

World Petroleum Council Guide

Petrochemicals and Refining



www.world-petroleum.org



ENGINEERING & CONSTRUCTION, Outstanding solutions for the biggest Oil & gas challenges

Saipem is a leading global general contractor, with a full range of project management, engineering, procurement, construction and installation services, with distinctive capabilities in the design and execution of large-scale offshore and onshore projects, particularly in oil & gas markets.

Saipem has a growing focus on activities in remote and difficult areas, as well as on major technological challenges, such as deep waters exploitation, gas monetization and liquefaction, heavy and unconventional oils production and conversion, and many others.

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World Petroleum Council Guide

Petrochemicals and Refining

Published by International Systems and Communications Limited (ISC)
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Saipem: 60 Years of Achievements in Refining, Petrochemical and Fertiliser Plants

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Saipem has a long and articulated history of designing and building new refineries, petrochemical and fertiliser plants, based on proprietary as well as on top-of-the-line third-party technologies. This history originates in the 1950s with Snamprogetti, acquired in 2006, as well as with Sofresid, acquired together with Bouygues Offshore in 2002, and was later much reinforced by Saipem as a fully integrated global company. Today, more than 100 major integrated complexes, including 36 grassroots refineries, and almost 2,000 individual process units bear the Saipem signature, mostly as the main EPC contractor.

By the end of the 1950s, before the tenth anniversary of its foundation, Snamprogetti had designed, built and started up 14 new refineries, in several countries in North and West Africa, in India and Pakistan, in Europe and of course in Italy. Indeed, over the following decades, grassroots refineries had become one of Snamprogetti's main areas of activity, particularly in the then new world markets: many new achievements in the Middle East, Eastern Europe, Asia, Latin America, as well as many more in India and Pakistan.

Following the market shift in the 1990s, away from simple refineries in favour of larger complexes with enhanced conversion capacities to maximise gasoline and diesel production, Snamprogetti had focused on the design and construction of major "bottom-of-the-barrel" upgrading projects. Thus, the constituent companies of Saipem have become one of the world leaders in hydrocracking (30 units to date), residue conversion (7), solvent deasphalting (13), IGCC (4, two of which are the world largest) and generally in heavy oil upgrading.

Saipem's extensive know-how in this area was also applied to the development, in support of Eni's efforts, of EST – the Eni



Inauguration by Mr. Enrico Mattei, President of Eni, of the first Samir Refinery in Morocco, designed and built in 1960 by Snamprogetti, now Saipem.

Slurry Technology, a revolutionary process for almost complete conversion of heavy residues and unconventional crude oils. Following satisfactory test results at lab and pilot plant scale and after the semi-commercial demonstration in a 1,200 bpsd unit, the first full scale 22,400 bpsd commercial plant is close to completion in Eni's flagship refinery at Sannazzaro de' Burgondi, close to Milan, Italy.

Saipem's activity included also some very novel technology applications in new market settings; for example:

- In the 1970s and 1980s, the invention, licensing and often design and construction of numerous plants to produce MTBE, the popular octane-booster. This area of activity continues today with the licensing of the more environmentally friendly ETBE.



Horizon Project, Phase I, for Canadian Natural Resources, Fort McMurray, Alberta, Canada.

- The design and construction under turnkey contractual schemes, innovative for Alberta, Canada, of two hydrotreating complexes for Canadian Natural Resources Ltd. to produce syncfuels from oil sands (Horizon Project, phases 1 and 2).
- Most recently the design and construction on an entirely modular basis of the expansion of Staatsolie's Tout Lui Faut Refinery in Suriname.

All this in addition to the design and execution of equally important but more traditional projects, such as the aromatics complex, currently in progress, for the Rabigh II project in Saudi Arabia, for the Saudi Aramco-Sumitomo JV.

Almost since its earliest days, many decades ago, Saipem has been a world leader in the licensing, design and construction of urea-based fertiliser plants, with 130 units licensed to date based on the proprietary Snamprogetti urea technology, in every corner of the world.

In the quest for economies of scale, following the successful start-up of the largest single-train urea unit in operation, Profertil's Bahia Blanca Fertiliser Complex in Argentina, which achieved an average yearly production of about 3,600 t/d in 2006 and has become the reference for the subsequent design and construction of today's biggest ammonia-urea complexes, at the end of 2010 Saipem completed and put on stream the first of the new wave of world largest single train units, the Daharki Ammonia-Urea Complex for Engro in Pakistan, with the design production capacity of 3,835 t/d of urea. Two more such units, with the capacity of 3,850 t/d, were recently completed in Qatar and several others are at various stages of design and construction in India, Saudi Arabia and Nigeria.

In addition to continuous technology improvements, e.g. the new Omegabond Advanced Tubing Technology for improved stripper performance, developed in collaboration with ATI WahChang, and the adoption of continuously improved process schemes for increased reliability and availability, environmental impact reduction and energy savings, Saipem has recently developed a ready-for-implementation design for single-train plant capacities exceeding 5,000+ t/d.

Also in petrochemicals, the early steps of Saipem's involvement as an engineering and construction main contractor date back to the late 1950s, with Snamprogetti's contribution to the creation of Eni's chemical production sites in Gela, Sicily, and during the 1960s of other sites, in support of the rapid growth of the leading shareholder at that time.



Rio Polimeros Gas Chemical Complex, Brazil.

Since the 1970s, Saipem has been engaged as an EPC general contractor in many petrochemical projects in rapidly growing world markets, from China to the Americas, completing more than 160 petrochemical plants and integrated complexes worldwide, producing olefins and diolefins, polymers and elastomers as well as base and intermediate chemicals, all this by adopting the most modern technologies from leading licensors (e.g. Univation). An example of such an involvement in a multi-billion dollar project is the recent design and execution of the Rio Polimeros Gas Chemical Complex in Brazil, in JV with ABB Lummus.

Therefore, in downstream as well as in upstream markets, onshore as well as offshore, Saipem confirms that it is today not only one of the world largest, but also one of the most balanced engineering and construction contractors in the oil and gas industry. Its many achievements in other markets have not distracted it from its strong focus also on the most exacting challenges in the downstream process industries.

Daslav Brkic

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Engro's Daharki Ammonia-Urea Complex, Pakistan.



Building partnerships that deliver



From our home base in South Africa, Sasol is a global leader in gas-to-liquids (GTL) and coal-to-liquids (CTL) technologies, and is the world's largest producer of synthetic fuels. Our international growth is based on our unique value proposition, which links our diverse businesses into an integrated value chain. This enables us to produce a range of high-value product streams, including liquid fuels, chemicals and lower-carbon electricity.

Our ability to deliver sustainable shareholder value is premised on maintaining solid operations, and accelerating our growth strategy. The positive position we find ourselves in today is as much due to the strengths we have in our organisation as it is to the strong partnerships we are harnessing to deliver mutually beneficial results.

We pride ourselves on developing our people, keeping them safe and healthy, contributing meaningfully to the social and economic development of the countries and communities within which we work, and doing so in an environmentally responsible fashion.

Having shown our resilience in facing the global financial crisis, Sasol is well positioned to further expand and excel. In collaboration with our business, government and social partners, we look to the future with confidence.



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Unless otherwise stated, the dollar (\$) values given in this book refer to the US dollar.





The President's Opening Remarks

Petrochemical producers need to innovate and focus on sustainability in a world that is undergoing rapid social, political and economic change.

It has been a long trajectory since the first World Petroleum Congress was held in London in 1933, but the principles of the WPC's mission never changed: Sustainable production and consumption of oil, natural gas and its products for the benefit of humankind.

This WPC Guide has been prepared with those principles in mind. It is aimed at those who have an interest, either as a regulator, producer or consumer, in refined products and petrochemicals. That means all of us. Modern life is all but impossible without such products. This book aims to assist in the understanding of the issues associated with this capital-intensive, socially and economically high-impact sector of the petroleum value chain.

In the last two decades, we have witnessed social, economic and political change at unprecedented speed. It is quite common for new products and technologies to become obsolete just a few years after they are introduced. Consumer demand patterns can change almost overnight and social media can trigger rapid political and economic reforms.

This pattern of constant, fast change is no different in the petrochemical sector. But it is not uncommon for the gap between the first viability



Renato Bertani.

study and the first gallon of a processed product to span a full decade. This is more than enough time for significant changes in availability, grade and price of feedstocks, demand, specification requirements, environmental and safety regulations. This is only a short list of the enormous uncertainties that need to be taken into consideration when planning large and long-term investments.

While planning for and dealing with changes may impact on economic performance, accounting for human needs is essential when it comes to sustainability. It is only those projects that prioritise the safety of employees and communities nearby, environmentally friendlier processes and products, and superior business ethics that will be sustainable and profitable in the long term.

We trust that the information provided in this guide will facilitate the understanding of these interrelated issues. And that all of us, as producers or consumers, will be able to make more informed decisions, even if only at choosing the right fuel grade at the petrol pump.

Renato Bertrani
President, World Petroleum Council



Message from the Director General

Over the decades, the technology has changed but oil, gas and coal are still being used to create many products we take for granted.



Dr Pierce Riemer.

This book emphasises that nearly every aspect of modern life is impacted by oil and gas. Oil is used for fuels that drive our vehicles. Power stations burn oil and gas to produce electricity, oil and gas are used to create medicines, plastics, textiles, cosmetics and many other products that enhance our lives.

In the 1800s, oil was a by-product of the salt business as wells drilled for salt water produced "foul-smelling petroleum". Following experimentation in distilling this liquid petroleum, a lamp oil called carbon oil was produced in 1851. It burned with little smoke and odour and was sold for \$1.50 a gallon. Prices – and chemistry – have changed since then. In Pennsylvania, USA, Colonel Drake recognised the value of this product and his first oil well kicked off the petroleum industry in 1859. At this time, Lenoir's development of the internal combustion engine paved the way for the modern automobile industry.

From 1859 to 1900, there were many technological innovations as auto inventors tapped the potential of the internal combustion engine, and petroleum pioneers improved methods of producing, refining and delivery. Entrepreneurs such as John D. Rockefeller and Henry Flagler dis-

covered new oil fields, drilled deeper oil wells than Colonel Drake's first 70-foot well, and made great strides in refining and distribution. The first oil refinery was constructed in 1862. Gasoline was a by-product of these early units, and emerged as their most important product. The interdependency of the oil and auto industries became clear as priorities overlapped, and superior engines and cleaner burning fuels were produced.

Since the 1960s, refiners have worked on cleaner burning fuels to satisfy environmental concerns. We are now entering the age of the unconventional refinery. From the early days of coal-to-liquids (CTL) technology in the 1930s and 40s and more recently gas-to-liquids (GTL), we now have operations like Pearl in Qatar which demonstrate the "refinery" of the future. The refining industry will continue to take on challenges and meet them through science and innovation.

We hope that this guide will give you an insight into a vital and fascinating side of our industry.

Dr Pierce Riemer

Director General, World Petroleum Council



WPC Vision, Mission, Values and Principles

Vision

An enhanced understanding and image of the oil and gas sector's contribution to sustainable development.

Mission

The World Petroleum Council (WPC) is the only organisation representing the global oil and gas community. WPC's core value and purpose centres on sustaining and improving the lives of people around the world, through:

- Enhanced understanding of issues and challenges
- Networking opportunities in a global forum
- Cooperation (partnerships) with other organisations
- An opportunity to showcase the industry and demonstrate best practice
- A forum for developing business opportunities

- Information dissemination via congresses, reports, regional meetings and workshops
- Initiatives for recruiting and retaining expertise and skills to the industry
- Awareness of environmental issues, conservation of energy and sustainable solutions

Values

WPC values strongly:

- Respect for individuals and cultures worldwide
- Unbiased and objective views
- Integrity
- Transparency
- Good governance
- A positive perception of energy from petroleum
- Science and technology
- The views of all stakeholders
- The management of the world's petroleum resources for the benefit of all

Principles

WPC seeks to be identified with its mission and flexible enough so that it can embrace change and adapt to it. WPC has to be:

- Pro-active and responsive to changes and not merely led by them
- Creative and visionary, so that we add value for all
- Challenging, so that our goals require effort to attain but are realistic and achievable





- Focused, so that our goals are clear and transparent
- Understandable to all

Key strategic areas

- **World Class Congress** to deliver a quality, premier world class oil and gas congress.
- **Inter-Congress activities** to organise forums for cooperation and other activities on specific topics; and to organise regional events of relevance to WPC members and all stakeholders.
- **Cooperation with other stakeholders** to add value by cooperating with other organisations to seek synergies and promote best practice.
- **Communication** to increase awareness, of WPC's activities, through enhanced communication, both internally and externally.
- **Global representation** to attract and retain worldwide involvement in WPC.
- **Youth and gender engagement** to increase the participation of young people and women in oil and gas issues, including the establishment of a dedicated Youth Committee for the development of active networking opportunities with young people.
- **Legacy** to create a central WPC legacy fund to benefit communities and individuals around the world based on WPC's mission.

