-to-carbon reformer project.

The South African Institute of Mechanical Engineering, too, in 1999 formally recognised Sasol's success in efficiently replacing replacing Synthol reactors with new-generation Sasol Advanced Synthol (SAS) reactors at Secunda. Earlier in the 1990s, the National Productivity Institute had given Sasol Technology a silver award for the work it had done for Sasol Chemical Industries in Sasolburg in the areas of business development, conceptual engineering, project implementation and plant support services.

Nor has recognition of Sasol's achievements come only from South African organisations. The worldwide Project Management Institution gave Sasol Technology its International Project Management Award in 1991 for fast-track construction of the polypropylene plant at Secunda in 1990/91. In 1995 America's Council on Alternate Fuels honoured Sasol with its Walter Flowers Achievement Award for its pioneering work in developing and commercialising coal-conversion technologies.

Credits

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