World Petroleum Congresses

2014 21st WPC Moscow

2011	20th WPC	Doha	1979	10th WPC	Bucharest
2008	19th WPC	Madrid	1975	9th WPC	Tokyo
2005	18th WPC	Johannesburg	1971	8th WPC	Moscow
2002	17th WPC	Rio	1967	7th WPC	Mexico City
2000	16th WPC	Calgary	1963	6th WPC	Frankfurt
1997	15th WPC,	Beijing	1959	5th WPC	New York
1994	14th WPC	Stavanger	1955	4th WPC	Rome
1991	13th WPC	Buenos Aires	1951	3rd WPC	The Hague
1987	12th WPC	Houston	1937	2nd WPC	Paris
1983	11th WPC	London	1933	1st WPC	London



WPC overview

Since 1933, the World Petroleum Council (WPC) has been the world's premier oil and gas forum and is the only international organisation representing all aspects of the petroleum sector.

The World Petroleum Council (WPC) was established in 1933 to promote the management of the world's petroleum resources for the benefit of all. It is a non-advocacy, non-political organisation and has received accreditation as a non-governmental organisation (NGO) from the UN. WPC's prime function is to facilitate dialogue among internal and external stakeholders on technical, social, environmental and management issues in order to contribute towards finding solutions to those issues.

Headquartered in London, WPC includes 65 member countries representing more than 95% of global oil and gas production and consumption. Membership is unique, as it includes both OPEC and non-OPEC countries with high-level representation from National Oil Companies (NOCs) and Independent Oil Companies (IOCs). Each country has a national committee made up of representatives of the oil and gas industry, the service sector, academia, research institutions and government departments.

The governing body of WPC is the Council with representation from all national committees. Its global membership elects the President and an

Executive Committee every three years to develop and execute its strategy. The Council also selects the host country for the next World Petroleum Congress from the candidate countries.

Every three years, the Council organises the World Petroleum Congress. Known as the "Olympics of the petroleum industry" it covers all aspects of oil and gas from technological advances in conventional and unconventional upstream and downstream operations, the role of natural gas and renewables, industry management and its social, economic and environmental impact.

In addition to industry leaders and experts, outside stakeholders such as governments, other industry sectors, NGOs and international institutions also join the dialogue. To ensure the scientific and topical quality of the event, the WPC Council elects a Congress Programme Committee whose members are responsible for delivering the high-level content for its Congresses. Moscow will be the host of the 21st World Petroleum Congress in 2014 (www.21wpc.com).

WPC is also involved with a number of other meetings such as the WPC Youth Forum, the WPC-UN Global Compact Best Practice Forum, joint WPC/OPEC workshops and other regional and topical events on important industry issues.

Legacy

As a not-for-profit organisation, WPC ensures that any surpluses from its events are directed into educational or charitable activities, thereby leaving a legacy. WPC has set up a dedicated WPC Legacy Fund to spread the benefits beyond the host countries and its members and alleviate energy poverty through carefully selected projects.

The concept of leaving a legacy in the host country started in 1994 with the 14th World Petroleum Congress in Stavanger, Norway. After this Congress, the surplus funds were put towards



the building of a state-of-the-art Petroleum Museum in Stavanger.

The 15th World Petroleum Congress in Beijing adopted the issue of young people as part of its theme: "Technology and Globalisation – Leading the Petroleum Industry into the 21st Century". To support the education and future involvement of young people in the petroleum industry, the Chinese National Committee donated all computer and video equipment used for the Congress to its Petroleum University.

Profits from the 16th Congress in Calgary endowed a fund that gives scholarships to post-secondary students in several petroleum-related fields. The Canadian Government Millennium Scholarship Foundation matched the amount dollar-for-dollar, creating an endowment which supported more than 2,000 students until its conclusion in 2010.

The 17th World Petroleum Congress was the first to integrate the concept of sustainability throughout its event, taking responsibility for all waste it generated. The congress and the Rio Oil & Gas Expo 2002 generated 16 tonnes of recyclable waste. All proceeds of the recycling activities were passed on to a residents' cooperative of 6,000 members in the port area of Rio de Janeiro. An army of 250 volunteers collected 36 tonnes of rubbish in 10 days in a community effort to clean up the Corcovado area before the Congress, donating all proceeds to the rubbish collectors, some of the poorest inhabitants of Rio. The Congress's surplus funds were used to set up the WPC Educational Fund in Brazil, which was increased in 2005 with tax initiatives by the Brazilian government.

The 18th World Petroleum Congress also chose a sustainability focus for the first-ever Congress to be held in Africa: "Shaping the Energy Future: Partners in Sustainable Solutions". Education was the focus of the 18th World Petroleum Congress Legacy Trust, set up by the South African National

Committee to provide financial assistance to help needy young South Africans pursue qualifications in petroleum studies.

In 2008, with the 19th Congress in Madrid, the trend continued and the organisers selected a number of projects and foundations to receive the surplus from the event for charitable and educational programmes in Spain and around the globe. The 19th Congress was the first one to offset all its carbon emissions and receive a certification as a sustainable event.

The most recent Congress in Qatar also offset all of its carbon emissions and has chosen a project to educate and support young people as recipients for the 21st WPC Legacy Programme.

Youth outreach

Youth is a critical factor in the sustainability of the oil and gas industry. Involving young people in the design of future energy solutions is a major issue for WPC's 65 member countries. WPC recognises their significance to the future of the petroleum industry and the importance of giving the young generation scope to develop their own ideas, talents and competencies to create viable solutions for the future of our world.

As part of its outreach to the next generation, WPC created its Youth Committee in 2006 to provide a channel through which young people have a direct involvement and say in the strategy and activities of the organisation. It aims to create and nurture a collaborative, global forum for young people to be heard, to champion new ideas within the petroleum industry, to promote a realistic image of the petroleum industry, its challenges and opportunities, and to bridge the generation gap through mentorship networks.

In 2011, WPC launched a pilot Mentorship Programme to provide a bridge between international experts and the next generation of our industry. This programme is now in its second successful cycle and has already created 150 matches.

Air Liquide Global E&C Solutions

Air Liquide Global E&C Solutions has a very comprehensive portfolio of proprietary syngas production technologies, thereby enabling the customer to convert a broad feedstock basis with changing composition into a tailored intermediate feedstock, with a defined composition as demanded by our client according to its downstream use. The corresponding technologies are the result of long-term development and are outstanding in their performance and reliability.

The illustration below summarises the different routes to produce syngas from different carbonaceous feedstock material from natural gas and coal, illustrating the unique feature of syngas production, making carbon in its various forms accessible to the chemical and petrochemical industry, i.e. converting a broad feedstock basis with changing composition into a tailored intermediate with defined composition demanded by its downstream use.

When the syngas production is combined with the appropriate emission control (gas cleaning in general, CO₂ and sulphur management, etc.) a competitive and environmentally sound solution can be implemented.

Since the syngas route, when used for the production of fuels (Fischer-Tropsch) or chemicals (e.g. propylene via MTP™, methanol-to-propylene) can decrease the dependence on oil by utilising alternative feedstock material, this technology chain is expected to play a central role in mastering

the challenges pertaining to the vision called "beyond petroleum".

Air Liquide's portfolio of proprietary syngas production technologies enables our clients to utilise the following feedstock choices:

Our technologies for natural gas as a feedstock.

- SMR: for the production of hydrogen, carbon monoxide and the required mixtures thereof.
- Autothermal reforming (either as a stand-alone technology or in combination with a SMR, so-called combined reforming, for large amounts of syngas, typically for the production of methanol or fuel).
- Partial oxidation for CO-rich gases (e.g. for oxo-synthesis).

Our technologies for LPG, refinery off-gases and naphtha as a feedstock.

- SMR, typically in combination with a pre-reforming step, for the production of hydrogen, carbon monoxide and the required mixtures thereof.
- Should oxygen be available, partial oxidation can also be an option.

Our technologies for residues (from refinery processing) as a feedstock.

- Partial oxidation as the process of choice. Downstream gas cleaning takes care of the relevant impurities contained in the residue.

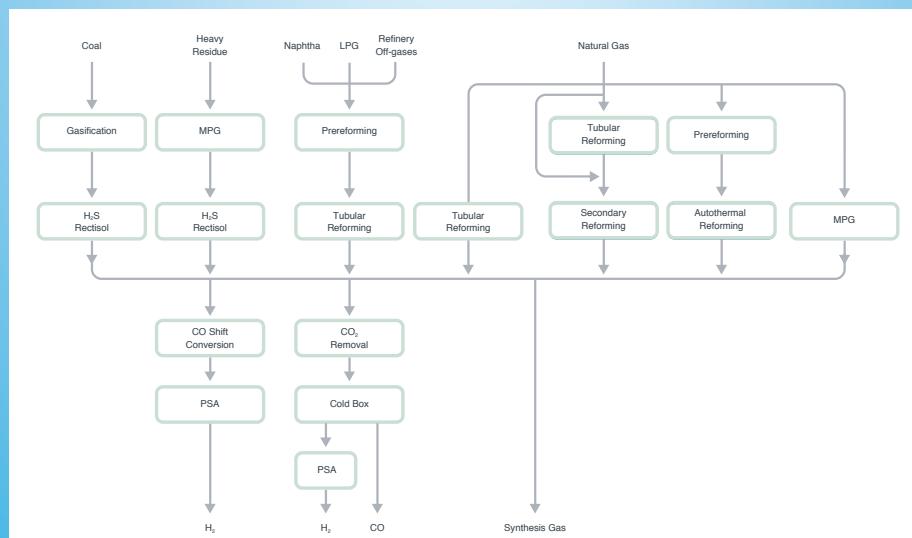
Our technologies for coal as a feedstock

- Gasification by fixed bed dry bottom (FBDB).

Air Liquide Global E&C Solutions' references include both the world's largest single train syngas unit based on combined reforming, and the world's largest multiple train syngas unit based on natural gas, proving an impressive track record of successful syngas projects.

Looking to the future, the market for hydrogen and syngas stays bullish: hydrogen demand for refinery applications will continue to grow as the need for clean fuels increases while the quality of crude oil is declining; the demand for syngas will continue to increase benefiting from readily available sources (shale gas and locked coal).

Pushing the frontiers for syngas generation is key. One of the most promising options, in particular in the context of the North American shale gas boom, is the production of high pressure syngas (HP ATR), which allows a single train production of 10,000 MTPD of methanol. The basis for this technology builds on our high pressure pilot plant for oxygen-based syngas, commissioned in 2004. The investment for this pilot plant underlines, again, our commitment to be the leading syngas supplier to the industry. To conclude, when you talk syngas, you talk Air Liquide.





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The only thing longer than our company history
is the list of our innovations.

Because our genes lead us to an irrepressible passion for new solutions.

When it comes to providing innovative plant and system solutions, Air Liquide Global E&C Solutions is your partner of choice – worldwide. No surprise, since we innovate relentlessly in order to bring sustainable and cost-effective solutions to society,

leveraging partnerships with customers, suppliers, academics and communities. This is not only demonstrated by thousands of patents, but by pioneering reference projects around the globe as well. Yours could be the next one.

www.engineering-solutions.airliquide.com



Designing your success







Petrochemicals historical timeline

1835 Polyvinyl chloride (PVC) discovered by French chemist and physicist Henri Victor Regnault after leaving a sample of vinyl chloride gas in the sun. The sample hardened into a white solid but it was not patented until 77 years later.

1839 Polystyrene discovered by accident by German pharmacist Eduard Simon when he tried to distil a natural resin called storax. He obtained an oily substance he called "styrol" and this thickened, probably due to oxidation. This substance wasn't recognised as being made up of many styrene molecules until 1920.

1851 Carbon oil for lamps first produced.

1856 Synthetic dyes first discovered by 18-year-old student William Perkin at the Royal College of Chemistry in London when trying to develop an artificial form of quinine from coal tar. Instead of quinine, he was left with a purple powder which was used as an affordable fabric dye. Before this, fabric was dyed purple using shells of a Mediterranean mollusc and was very expensive. This discovery, making purple fabrics more widely available, boosted the petrochemical industry by demonstrating the usefulness and profitability of petrochemical products.

1859 Oil discovered when retired railway conductor Colonel Edwin L. Drake drills a well near Titusville, Pennsylvania. Annual US oil production is 2,000 barrels.

1862 Industrialist John D. Rockefeller finances his first oil refinery and created the Standard Oil Company with his brother, William and several associates.

1865 First successful oil pipeline built from Titusville to a railway station five miles away. Trains then transported oil to refineries on the Atlantic coast.

1878 John D. Rockefeller controls 90% of the oil refineries in the United States.

1879 The first synthetic rubber was created.

1888 The study of liquid crystals begins in Austria when scientist Friedrich Reinitzer found that a material known as cholesteryl benzoate had two different melting points. However, it has only been in the last few decades that liquid crystal use has come into its own with appli-



Edwin Drake (right) in 1866, pictured in front of the well where he first struck oil in 1859, heralding the birth of the global oil industry.



cations including mobile phones, electronic toys and computer screens.

1900 Texas, California and Oklahoma all producing oil. Annual US production at 64 million barrels.

1909 The discovery of Bakelite is announced. Considered the world's first plastic, it was invented by Belgian Leo Hendrik Baekeland when he tried to make a substitute for shellac. It helped transform the radio industry in the 1930s.



Bakelite, the original plastic, found many uses from radios to cameras and beyond, and examples are still much sought-after today.

1908 First major discovery of oil in Iran.

1912 German chemist Fritz Klatte develops a new process for producing PVC using sunlight. He was the first to patent PVC but had difficulties processing the sometimes brittle polymer.

1913 High-pressure hydrogenation process for transforming heavy oils into lighter oils developed by German organic chemist Friedrich Bergius.

1913 Thermal cracking patented as a method of oil refining by chemical engineers, William Burton and Robert Humphreys, of Standard Oil.

1914-1918 During World War I, Germany started large-scale production of synthetic rubber and further investigations into its production continued after the war.

1920s-1940s A busy era for petrochemicals with nylon, acrylics and polyester materials developed, as well as new compounds derived from oil-refining by-products entering the market. Other successful materials included polystyrene, polyvinyl chloride (PVC) and polyethylene. Nylon, acrylics and polyester developed for a wide range of uses, such as clothing, sports gear, industrial equipment, parachutes and plexiglass.

1920 German chemist Hermann Staudinger recognised that polystyrene (see 1839) is made up of many styrene molecules joined together in a chain. (see 1929)

1925 US oil production exceeds 1 billion barrels.

1925 Synthetic fuels pioneered with the development of the Fischer-Tropsch process by German researchers Franz Fischer and Hans Tropsch. Coal, biomass or natural gas could now be converted into synthetic fuels.

1926 IG Farben acquires patent rights to the Bergius hydrogenation process (see 1913). Carl Bosch had already been working on high-pressure hydrogenation processes for IG Farben.

1926 American inventor Waldo Semon plasticises PVC by blending it with different additives to create a more flexible material.

1927 First major discovery of oil in Iraq.

1928 Portable offshore drilling on a submersible barge pioneered by Texan merchant marine captain Louis Giliasso.

1929 Scientists at chemical company BASF develop a way to commercially manufacture polystyrene based on Staudinger's findings (see 1920) and a year later, large-scale polystyrene production started.

1930s New process of alkanisation and fine-powder fluid-bed production increases the octane rating of aviation gasoline.

1931 Neoprene invented by DuPont scientists after attending a lecture by Belgian priest and chemistry professor Dr Julius Nieuwland.

1931 German organic chemist Friedrich Bergius and Carl Bosch share a Nobel Prize for their work in high-pressure hydrogenation. (See 1913 and 1926).

1933 German scientists invent Buna-S, a synthetic rubber made from styrene and butadiene. Mainly used for car tyres.

1933-1935 Plexiglass is discovered by accident by German researcher Otto Röhm. He developed





a method for polymerising methyl methacrylate which was intended for use as a drying oil in varnishes but found it could also be used as a coating for safety glass. Plexiglass was manufactured from 1938, used in war planes from 1940 and in car exteriors from 1974.

1933 A white, waxy material, is discovered by accident by two organic chemists at the UK's Imperial Chemical Industries (ICI) research laboratory. ICI chemist Michael Perrin develops a high-pressure synthesis process in 1935 to turn the waxy material into polyethylene. It was available on the mass market in the toy sector from the 1950s.

1935 American chemist Wallace Hume Carothers creates a fibre which came to be known as Nylon. Nylon stockings were introduced to the US market in 1940 to great acclaim. The material is used today for multiple purposes including fabrics, carpets, ropes and guitar strings. Solid nylon is used for mechanical parts.

1936 Catalytic cracking, using silica and



Otto Bayer conducting an experiment demonstrating polyurethane foam in 1952.

alumina-based catalysts, introduced by French scientist Eugene Houdry.

1937 Ethylene glycol and propylene glycol become available as an anti-freeze. Methanol was used until this time.

1937 German chemist Otto Bayer patents polyurethane and further tests created moulded foam with bubbles. Between 1943 and 1944, the Germans secretly used polyurethane in wartime aircraft components. In the post-war years, it became highly successful in mattresses, insulation and furniture padding. Polyurethane is also used in paints, varnishes and sportswear fabrics.

1938 First major discovery of oil in Saudi Arabia.

1938 Dow Chemical Company introduces STYRON polystyrene resins.

1938 American chemist Roy Plunkett develops Teflon after accidentally exploding tetrafluoroethylene gas. The white, waxy powder that remained was a polymer of tetrafluoroethylene which was used as the basis for Teflon, a new non-stick, heat-resistant plastic. Gore-Tex, the breathable, waterproof textile, is also a result of this discovery.

1939-1945 World War II. During this time, the US supplied more than 80% of aviation gasoline to the allies and American refineries manufactured synthetic rubber, toluene, medicinal oils and other important petrochemical-based military supplies.

1941 DuPont chemists John R. Whinfield and James T. Dickinson created the polyester fibre from ethylene, glycol and terephthalic acid. This was called Terylene and was manufactured by ICI.

1941 Polyethylene terephthalate – or PET – is developed from ethylene and paraxylene. It was originally used in synthetic fibres, was first used in packaging in the mid-1960s and pioneered for bottles in the early 1970s. It was first recycled in 1977.

1942 The first catalytic cracking unit is put on stream by Standard Oil in Baton Rouge, Louisiana.

1946 DuPont buys all legal rights for polyester





► By the time this photograph of an oil refinery and storage tanks was taken in 1956, Saudi Arabia was well on the way to capitalising on the world's largest oil reserves.



and develops Dacron, a second polyester fibre.

1946 It is believed that the first synthetic detergents were developed by the Germans in World War I because of a shortage of fats for making traditional soaps. In 1946, there was a breakthrough in detergent development when the first man-made detergent, containing a surfactant/builder combination, was introduced in the US.

1947 German-born American chemical engineer Vladimir Haensel invents platforming, a process for producing cleaner burning high-octane fuels. The process uses a platinum catalyst to speed up chemical reactions.

1949 BASF chemist Fritz Stastny starts work on a process to turn polystyrene into a foam form. In 1951, he succeeded and turned STYRON, a substance that is 98% air, into one of the world's most successful plastics.

Early 1950s Polypropylene discoveries were made in different places because of improved knowledge-sharing but this led to nine different teams claiming to have invented it. Patent litigation was finally resolved in 1989. American chemists Paul Hogan and Robert Banks, working for Phillips Petroleum, are generally credited as the inventors.

1955 South Africa starts making its own synthetic fuels using the Fischer-Tropsch method

because of limited oil imports with the trade sanctions under the apartheid regime.

1960s Work conducted on water conservation for soils in the US led to the development of a resin in the form of an acrylic gel which was then developed into super-absorbent fibres. Commercial production began in Japan in 1978 and in 1980, super-absorbent polymer was used in baby nappy production.

1960s The first synthetic oils are developed with Mobil Oil and AMSOIL leading the field. The synthetics contain additives such as polyalpha-olefins derived from olefins. Introduced commercially in the 1970s to the automotive market.

1963 Australian chemists start work on conducting polymers which are now used as anti-static substances for computer screen shields, windows that can exclude sunlight and photographic film.

1965 Kevlar is invented at DuPont as a result of research involving high performance chemical compounds. It is used in bullet-proof vests, underwater cables, space vehicles, brake linings, building materials, parachutes, boats and skis.

2000 The Nobel Prize for Chemistry is awarded to three Australian researchers, Alan J. Heeger, Alan G. MacDiarmid and Hideki Shirakawa, for their discovery and development of conducting polymers.



Introduction to extraction, refining and processing

By William Srite

Oil, gas or coal can all be refined for the creation of petrochemical products.

The importance of carbon chemistry

Around the 1950s, carbon chemistry was developed and we started using hydrocarbons in oil in new ways. While advances in new uses for hydrocarbons occurred before the 1950s, such as the invention of

Bakelite, the 1950s heralded a new and powerful era for the petrochemical industry. This continues to this day.

Oil and gas were broken down into constituent parts and reassembled to make what we need. It was discovered that oil has every element needed to make any other organic compound. To do this, heat is used, certain catalysts and certain properties of physics will separate the elements and recombine them in more useful ways. It is similar to oil floating on water – that is a physical separation technique that can be applied to any two compounds that don't mix.

Mixing is related to the stability of atoms, electrons and valence shells and is outside the scope of this article. But when two compounds are stable (have the right number of electrons in their outer shell, usually eight, but it can vary and be as many as 32) they don't mix, then you can use physical separation techniques, like the one described above. This allows us to ultimately make products as diverse as Kevlar, nylon, plastic, artificial sweeteners, rubber tyres, and carbon fibre.



The Sauber Mercedes C 291: The use of carbon-fibre reinforced plastic allowed the driver's cell, safety bar and roof to be made in one piece for the first time.



Substances such as ethylene, propylene, butadiene, benzene, toluene and xylenes are processed in petrochemical plants into more specialised products – and it can take more than one step for these products to become fit for use by downstream industries and then to be made into familiar products. For example, it takes one operation, albeit a complex one, to turn ethylene into plastic polyethylene but there are more than seven steps involved in turning benzene into Nylon, one of the most commonly used materials in clothing and sporting equipment manufacturing.

The science behind carbon chemistry

Let's step back for a moment and talk about physics and chemistry and how they work together. "Organic" chemistry can be explained as an "artificial" branch of chemistry that harkens back to a time when chemists were still trying to find the "essence of life" in elements – those that were thought to have this "essence" were organic elements and everything else was inorganic. Today, we know there is no such thing as an "essence of life", at least not in chemical elements. But, we still use the term and today it simply means chemistry or chemicals that use carbon as a building block. We've all heard that carbon is the building block of life and we'll talk about why that is in a moment, but it is good to start with some basic science.

First, we need to explain what an element is. An element is a substance made from just one kind of atom. So, the element hydrogen is an atom made from one proton and one electron. It can also have a varying number of neutrons, as can all atoms. In an atom, a proton has a positive electric charge, a neutron has no charge at all and an electron is negatively charged. When there is an imbalance in the charge, elements seek other elements to balance out.

Carbon is such a useful element and is the basis of all life. This is because in its natural state it lacks



The 12 Pipestill Unit at BP's Whiting oil refinery in Indiana. Currently undergoing modernisation, the refinery first started operation in 1889, predating the advent of the motor car.

four electrons in its outer shell, which makes it very, very promiscuous and willing to bond with almost any other element to try to fill that outer shell with four more electrons. That's why we can string together long chains of hydrocarbons. Carbon has four different places where we might attach another element, unlike, say helium, which has a full shell. Carbon is one of the most imbalanced elements in organic chemistry but, thanks to carbon chemistry, it continues to be one of the most useful, particularly in the field of petrochemical production.

Refineries come in many different sizes and configurations, depending on the local market, the types of products required and the types of feedstocks available for processing. But all refineries perform the same basic tasks – distilling crude oil, gas or coal into its various constituent frac-





tions; chemically rearranging low-value configurations of hydrocarbon molecules into high-value combinations to produce a variety of end-products; and treating these products to meet environmental and other specifications and standards by removing impurities, such as sulphur.

Refining oil for feedstock

There are two types of oil, sweet and sour. Sour crude has lots of sulphur (inorganic) in it so requires an additional step to make it ready for the refining process, which in turn makes it more expensive to refine. Sweet crude is the industry standard and is what is quoted when you hear things like "Brent crude", "West Texas Intermediate", and so on in reports on the markets.

Refining oils is very similar to making whiskey. With whiskey, you mix up grains and yeast and let it ferment until the yeast converts sugars in the "beer" or "mash" into alcohol and carbon dioxide. Then it is put in a kettle that has a lid and a means for the vapours to escape, and heat is then applied. The process with oil is much the same, with heat being applied, usually around 350°C, and the vapourised petroleum being pumped into a fractionating tower.

In whiskey, the alcohol is the second most volatile chemical in the mix, methyl is first and that why distillers throw away the first gallon or so. In the case of oil, it rises up the tower, cools down and its components condense back into several distinct liquids, collected in a series of trays. Lighter liquids, such as kerosene and naphtha (commonly known as Zippo lighter fluid), collect near the top of the tower, while the heavier ones, such as lubricants and waxes, fall to the bottom.

The role of a refinery is to produce physical and chemical changes in crude oil and natural gas. This is done via an arrangement of specialised manufacturing processes. One of these processes is distillation – the separation of heavy crude oil into lighter groups (called fractions) of hydrocarbons.

One, fuel oil, is used for heating or for diesel fuel in the automotive industry. Another one is naphtha, used in gasoline and also as the primary source from which petrochemicals are derived.

In addition to the various fractions, the "dregs" still remain. But these "dregs" are very useful because they are heavy residues that contain carbon and hydrogen which is used to produce more complex compounds and, ultimately, to create useful products. These are generally processed using high temperatures and low pressures.

At this stage of the refining process, certain products, such as jet fuel, are pretty much ready for use but most products are not yet finished and further heating, pressure and chemical catalysts are required to make them into desirable products. Naphtha and by-products of the oil refining process, such as ethane and propane, are feedstocks which are processed using an operation known as cracking, which takes place, logically, in a cracker. Cracking is the process of breaking down heavy oil molecules into lighter, more useful fractions. When a catalyst is used, the process is known as catalytic cracking.

After cracking, new products are obtained. These form the building blocks of the petrochemical industry – olefins (mainly ethylene, propylene and butadiene) and aromatics, named for their distinctive perfumed scent (mainly benzene, toluene and xylenes). These new products are then processed in petrochemical plants to become more familiar products. The steps required for transforming olefins and aromatics into useful, more specialised, products varies, depending on what the final product is going to be.

Refining oil from unconventional sources

The refining sector has had to adapt to new challenges as feedstocks diversify to include oil from unconventional sources, such as oil sands and shale. These feedstocks require different extraction and refining techniques that are often



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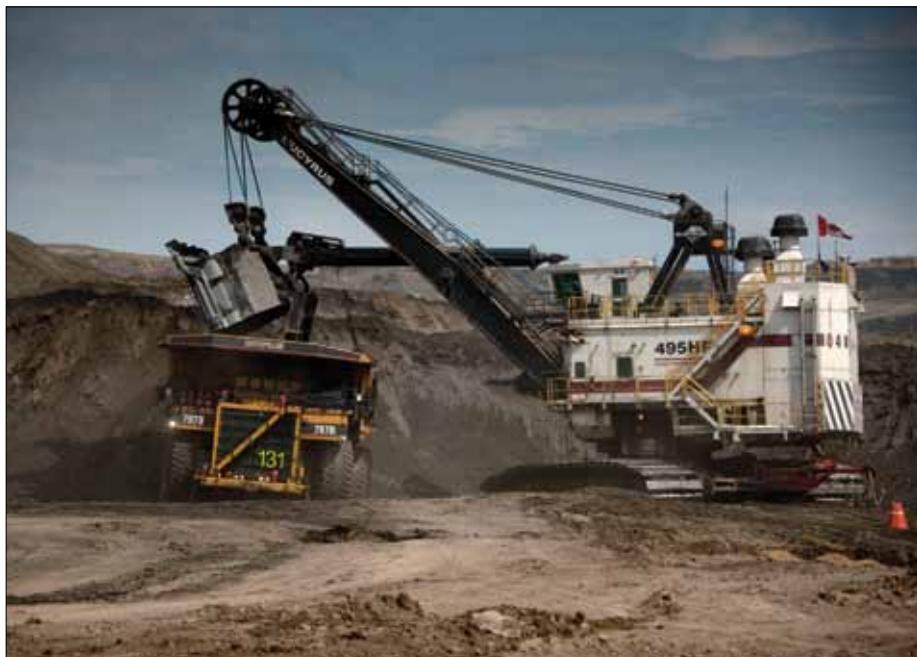
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Loading a truck with oil sand in Alberta, Canada. The extraction of unconventional oil and gas remains both difficult and controversial.

more complicated than the processes used for converting conventional crude oil.

Extraction and refining from oil sands

Oil sands are a combination of clay, sand, water and bitumen. Around two tonnes of tar sands are needed to produce one barrel of oil and many of the techniques use vast quantities of water and energy. Oil sands are also known as tar sands, as the bitumen was used for roofing and paving tar, but this particular use for bitumen has been largely superseded by more modern materials.

This oil is retrieved from these sands by strip mining, open pit techniques, steam injection, solvent injection or underground heating with additional upgrading. The oil that is retrieved is similar to oil pumped from conventional oil wells but a separation process is required to remove the bitumen from the clay, sand and water. A hot water pro-

cess separates the four different parts. Hot water is added to the sand to form a slurry which is piped to an extraction plant for agitation. The combination of hot water and agitation released the bitumen and causes tiny air bubbles to attach to bitumen droplets. These droplets float to the top of the separation vessel and are skimmed off. Additional processing removes residual solids and water.

Bitumen then requires further upgrading before it can be refined into synthetic crude oil, which can then be used as the basis of petrochemical products. It is a very viscous substance so it needs to be diluted with lighter hydrocarbons so it can be transported by pipeline for refining.

The bitumen can then be used as a feedstock for useful petrochemicals such as ethylene, propylene, benzene and paraxylene. Off-gas, a by-product of bitumen processing that is rich in vapours that can be condensed into ethane,



propane and butane is currently being used as a fuel, but it is expected that in the future, ethane and other gas liquids, extracted from off-gas, will not only supplement conventional gas supplies but also be used to meet ethane demand. Upgraded bitumen can be used as a feedstock in the form of intermediary refined petroleum products, such as naphtha, aromatics and vacuum gas oil.

Both light hydrocarbons from off-gas and intermediary products from oil sands are not being exploited to their full potential as a source of petrochemical feedstock because of issues surrounding environmental concerns and developing integrated approaches to reach economies of scale. While the Canadian province of Alberta is a world leader in petrochemical refining from oil sands, market conditions and technology still need to evolve further for bitumen and off-gas to offer a secure, stable-priced feedstock for the sector.

Extraction and refining of shale oil

Like oil extracted from oil sands, shale oil has not been processed in vast quantities for petrochemical feedstock. The process for extracting shale oil is more complicated than extracting liquid crude oil from the ground. Getting crude oil from shale rock remains difficult and controversial, as is also the case with shale gas extraction.

Oil shale is mined using either underground- or surface-mining methods. After excavation, the mined rock undergoes a retorting process – this is the exposure of mined rock to pyrolysis, the application of extreme heat without the presence of oxygen to produce a chemical change. Between 345°C-370°C, the fossil fuel trapped within starts to liquefy and separate from the rock. The emerging oil-like substance can be further refined to a synthetic crude oil.

When it is mined and retorted above ground, the process is called surface retorting. This process adds two extra steps to the conventional extrac-

tion process in which liquid oil is simply pumped out of the ground.

Royal Dutch Shell has developed In Situ Conversion Process (ICP) to simplify the refining process for shale oil. With ICP, the rocks are not excavated from the site. Instead, holes are drilled into the shale and heaters are lowered into the earth. Over the course of at least two years, the shale is slowly heated and the kero-gen (the fossilised material in rock that yields oil when heated) seeps out. The kerogen is then collected in situ and pumped to the surface for further refining.

Refining natural gas for feedstock

Natural gas plays an important role in today's global petrochemical industry. It is a common building block for methanol which has many industrial applications. Natural gas is converted to synthesis gas (syngas), which is a mixture of hydrogen and carbon oxides created through a process called steam reforming. Ethane, an alternative to crude oil-derived ethylene, is a by-product of natural gas and the US shale gas boom in particular is capitalising on the abundant supply.

Steam reforming occurs by exposing natural gas to a catalyst that causes oxidisation when it is



Measuring the viscosity of a shale oil sample in Enefit's oil laboratory in Estonia.





A coal gasification plant in Yueyang, China with the capacity to gasify 2,000 tonnes of coal a day. (INSET) Examples of the products derived from coal gasification.



brought into contact with steam. This process is similar to the Fischer-Tropsch process. Once this process results in synthesis gas, it can be used to produce methanol (CH_3OH), also known as methyl alcohol, which is then used to produce useful substances such as formaldehyde, acetic acid, a fuel source in fuel cells, insulation materials, varnishes, paints, glues, and methyl tertiary butyl ether (MTBE), which is used as an additive for gasoline that burns more cleanly. It can also be used within the energy industry as an agent to prevent hydrate plugs forming in oil and gas pipelines at low temperatures.

Mineral fertilisers are also produced from natural gas feedstocks. This involves a series of several chemical conversions. The first stage is am-

monia. The process of ammonia production for fertiliser use is similar to the gas-to-liquid process, but different catalysts, pressure and temperature are required.

To produce ammonia, the natural gas is first cleaned of sulphur and mixed with heated water vapour. It is then supplied to a reactor where it passes through catalyst beds. This is the primary reforming stage, also known as gas-vapour conversion. A gas mixture made up of hydrogen, methane, carbon dioxide (CO_2), and carbon monoxide (CO) emerges from the reactor. The mixture is then sent to a secondary reforming gas-vapour conversion stage where it is mixed with oxygen, vapour and nitrogen. For the next stage, CO and CO_2 are removed from the mixture. Finally, a mixture of



hydrogen and nitrogen gases are added at high temperature and high pressure in the presence of a catalyst to form ammonia. This final stage is known as the ammonia synthesis process.

Refining coal for feedstock

Coal is made up primarily of two main elements, hydrogen and carbon. These elements have been important to the energy sector for decades and they are also the building blocks for chemicals, feedstocks and synthetic materials, all of which are in high demand. While much of this growing demand has been met by oil and gas refining, coal has also been exploited as a source of petrochemical feedstock. Refining coal can be highly profitable with many high-value chemicals being produced in this sector.

Over the years, governments and private companies in multiple countries have devoted significant resources towards researching and developing coal refining. While coal was first used in blast furnaces in Britain in the early 17th Century and first successfully carbonised for commercial use in Britain in 1709, the major breakthrough for coal's use in the petrochemical sector came in 1913. This is when Friedrich Bergius, a German chemist, discovered that if coal is treated with hydrogen at high temperature and pressure in the presence of a catalyst, an oil similar to crude petroleum is produced.

In the 1930s and 40s, research into using the Fischer-Tropsch process for coal refining led to coal liquids being used for transportation fuel for the German army in World War II. Sasol's facilities in South Africa started making liquid and gaseous fuels from coal thanks to this early work on the Fischer-Tropsch process. Oil embargoes and natural gas shortages in the early 1970s precipitated more recent efforts to refine coal. China is now a world leader in coal refining with 34 coal-to-chemical facilities in operation and more planned for the future.

The coal chemical sector can be divided into traditional coal chemical and new coal chemical sub-sectors. Traditional coal chemical production mainly includes synthetic ammonia, coke and calcium carbide, while new coal chemical production includes petroleum substitutes such as ethylene glycol, oil and olefins.

Coal is usually refined for the petrochemical sector by either gasification or liquefaction.

Coal gasification

Coal gasification is used to produce chemicals and feedstocks as well as fuels and electricity. It is more efficient and less expensive than liquefaction. One of the guiding principles behind developing fully integrated gasification sites where coal could be turned into electricity and chemicals is that energy production costs, air emissions and solid waste production could all be reduced. The gasification process can take place in-situ within natural coal seams or in coal refineries.

The US Department of Energy has cited numerous advantages to processing coal by gasification. These include product flexibility, with a number of different commodities produced by the resulting synthesis gas (syngas), especially methanol and ammonia. Gasification produces lower emissions, is more efficient than other forms of coal refining and gasification plants can cope with refining different types of coal.

In this process, coal is gasified to produce a low- or medium-Btu fuel gas. During gasification, elemental sulphur and carbon dioxide can be recovered, steam can be produced and the slag left over from the gasification process can be used for road construction or as a building material. The coal gas, a type of syngas, can also be used to produce industrial chemicals, such as ammonia, as well as petrochemical feedstocks.

The coal is dried before it is devolatilised. Devolatilisation is an important part of the process in which high temperatures are used in order to extract



Shenhua's direct coal liquefaction plant, the first of its kind in the world, has been in operation since 2008.

tar, primary gaseous volatiles, such as carbon monoxide and carbon dioxide, and residual char. The tar also yields gaseous volatiles, as well as residual soot. After devolatilisation, volatile combustion, char combustion and gasification can take place.

Coal is blown through with oxygen and steam as well as being heated and, in some instances, pressurised. If the heat comes from an external source, it is called "allothermal" and if it is heated with exothermal chemical reactions which take place inside the gasifier, it is called "autothermal." During the reactions, oxygen and water molecules oxidise the coal to produce a gaseous mixture of carbon monoxide, carbon dioxide, water vapour and molecular hydrogen.

If a refiner wants to produce alkanes, coal gas is routed to a Fischer-Tropsch reactor, and if hydrogen is the desired final product, the coal gas undergoes a water gas shift reaction, whereby more hy-

drogen is produced by further reaction with steam.

In general, existing methods for coal gasification use the same chemical process. Low-grade coals, which are high in water, can be gasified using technology where no steam is needed for the reaction and carbon and oxygen are the only reactants. Furthermore, some gasification methods do not require high pressure and use pulverised coal as fuel.

The technologies for supplying the blowing part of the process also vary. With direct blowing, the oxidiser passes through coke and ashes to the reaction zone where it interacts with coal. Hot gas is produced which passes fresh fuel and heats it while absorbing tars and phenols. Significant refining is then required before being used in the Fischer-Tropsch reaction. This creates highly toxic products which require special treatment before they can be used.



Reversed blowing, a newer form of technology, has the gas produced in the reaction zone pass through coke and ashes and the carbon dioxide and water is chemically restored to carbon monoxide and hydrogen. There is no chemical interaction between the coal and the oxidiser before it reaches the reaction zone and no toxic by-products are present in the gas as these are disabled in the reaction zone. As well as being more ecologically friendly, reversed blowing produces two useful products – gas and middle-temperature coke. The gas can be used as fuel and the coke can be used as a technological fuel in metallurgy, a chemical absorbent or in products such as fuel briquettes.

Coal liquefaction

Liquids that have been obtained via the coal liquefaction process can potentially be used as fuels or feedstocks for a wide range of petrochemical products. It is generally more expensive than refining crude oil but it can be cost-effective if crude oil is in limited supply, unavailable or the supply has been disrupted. This process was first used in the 19th Century to provide fuel for indoor lighting. Coal liquefaction has a long history in countries such as Germany and South Africa where there is not a secure supply of crude oil.

Pioneers in coal liquefaction technology development included American companies such as HRI, Exxon, Gulf Oil, Conoco, Chevron, Amoco, Lummus, Kerr-McGee and Consol; Germany's Ruhrkohle; the UK's British Coal Corporation; and Japan's NEDO and Mitsubishi Heavy Industries.

Coal liquefaction can be a more efficient process if it is combined with electricity production as this utilises some of the heat that would otherwise be wasted.

There are two main stages to the coal liquefaction process when indirect coal liquefaction (ICL) is used – coal gasification and gas-to-liquid (GTL). During gasification, air and steam are added to raw coal and this is heated. The carbon

in the coal reacts with oxygen and water to produce carbon monoxide, carbon dioxide, hydrogen and methane. The CO₂ is waste and other gases can be burnt or processed further.

The second stage for liquefaction is the Fischer-Tropsch process. Once the coal gas is filtered and processed, the carbon monoxide and hydrogen ratio is adjusted by the addition of water or carbon dioxide. This hot gas is passed over a catalyst, causing the carbon monoxide and hydrogen to condense into long hydrocarbon chains and water. These chains can be used as an alternative to oil products such as heating oil, kerosene and gasoline. The water, meanwhile, can be recycled and used as steam for the liquefaction process.

Aside from this two-stage process, coal can also be liquefied via direct coal liquefaction (DCL). This can take place as a one- or two-stage process. In the 1960s, single-stage DCL techniques were pioneered but these first-generation processes have now been largely superseded or abandoned. The single-stage processes attempted to convert coal to liquids with a single reaction stage, usually involving an integrated hydrotreating reactor.

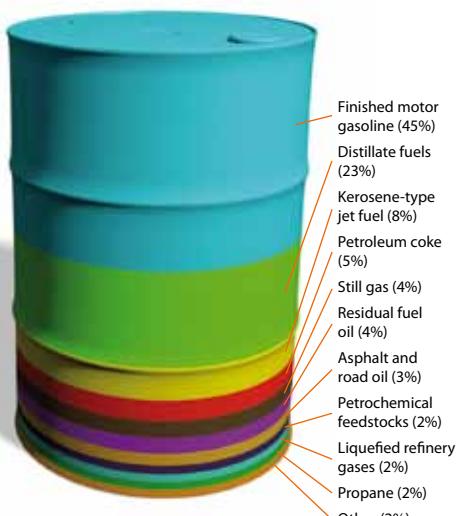


Ongoing research and development efforts are vital to the future of the petrochemicals industry.





What you get from a barrel of crude



In DCL, the coal is put in direct contact with the catalyst at very high temperatures (850°F/455°C) in the presence of additional hydrogen. This reaction takes place in the presence of a solvent. The solvent facilitates coal extraction. The solubilised products, which consist mainly of aromatic compounds, may then be upgraded by conventional petroleum refining techniques, such as hydrotreating.

DCL processes are more efficient than ICL but a higher quality coal is required for best results. However, since the late 1980s, very few DCI programmes were continued with the exception of HTI, now called Headwater Inc, who developed a two-stage catalytic liquefaction process that was funded by the US Department of Energy. This technology was then licensed to China's Shenhua

Corporation in 2002 for the construction of a 20,000 bpd plant in Inner Mongolia that commenced demonstration testing in 2008 and has been operational ever since.

High-tech challenges

Simply continuing to churn out products we already know how to make isn't an option for companies to remain competitive and profitable. Companies need to create new products and find cheaper ways to do things, which is why research and development is important to petrochemical producers.

The chemical and manufacturing processes in this part of the downstream business require a huge pool of expertise – and a lot of money – to ensure engineers and scientists continue to make breakthroughs. The drive to produce more with less, and more cheaply, provides researchers with access to the sort of facilities rarely found beyond the commercial sector.

Keeping costs down is vital, because the facilities are expensive to build, maintain and run. Refiners and petrochemical producers must also contend with ongoing volatility in the prices of commodities, with forward-planning essential for years when margins are low.

Environmental issues are a vital part of research in the sector, so firms have to focus on how the industry can meet increasingly stringent standards for cleaner refining and manufacturing processes, and high health and environmental standards required of the final products. These high standards are often imposed at a self-regulatory level by the companies themselves and by governments.

In the US, for example, which has more refining capacity than any other nation on Earth, the sector is, in the words of the US Department of Energy, "one of the most heavily regulated industries." If refineries fail to comply, they cannot operate.

For alternatives to fossil fuel-based petrochemicals, see page 102.

William Srite is a freelance journalist.

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Petrochemical feedstocks

Oil, gas and coal provide the hydrocarbons for feedstocks.

Feedstocks are the various hydrocarbons derived from the refining of oil, gas and coal. These are then further refined to produce petrochemical products. They are the building blocks of the petrochemical industry.

These building blocks are converted into a wide range of chemical products with a wide array of uses. At the feedstock stage, they are usually known as intermediates – then the intermediates are processed into plastics, liquids and resins which ultimately are turned into useful products. Some feedstocks, however, are used directly to produce petrochemicals, such as methane and BTX. But ethane, propane, butanes, naphtha and gas oil are optional feedstocks for steam crackers that produce intermediate petrochemical feedstocks. Other examples of intermediate feedstocks include ethylene, propylene, butenes and butadiene.

Gas and oil are the most common starting points for feedstocks because they are still readily available, can be processed efficiently and are usually less expensive than other raw materials. This is why petrochemical companies often build their plants close to oil and gas refineries – as a

result, operational costs, such as transportation, are reduced. Coal-derived feedstock, meanwhile, is predominantly methanol, obtained from a coal-to-liquids process. Coal can also be gasified to produce feedstocks.

Methane, ethane, propane and butanes are mainly obtained from natural gas. Naphtha and gas oil, as well as benzene, toluene and xylenes, (a group commonly referred to as BTX) are obtained from petroleum refineries. Ethylene, propylene and butadiene are the basic building blocks of all olefins (also known as alkenes) and these form the basis for many common products (see diagram on page 34).

Synthesis gas, also known as syngas, is the term for gas obtained from synthesising hydrogen and carbon monoxide, and this can also be converted into feedstock. Syngas can also be an intermediate by-product developed during the processing of ammonia, methanol, synthetic petroleum or synthetic natural gas. Petroleum by-products that might otherwise end up as waste can be conserved as feedstock. During the gasification refining process, any material which contains carbon can also be converted.

Since feedstocks and the end products vary, there are many different production methods (see page 22). For example, an ethylene-producing plant is most likely to use catalytic cracking, a technique that uses high pressure and high temperatures to crack natural gas. But in a methanol-producing plant, a reforming process, using high temperature steam, medium pressure and a catalyst, will produce the product.

While oil, gas and coal are still in plentiful supply in many parts of the world, alternative sources for petrochemical feedstocks have been developed and will continue to be developed as fossil fuels are depleted (see page 102). For example, feedstocks can be produced from sugar cane, corn and other organic agricultural sources. While there is controversy over using food for fuel, this is seen as





a viable alternative for areas with few fossil fuel resources but space for large-scale agriculture.

Feedstock and geography

Feedstock supplies vary between different regions and supply trends can change, especially when new.

Ethane feedstock supply has decreased in the Middle East and Canada, for example. New oil and gas discoveries have impacted on the petrochemical industries of the US, Brazil and Canada. In the case of the US and Brazil, both countries have benefited with the respective discoveries of shale gas and pre-salt reserves.

In Canada, ethane production is down because of reduced natural gas supply from the Western Canadian Sedimentary Basin. The Canadian petrochemistry sector is now focusing on the discovery of bituminous oil, which now accounts for more than 50% of the country's crude oil production, for meeting future feedstock needs.

The petrochemical sectors of Saudi Arabia, Iran and Qatar use ethane as the main petrochemical feedstock, but securing new ethane supplies has become difficult because of high demand from existing petrochemical plants and the energy sector. As such, planned petrochemical plants in the Middle East are based on naphtha feedstock.

Natural gas production has increased in Saudi Arabia, Iran and Qatar but it's not enough to satisfy requirements. Despite the increases in natural gas production in Saudi Arabia and Iran, ethylene capacity has increased even more. Qatar's ethane production has been restricted because of a moratorium on its North Dome gas field.

The emergence of China's shale gas and coal industries has also changed the face of the world's feedstock supplies. This ongoing development in China will serve to bolster the country's growing economy. For more detailed information on the world's petrochemical markets, turn to page 82.



FPSO Cidade de São Paulo leaving port bound for the Sapinhoá field, offshore Brazil. Pre-salt discoveries, though challenging to extract, will have a major impact on the country's oil and gas industries.



Petrochemical feedstocks

Methane & Derivatives

Reaction solvent, textile dry cleaning, fire extinguishing, metal degreasing, grain fumigant, packaging, auto parts, appliance parts, plumbing & hardware, pens & pencils, lighters, shavers, moulding compound, particle board adhesive, foam insulation, automotive parts, furniture, dinnerware, plastics, gasoline component, single cell protein (use as additives and animal feeds), chemical intermediate (e.g. perfumery chemicals), windscreen wash, ethyl alcohol denaturing, latex paints, lacquer resins, enamel resins, oil additives, leather finishes, paper coating, textile coating, floor polishes, high octane gasoline component & oxygenate.

Ethylene & Derivatives

Packaging film, plastic bags, milk bottles, oil cans, fuel tanks, caps & lids, insulation, pipe & tubing, diaper covers, homewares, toys, comonomer (linear low density polyethylene), synthetic lubricants, chemical intermediate, detergent, paper & textile, wax substitute, oil field chemical, mould release, plasticiser, leather treating, cement additives, cosmetics, corrosion inhibitor, photo chemicals, non-ionic surfactant, fumigant, sterilising agent, pharmaceuticals, latex paints, antifreeze, polyester fibre & resin, brake fluid, hydraulic fluid, clothing fibre, household, non-woven, draperies, plastics, lacquer, aspirin, fragrances, chemical intermediate, starch modifier, solvents - coatings, plastics, toiletries, medical applications, chemical feed-stocks, gasohol, flavours, mouthwash, wood glue.

Butylenes & Derivatives

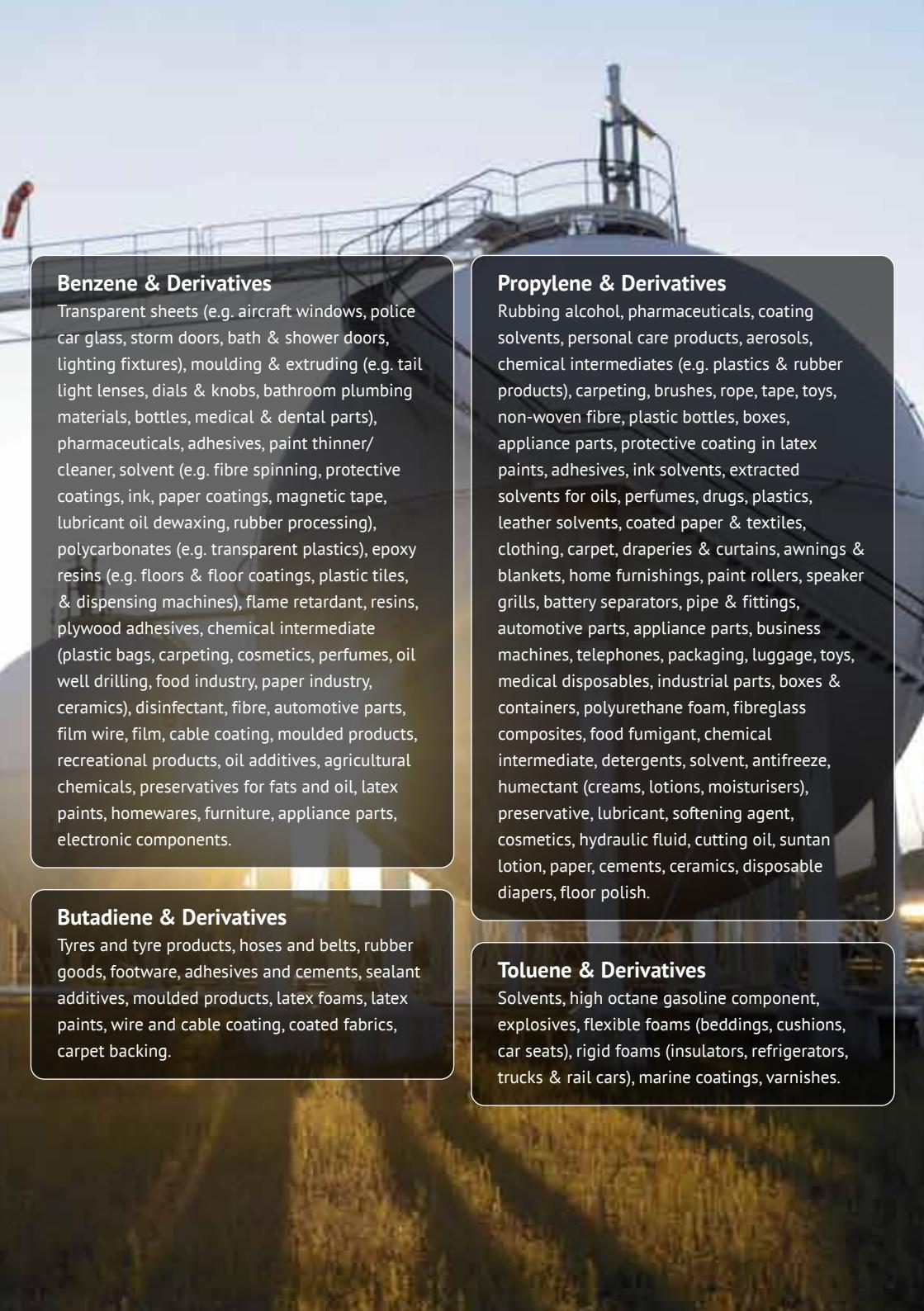
Sealants, caulking compound, adhesives, tyre products, lubricant viscosity improver, adsorbent fibre, pipe fabrication, solvent (e.g. vinyl coatings, acrylic coating), paper and ink manufacture, lubricant oil dewaxing.

Butanes & Derivatives

Domestic (e.g. space-heating, cooking, lighting, hot water supply and refrigeration), leisure (e.g. caravans and boats, barbecues and green-houses, camping and outdoor activities, blow lamps and other hand tools), industrial (e.g. welding, jewelry making/soldering, aerosol propellants), automotive fuel (for fork lift trucks, cars, taxis and other vehicles which operate within a restricted radius of their base depots).

Xylene & Derivatives

Plasticisers, dyes, chemical intermediate, clothing, carpet upholstery, tyre cord, conveyor belts, home furnishings, beverage bottles, coatings, adhesives, films & tapes, moulded products, hoses, wheels & rollers, insulation, recreational products, tubing, furniture, pipes, tanks, automotive parts, simulated marble, bowling balls, shower cubicles, cements, buttons, automobile parts.



Benzene & Derivatives

Transparent sheets (e.g. aircraft windows, police car glass, storm doors, bath & shower doors, lighting fixtures), moulding & extruding (e.g. tail light lenses, dials & knobs, bathroom plumbing materials, bottles, medical & dental parts), pharmaceuticals, adhesives, paint thinner/cleaner, solvent (e.g. fibre spinning, protective coatings, ink, paper coatings, magnetic tape, lubricant oil dewaxing, rubber processing), polycarbonates (e.g. transparent plastics), epoxy resins (e.g. floors & floor coatings, plastic tiles, & dispensing machines), flame retardant, resins, plywood adhesives, chemical intermediate (plastic bags, carpeting, cosmetics, perfumes, oil well drilling, food industry, paper industry, ceramics), disinfectant, fibre, automotive parts, film wire, film, cable coating, moulded products, recreational products, oil additives, agricultural chemicals, preservatives for fats and oil, latex paints, homewares, furniture, appliance parts, electronic components.

Propylene & Derivatives

Rubbing alcohol, pharmaceuticals, coating solvents, personal care products, aerosols, chemical intermediates (e.g. plastics & rubber products), carpeting, brushes, rope, tape, toys, non-woven fibre, plastic bottles, boxes, appliance parts, protective coating in latex paints, adhesives, ink solvents, extracted solvents for oils, perfumes, drugs, plastics, leather solvents, coated paper & textiles, clothing, carpet, draperies & curtains, awnings & blankets, home furnishings, paint rollers, speaker grills, battery separators, pipe & fittings, automotive parts, appliance parts, business machines, telephones, packaging, luggage, toys, medical disposables, industrial parts, boxes & containers, polyurethane foam, fibreglass composites, food fumigant, chemical intermediate, detergents, solvent, antifreeze, humectant (creams, lotions, moisturisers), preservative, lubricant, softening agent, cosmetics, hydraulic fluid, cutting oil, suntan lotion, paper, cements, ceramics, disposable diapers, floor polish.

Butadiene & Derivatives

Tyres and tyre products, hoses and belts, rubber goods, footware, adhesives and cements, sealant additives, moulded products, latex foams, latex paints, wire and cable coating, coated fabrics, carpet backing.

Toluene & Derivatives

Solvents, high octane gasoline component, explosives, flexible foams (beddings, cushions, car seats), rigid foams (insulators, refrigerators, trucks & rail cars), marine coatings, varnishes.



Gas-to-liquids

By Mark Blacklock

The gas-to-liquids (GTL) process offers a means of extracting greater value from an important resource.

Today's GTL business draws on the pioneering work on synthetic fuels carried out by Franz Fischer and Hans Tropsch in Germany in the 1920s. They developed a process to turn gasified coal into liquids, and gave their names to the generic term Fischer-Tropsch (F-T) synthesis. However, Germany's synthetic fuel production during World War II (which reached a peak of 50% of consumption in 1943) was largely based on hydrogenation with F-T production accounting for about 8% at the peak. It was South Africa which took the lead in developing large-scale F-T liquefaction plants



Professor Franz Fischer (LEFT) and Dr Hans Tropsch carried out pioneering work on synthetic fuels.

after the war, initially using coal as a feedstock and later natural gas as well.

The original development of synthetic fuels was subsidised for strategic reasons; Germany and South Africa had large coal reserves but had to import oil. The challenge of subsequent R&D was to make synthetic fuel production commercially viable, and a number of proprietary technologies using F-T synthesis have been developed.

The basic process (see box) sees methane converted to carbon monoxide and hydrogen (syngas) for processing in a reactor to produce paraffinic waxes which can then be refined. The various proprietary technologies use different combinations of catalysts, reactor types and process conditions. The production phase of GTL uses more energy and thus entails higher emissions of greenhouse gases compared to a standard refinery, but the end products are cleaner.

The main product of a typical GTL plant is automotive diesel with virtually no sulphur or aromatics and a high cetane number. High-quality naphtha for petrochemical feedstock, kerosene for blending into jet fuel, normal paraffins and base oils for top-tier lubricants are also produced.

Monetising gas

GTL is a means of monetising gas resources that are abundant, undervalued or wasted by flaring.

A barrel of oil has roughly six times the energy of a million Btu (mmBtu) of gas. Oil has traditionally traded at a premium to gas given the ease of refining it to produce a range of products, but this premium is increasing in some markets. At the time of the 19th World Petroleum Congress in 2008, for example, the oil price of \$147/b and the US Henry Hub price for gas of \$13/mmBtu meant the oil premium was about 100%. With the Henry Hub price now around \$4/mmBtu the US oil premium is 370%.

It is the flood of unconventional gas which has driven US prices down and is now driving interest

in developing GTL plants. Sasol is moving ahead with the front-end engineering and design (FEED) stage of Westlake GTL in Louisiana and is also looking at a GTL plant in western Canada. Both would use shale gas as a feedstock. Other companies are considering projects.

For countries with abundant conventional gas resources, GTL is a way of providing high-quality products to the domestic market as well as extracting greater value from exports. Qatar Airways, for example, plans to fuel its aircraft with a 50:50 blend of locally-produced GTL kerosene and conventional jet fuel. The resulting GTL jet fuel is not only cleaner but has a higher concentration of energy and weighs less than conventional jet fuel.

Flaring gas associated with oil production is polluting and wasteful. Nigeria is one of the members of the World Bank-led Global Gas Flaring Reduction (GGFR) public-private partnership, and

the Escravos GTL plant being built by Chevron and the Nigerian National Petroleum Company will help the country eliminate flaring.

Brazil also wants to avoid flaring associated gas. For its offshore oil fields Petrobras is evaluating a project to include a small GTL plant on floating, production, storage and offloading (FPSO) vessels. This would produce a synthetic crude (syncrude) which would then be shipped with the main crude production to be refined elsewhere.

GTL plants around the world

The first large-scale plants using gas as a feedstock were commissioned in 1992 by Mossgas (now part of Petro SA) in Mossel Bay, South Africa (using Sasol's advanced synthol process), and in 1993 by a Shell-led consortium in Bintulu, Malaysia (using Shell middle distillate synthesis – SMDS). The Malaysian plant suffered an explosion

Processing natural gas

After raw natural gas has been treated, there are three main operations in a gas-to-liquids plant. Firstly, synthesis gas (syngas) is produced. This is typically a combination of hydrogen and carbon monoxide in a ratio of 2:1, and four alternative methods are used:

- Steam reforming of the feedstock in the presence of a catalyst.
- Partial oxidation – oxygen is separated from nitrogen in a cryogenic air separation unit (ASU) and burned with natural gas at high temperatures and pressures. Alternatively, air may be used instead of pure oxygen.
- Autothermal reforming, where partial oxidation is combined with steam reforming.
- Gas-heated reforming of natural gas with steam and oxygen.

Then Fischer-Tropsch synthesis converts syngas into paraffinic hydrocarbons, a waxy synthetic crude. There are three principal types of process:

- Fluidised bed processes, in which syngas is passed rapidly at high temperatures through a catalyst bed, such as the Sasol advanced synthol process. This uses an iron-based catalyst. It has been superseded by SPD in the international market.

- Slurry processes, in which syngas is reacted in a slurry with a catalyst and molten wax (produced in the reactor), such as the Sasol slurry phase distillate (SPD) low-temperature process. This uses a cobalt-based catalyst.

- Fixed bed processes, where the syngas flows through tubes containing catalyst, such as Shell middle distillate synthesis (SMDS). This uses a cobalt-based catalyst.

The synthetic crude is then converted into marketable petroleum products using conventional petrochemical upgrading processes, depending on the final slate of products required by the plant operator.



Petro SA's plant in Mossel Bay was the first to start volume GTL production.

in its air separation unit in December 1997 and was closed until May 2000, but this was caused by an accumulation of air-borne contaminants from forest fires and was not related to the GTL technology.

Oryx in Ras Laffan, Qatar was the next GTL plant and uses the slurry phase distillate (SPD) process developed by Sasol at a test plant in Sasolburg. Oryx shipped its first product in April 2007 but a higher than design level of fine material in the paraffinic wax initially constrained output, and it took several years to resolve the problems and achieve full output. Oryx is now working on expanding capacity through debottlenecking.



The Oryx GTL plant in Qatar is expanding capacity.

Meanwhile, in Nigeria, the problems of building Escravos GTL in the Niger Delta caused long delays and cost over-runs. The plant was originally expected to cost \$1.7 billion and be in service by 2008. The cost is now \$8.4 billion and it is due to start operations in late 2013. This is around six times the cost of the similarly-sized Oryx plant (which was built under a fixed-price contract signed before construction costs in the petroleum industry escalated) but it will still be profitable at current oil prices. Escravos will use SPD.

However, the largest GTL plant, Pearl in Ras Laffan, Qatar, was built on time and budget. The first product was shipped in June 2011 and full



SMDS was proved at the Bintulu GTL plant in Malaysia.



HH Sheikh Hamad bin Khalifa Al-Thani, Emir of Qatar (*second right*) inaugurated Pearl GTL in a ceremony on November 22, 2011, accompanied by HE Abdullah bin Hamad Al-Attiyah, Deputy Prime Minister (*left*), Peter Voser, CEO of Shell (*second left*) and HE Mohammed bin Saleh Al-Sada, Minister of Industry & Energy (*far right*).

output was achieved in mid-2012. Pearl is an integrated project and its \$19 billion cost covered the upstream as well as the downstream development. The project produces 120,000 b/d of upstream products (condensate, LPG and ethane), while the GTL plant has two 70,000 b/d trains and uses SMDS with improved catalysts based on experience from the Bintulu plant.

GTL projects

Looking ahead, a GTL plant using SPD in Uzbekistan is at the FEED stage, while the Sasol projects in Canada and the USA would also use SPD. And now that Pearl is in full operation Shell is evaluating its future GTL options, including a plant on the US Gulf Coast.

SMDS and SPD are the two principal proprietary F-T technologies in commercial operation; others are on the verge of commercialisation.

One is GTL.F1, a low-temperature process using a cobalt-based catalyst in a slurry bubble column reactor. This was developed by Petro SA, Lurgi and Statoil in a 1,000 b/d semi-commercial unit (SCU) at Mossel Bay. Statoil has since withdrawn and the two remaining partners are looking at opportunities for GTL.F1 in North America.

Another has been developed by CompactGTL and is the technology being used by the Petrobras project in Brazil. It is for small, modular plants ranging in capacity from 200 to 5,000 b/d and does not require pure oxygen to convert the feedstock into syngas, meaning there is no need for a separate



Escravos GTL is due to start up in late 2013.

oxygen plant and a GTL plant can be integrated on a vessel. The capacity of the plant can be adjusted to match the declining flow of associated gas throughout the life of an oilfield, with plant modules being shut down and removed for refurbishment and/or re-deployed elsewhere.

A modular unit has been tested at the Petrobras research site in Aracaju and it has been approved for commercial deployment.

Syntroleum's proprietary F-T process also uses air rather than oxygen and the company was evaluating a number of GTL projects but is currently concentrating on biomass-to-liquids ventures.

A Japanese consortium has developed a process that allows natural gas containing CO₂ to be used directly as a feedstock rather than having to be treated first. Japan GTL was successfully trialled at a 500 b/d demonstration plant in Niigata between April 2009 and December 2011 by Inpex, Nippon Oil & Energy, Japan Petroleum Exploration, Cosmo Oil, Nippon Steel Engineering and Chiyoda in cooperation with Japan Oil, Gas and Metals National Corporation (JOGMEC). Commercial opportunities are now being sought.

Growing importance

By late 2013, GTL production will exceed 250,000 b/d. While this is still a small proportion of the overall market for refined petroleum products, a high oil price and premium over gas mean the sector is set to grow in importance.

Mark Blacklock is the Editor-in-Chief of International Systems and Communications.

GTL plants in operation, under construction and in FEED

Name/Location	Partners	F-T Process	Capacity (b/d)	Status/Notes
Pearl, Ras Laffan, Qatar	Qatar Petroleum, Shell	Shell middle distillate synthesis	140,000	Operational
Oryx, Ras Laffan, Qatar	Qatar Petroleum, Sasol	Sasol slurry phase distillate	34,000	Operational
Mossel Bay, South Africa	Petro SA	Sasol advanced synthol	22,000	Operational
Sasolburg, South Africa	Sasol	Sasol synthol	15,600	Converted from coal to gas feedstock in 2004
Bintulu, Malaysia	Shell, Diamond Gas (owned by Mitsubishi), Petronas, Sarawak govt.	Shell middle distillate synthesis	14,700	Operational
Escravos, Nigeria	Chevron Nigeria, Nigerian National Petroleum Co.	Sasol slurry phase distillate	32,400	In service late 2013
Shurtan, Uzbekistan	Uzbekneftegaz, Sasol, Petronas	Sasol slurry phase distillate	38,000	FEED underway, projected start-up in 2018
Westlake, USA	Sasol	Sasol slurry phase distillate	96,000	FEED underway, projected start-up phase 1 2018, phase 2 2019

Note: Sasol's Secunda plant in South Africa uses a mix of coal and gas feedstock.





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Alcohols

Alcohols can be created from hydrocarbons and their applications are many and varied.

Over the years, efficient processes have been developed for the mass manufacture of alcohols from hydrocarbons from the refining of oil and gas. These processes allow for economically viable production of aliphatic alcohols ("Aliphatic" refers to any organic compound in which the main structure of a chain of carbon atoms are joined to each other). They are created via the hydration of olefins, the air oxidation of paraffins and using synthesis reactions, such as catalytic hydroformulation of olefins with carbon monoxide and hydrogen.

Alcohols all have the signature hydroxyl group OH, which is bound to a carbon atom. The general formula for alcohols is R-OH, where the R group can represent the alkyl, alkenyl, or alkynyl groups. Alcohols are capable of being converted to metal salts, alkyl halides, esters, aldehydes, ketones and carboxylic acids.

Petrochemical-derived alcohol derivatives often perform better than other types of alcohols (such as those derived from palm kernel oil, known as "oleo-derived alcohols") because of higher formulation flexibility. Other reasons to choose petrochemical-derived alcohols over oleo-derived alcohols include: a growing global preference to use

food oils for food production rather than products such as fuels and plastics, and the uncertainty created by weather for palm kernel harvests, which impacts on feedstock availability.

Well-known alcohols include ethanol (also known as ethyl alcohol or grain alcohol), methanol (also known as methyl alcohol or wood alcohol) and isopropyl (commonly known as rubbing alcohol or surgical spirit and usually composed of around 70% ethanol), glycols and oxo alcohols. Alcohols are also used as intermediates in the synthesis of other compounds.

Ethylene and ethanol

Ethanol is manufactured by synthesis from ethylene. It is an oxygenated hydrocarbon and it is used in a wide variety of solvents. It can be found in dyes, detergents, disinfectants, toiletries, cosmetics, paints, lacquer thinners, inks and pharmaceuticals. It also acts as a chemical raw material for producing monomers. In transportation, it can be used as a fuel by itself, it can be blended with gasoline or it can be used as a gasoline ethane enhancer.

Large quantities of ethylene are also used to create acetaldehyde, acetic acid, acetate and ethyl alcohol. Ethylene oxide, as well as propylene oxide, are important in petrochemical synthesis as they are used for the production of glycols, surface-active agents, and ethanolamines (which are prepared by the reaction of ammonia and ethylene oxide and widely used as absorbents for acidic components of natural gas and petroleum refinery gas streams, as well as detergent and cosmetics uses and as a cement additive).

Glycols

Glycol is the term for any class of organic compounds that belong to the alcohol family. The term is often broadly applied to the simplest member of the class, ethylene glycol. It is produced commercially from ethylene oxide, which is obtained from ethylene (see above). Ethylene glycol is commonly





used as an automotive antifreeze as well as in brake fluid and man-made fibres. It is also mildly toxic.

Propylene glycol is similar in its physical properties to ethylene glycol, but it is non-toxic and used heavily in food preservation, cosmetics and dental hygiene products. Other important glycols include 1,3-butanediol, which is used in the manufacture of brake fluid and plasticisers for resins; 1,4-butanediol, which is used in polyurethanes, polyester resins for coatings and plasticisers, and for making butyrolactone, a solvent and chemical intermediate; 2-ethyl-1,3-hexanediol, which is used in insect repellent; and 2-methyl-2-propyl-1,3-propanediol, which is used in the production of some tranquillising drugs.

Methanol

Methanol is produced from carbon monoxide and hydrogen. It is used in the production of formaldehyde, acetic acid and methyl methacrylate (MMA) as well as a solvent. In the transportation industry, it is used to produce methyl-tert-butyl-ether (MTBE), which is used as an octane booster in fuel as well as a gasoline compound. Formaldehyde is mainly produced by the vapour-phase oxidation of methanol and large quantities are used to manufacture many resins and plastics.

Acetic acid is an intermediate used in the preparation of metal acetates, some printing processes, vinyl acetate (used to make industrial chemicals, glues, packaging, paints, paper, coating for plastic films and as a modifier of food starch), acetic anhydride (used in photographic film and other coated materials, aspirin production and as a wood preservative) and volatile organic esters, such as ethyl and butyl acetates (primarily used as solvents in nail care products).

Oxo alcohols

Oxo alcohols are prepared by adding carbon monoxide and hydrogen – usually combined as a synthesis gas – to an olefin. This blend creates an

aldehyde, the starting point for many products. A hydroformylation reaction and then the hydrogenating of the aldehyde is performed to obtain the alcohol. An intermediate step of adding two aldehydes together to obtain a larger aldehyde can be performed before the hydrogenation. Gas, rather than oil, is widely used in the oxo process.

Major oxo alcohols that are used commercially include 2-methyl-2-butanol (2M2B), n-butanol, 2-ethylhexanol, isononyl alcohol and isodecyl alcohol. The main global manufacturers of oxo alcohols include BASF, Dow Chemical Company, Eastman Chemical Company and ExxonMobil.

Oxo alcohols are used as solvents and coatings and in the manufacture of pharmaceuticals, flavouring agents, plastics, dyes and cosmetics. They are also reacted with phthalic anhydride to form phthalates which are used to manufacture vinyl plasticisers.



Part of BASF Petronas Chemicals' integrated site at Kuantan, Malaysia producing oxo alcohols and syngas.





Petrochemicals in healthcare and cosmetics

By Georgia Lewis

Petrochemical products have been developed for a wide range of applications across the healthcare and cosmetics industries.

Petrochemicals play a big role in the manufacture of many healthcare and beauty products. Many advances in healthcare and sanitation have been made possible by the use of petrochemicals and there is a long history of their use, with oils first being used in medicines at least 1,000 years ago.

In the world of cosmetics, petrochemicals have played a big role in the mass production and affordability of products that can be found in bathroom cabinets the world over.

Healthcare

Petrochemicals are used in healthcare products, from the most commonplace to the highly specialised. An everyday example is ASA – or Acetylsalicylic acid – an important part of many over-the-counter pain medications.

While penicillin, a drug that has saved countless lives since its discovery by Alexander Fleming in 1928 and subsequent development by Howard Florey and Ernst Chain in the 1940s, is manufactured via fungi and microbes, phenol and cumene are used as preparatory substances. These substances are also used in the production of aspirin, with acetylsalicylic acid being aspirin's main metabolite.

Other common medical products, some available by prescription, some over-the-counter, that use petrochemicals include antihistamines, anti-



Historical packaging for Aspirin on display at the Apothecary Museum in Heidelberg, Germany. The drug was first developed by Felix Hoffmann, a chemist working for Bayer, and was brought to market in 1899.



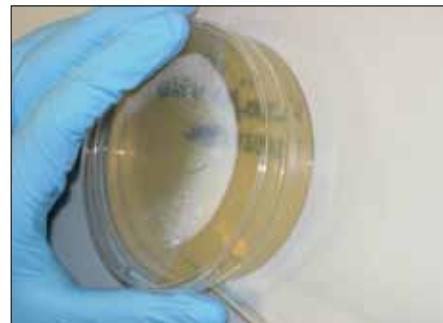


bacterials, rectal suppositories, cough syrups, lubricants, creams, ointments, salves, analgesics and gels.

Petrochemical resins have also been used in drug purification. These resins simplify mass production of medicine, thus making them more affordable to produce and then distribute. The resins have been used in the production of a wide range of medications including those for treating AIDS, arthritis and cancer.

Plastics play an important role in healthcare too. Resins and plastics from petrochemicals are used to make artificial limbs and joints. They are also a familiar sight in hospitals and other medical facilities for storing blood and vaccines, for use in disposable syringes and other items of medical equipment that are used once to prevent the threat of contagion. Specially created polymers are used extensively in healthcare, most notably during cardiac surgery or for auditory and visual stimulators.

Eyeglasses have benefitted from the use of plastics in frames and lenses and contact lenses



Plastics are used in the manufacture of surgical gloves, petri dishes and other laboratory equipment.

are also made of plastic. Even safety has improved thanks to the introduction of child-proof caps and tamper-proof seals for medication containers, all made using plastics. Surgical gloves are often made from pliable plastics, plastic petri dishes are essential to laboratories and at a larger level, for the housing of large diagnostic medical machinery.

As well as petrochemicals playing an important role in the manufacture of pharmaceuticals and medical equipment, petroleum use through



The main use of petroleum products in healthcare is actually in transportation fuel. Finding alternative means of power, especially for emergency response vehicles, may become an issue in the future.





transport is a major cost to healthcare systems globally, including ambulances, staff transport and transportation of supplies. Indeed, in the United States, according to US Bureau of Labor Statistics figures, it is estimated that the use of petroleum products in transport for healthcare is far greater than that used for drugs and plastics. The ongoing supply of the fossil fuels required to make all these relevant healthcare products may become a bigger issue as time goes on and if healthcare systems are placed under further financial pressure.

Finding alternatives to using petrochemicals for many medications and items of medical equipment may become important if healthcare is to remain accessible or, for some regions, to become more accessible. In the United States, the Center for Disease Control is investigating the impact of dwindling petroleum reserves on the provision of healthcare.

In the future, the healthcare industry may have to look at alternatives to using petrochemicals for pharmaceuticals and plastics although currently there are few alternatives. However, as only a tiny proportion of petrochemicals is used to produce specialised products for the healthcare industry, the supply chain for such products is currently considered to be secure.

Cosmetics

The production of cosmetic products makes up a very small proportion of global petrochemical use. However, they are products which many of us use on a daily basis and, as such, the role of petrochemicals in their manufacture has generated a lot of attention. While there has been a push towards "all-natural" ingredients in cosmetics in recent years as well as much debate over whether petrochemicals are safe to include in cosmetics, petrochemicals are a common component of many popular beauty products.

Common petrochemical-based ingredients of cosmetics include phenoxyethanol, waxes and

mineral oil. Phenoxyethanol is a very widely used ingredient in cosmetics but it is only used at less than 1% of the product composition, which is the legal maximum in most countries. It is an oily, slightly viscous fluid that smells faintly of roses. It is used in many skincare products, eye makeup, fragrances, blushers, detergents, baby products, sunscreens and cuticle softeners. It is synthesised for use in commercial cosmetic products.

Waxes are an important group of ingredients for the cosmetics industry and while some, such as lanolin, are animal waxes and others, such as jojoba, are plant waxes, mineral waxes and synthetic waxes are derived from petrochemicals.

Mineral waxes used in cosmetics include ozokerite, paraffin, microcrystalline wax, ceresin and petrolatum.

Ozokerite is a naturally occurring mineral wax but it is also produced as a mixture of microcrystalline wax, paraffin wax and other natural waxes that match the properties of ozokerite. It is often used in creams because of its thickening and emulsifying properties. Ceresin is usually a type of paraffin wax or it is made from a blend of petroleum waxes. It has similar properties to ozokerites so is generally used for similar applications.

Paraffin wax is a refined mixture of solid crystalline hydrocarbons. However, it is more brittle in texture than ozokerite and not very compatible with mineral oil so its cosmetic uses are generally



NIVEA Creme, in production since 1911, contains many ingredients derived from petrochemicals.



limited to use as a moisturiser or emollient, particularly in regard to manicures and pedicures.

Microcrystalline wax is less brittle and more malleable than paraffin wax, is more compatible with oils and often contains 1%-4% mineral oil. As such, it is widely used in the cosmetics and personal care industry. It is especially useful in lipsticks and lip balms to prevent the product from "sweating" and is also commonly used in baby products, makeup, nailcare, skincare, haircare, fragrance and sunscreen.

Mineral oil has a broad range of applications both in and out of the cosmetics and personal care industry. It is used in products that condition or protect the skin and hair and as a solvent. Medically, it is used in laxatives, and it is also used as a release agent for non-stick bakeware. It is a mixture of liquid hydrocarbons produced from the distillation of petroleum and then refined so it is suitable for commercial use.

Petrolatum is best known in its commercial form as Vaseline, the popular petroleum jelly product. Petroleum jelly is a semi-solid wax that can be used as an emollient and lubricant and is also used as a bodifying agent to improve the viscosity of cosmetic products.

Synthetic waxes are made by blending low molecular weight polymers of ethylene. Synthetic beeswax is made from a blend of fatty esters, fatty acids, fatty alcohols and high molecular weight hydrocarbons.

Myreth, oleteth, laureth and ceteareth ingredients are produced by reacting the starting material with ethylene oxide and are root names for groups of ingredients, usually followed by a number, such as "ceteareth-15". The number is usually, although not always, related to the average length of the ethylene oxide chain attached to the root molecule. Some of these root molecules may also be derived from petrochemical sources. Combinations of these ingredients are used mainly in soap and cleansing products where creating a foamy



An employee using a homogeniser at BASF's cosmetics lab in Ludwigshafen, Germany. The machine stirs ingredients at high speed to produce finished skincare products.

lather is desirable and the aim is to clean and soften the skin.

Polysorbates also contain ethylene oxide chains and are widely used in the cosmetics industry. The polysorbate ingredients used are numbered 21, 40, 60, 61, 65, 80, 81 and 85 and they are a series of general purpose surfactants. Main uses include skincare products such as fresheners and cleansers, makeup bases, foundations, shampoos, fragrances and products for creating permanent waves in hair.

Other petrochemical ingredients have been banned or restricted. Benzene, for example, has been identified as a Class A carcinogen and banned as a cosmetic ingredient in the USA, the European Union, Australia, China and Japan. Toluene, meanwhile, is only used in very tiny quantities in the cosmetics industry as an ingredient in some nail products, such as certain nail varnishes.

Georgia Lewis is the Deputy Editor of International Systems and Communications.





Are petrochemicals cosmetics toxic?

By Dene Godfrey

It is all too common to see claims on cosmetics and websites that the products are “free from” certain substances. There is a much debate as to the acceptability of this practice and certain countries, such as France, South Africa and Canada, ban companies from making such claims, either by regulation or industry code of practice. Indeed, the forthcoming revision of EU cosmetics legislation, the Cosmetics Regulation (EC) No. 1223/2009, due to be enacted mid-2013 will make it illegal to make such claims under most circumstances.

These days, it is virtually impossible to see the word “petrochemical” without it being associated with the word “free” or “does not contain” or a negative adjective such as “toxic”. Yet products containing oil or petrochemicals, which come from oil, are not necessarily toxic or harmful.

Oil itself is totally natural in origin. Synthetic chemicals produced from oil are not natural, although many may be described as “nature-identical”. However, this does not mean that petrochemicals used for cosmetics should all be classified as “toxic”. The fact that a chemical has been derived from oil/petroleum in no way determines the toxicity of the chemical. The toxicity of any substance, including petrochemicals used in cosmetics, is not related to its origin nor to the origin of its precursors.

While there are environmental issues surrounding the exploration, extraction and refining of oil, the singling out of the cosmetics industry for using “toxic” petrochemicals is not accurate. With less than 0.1% of total oil production used to provide ingredients for cosmetics, sustainability is not a major concern. Many products which claim to be “petrochemical-free” contain sodium benzoate and/or potassium sorbate which are both petrochemicals, albeit ones that exist in nature. These ingredients require a multi-stage synthesis with many petrochemicals involved along the way, but this does not make them any less safe.

A common claim for cosmetics is that they are “all-natural” or “100% natural”. However, this claim needs to be closely examined. “Natural” can also be confused with “organic”. Only two questions need to be asked to determine if a substance is “natural”. Does the substance exist in nature? Is the substance extracted from nature with any chemical modification? If the substance does not exist in nature, it cannot be described as “natural” even if natural substances have been used exclusively in its manufacture. This can only be described as “nature-derived”.

However, taking the “nature-derived” definition to its logical conclusion, the only question is to how many stages of processing has the substance been exposed. This introduces the concept of “degrees of processing”. Given that so few cosmetics ingredients are truly natural, how many degrees of processing are acceptable to keep the ingredient as close to nature as possible? This is where the discussion becomes subjective rather than scientific.

Furthermore, can “nature-identical” substances be described as “100% natural”? Part of the consideration here should be the source of raw materials used to manufacture “nature-identical” products. The two most common “nature-identical” ingredients are sodium benzoate and potassium sorbate – as stated earlier, these are both petrochemicals. There is no natural source for these ingredients and all usage in cosmetics is from synthetic production.

Many products which claim to be “all-natural” use petrochemicals but this does not mean they are unsafe.

Dene Godfrey, a scientist, council member and past president of the UK Society of Cosmetic Scientists, has written on the use of petrochemicals in the cosmetics industry and the safety issues. This is an edited version of his article, Petrochemicals: Confusion and Hypocrisy and 100% Natural? Almost 100% Certainly Not, first published on www.personalcaretruth.com.





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Petrochemicals in computers and electronics

By Georgia Lewis

So many of the electronic products we take for granted have been created thanks to petrochemicals.

These include mobile phones, television sets, CD players, radios, DVD and Blu-Ray players, games consoles, cords, cables and devices such as iPods. Computers are educational as well as economically essential, electronics have paved the way for improved international communication and even improved medical procedures – without petrochemical-derived plastics, very little of this would be part of our everyday lives.



The most visible use of petrochemicals in electronics is the plastic coating on wiring, clearly demonstrated in this Danish telephone exchange.

The use of petrochemicals has revolutionised the electronics sector through research, development and invention – as a result, the electronics industry is thriving as a global concern worth billions of dollars and creating an enormous number of jobs.

Virtually no electronic need is too big or too small for plastics to play a role, whether it is the rugged plastic required for water-resistant radios used by fire-fighters and light sockets on drilling rigs or more delicate applications, such as microwave transmission and heat-resistant automotive fuses.

There are many benefits to using petrochemical-derived products to manufacture computers and electronics. The latest electronic devices utilise new generation plastics because of their special features.

● **Resource-efficiency** Liquid crystal display (LCD) flat screens, commonly used in televisions and computer monitors, are made of liquid crystalline plastics which use at least 65% less electricity than screens with cathode ray tubes. Polymers are also useful for storing energy for longer.

Modern refrigerators are insulated with thermal-efficient plastic foam with interiors made of durable, easy-to-clean plastics. Other large appliances, such as dishwashers, are sporting more and more plastic components.

● **Light yet strong** Plastics are lightweight as well as being durable, attractive and cost-effective. As such, they are used in nearly all small appliances, such as coffee makers, irons, electric kettles, mixers, hair dryers, food processors, microwave ovens and shavers.

Films of polycarbonate are used to create the touchscreens used on products such as tablets and smartphones – this eliminates the need for a heavy keyboard. Such plastics are also used for phone handsets and MP3 players. Also, keyboards and computer housings are made from styrenic plastics which have the advantage of being light and strong.



While there is a strong drive today towards storing data online, CDs and CD-ROMs are still widely used. Most CDs consist of a clear polycarbonate, derived from benzene, cumene or bisphenol. This polycarbonate is easy to mould and thermoform. It is impressed with tiny bumps which are arranged as a long spiral track of data. This is then covered with an aluminium layer and then a thin layer of spray-on acrylic is added for protection. Finally, a label can be printed on the finished product. The plastic boxes in which CDs are usually stored are made from polystyrene, another petrochemical-based product.

- **Smaller size** Plastics are useful for making smaller components, especially those which cannot be seen. Nearly half of all plastics used in the electronics sector are for cable sheathing and small internal components. An obvious use of petrochemicals in computers is micro-chips, made using plastics which are cheaper to produce than sand-based silicone.

The ongoing miniaturisation of circuit boards and components such as computer chips, relies on high-performance plastics to provide tough, dimensionally stable parts that can withstand the stress of assembly and use. With plastics, electronics designers decrease size while increasing the functionality of circuitry in consumer, business and industrial applications.

Another innovation has taken place between the German Research Foundation and the University of Erlangen to develop polyether-etherketone (PEEK), which are heat-resistant films which can replace rigid printed circuit boards and can be produced as a lightweight, miniaturised alternative.

The extensive use of plastics in the computer industry is also largely thanks to the miniaturisation of many products – they need to be light, strong and durable. Mobile phones, digital cameras and laptops are just three



Compact disc cases are made from polystyrene.

products which have become steadily smaller and this has been aided by advances in plastics technology.

- **Safety** Plastics with thermal and insulating properties insulate almost all building wiring today and are used in switches, connectors and receptacles.

Fires can start from electronic sources so flame-retardant materials are important to manufacturers of electronic goods. Most commonly, a polymer will be formulated especially for each application for maximum resistance to fire and heat. Plastics are also used to improve safety when used for insulation on items such as cords and cables as well as the devices and appliances themselves.

On a basic level, smoke detectors made with plastics, have become standard fixtures in modern homes, cutting down on fire deaths and property losses.

- **Resistance** Resistance to electromagnetic radiation, mechanical shocks and stress, combined with durability and flexibility, make plastics ideal for applications such as safe, efficient power supplies.

- **Cost benefits** Plastics have improved the durability, weatherability and chemical resistance of many electrical products. As a result, cost savings are made with increased product life, estimated at 50%. Today's most





The basic materials for printed electronics are functional electrically conductive or semiconductive polymers. These soluble polymers are printed as a type of electronic ink.

popular appliances would cost at least 25% more to produce and consume at least 30% more energy than similar products without plastics. In short, plastics make electronic products practical and economical. Use of plastic has made products such as television sets far more accessible to more people globally with the cheaper production costs and corresponding drop in retail prices.

● **More efficient manufacturing** With computers playing a bigger role in the automated production lines of many modern factories, manufacturers rely heavily on a wide range of plastics for control panels, housings, wiring boards, sensors and robotic components.

● **Medical electronic applications** Electronics play an important role in the field of medicine – devices such as scanners and X-rays which allow early detection of medical conditions without invasive exploratory surgery rely on radiation-transparent plastic materials used in X-ray tables. These permit lower strength radiation to be used effectively.

● **Innovation and new advances** Due to a strong commitment to research and development, plastics in the electronic sector are constantly evolving. An example of this is lithium batteries which can now be made from recycled plastic bags. Plastic batteries that are

made from conductive polymers offer high power and low weight. The optical properties of polymers also help with facilitating the flow of data over long distances.

Improvements in design, aided by the use of many plastics, has also seen many common products evolve for the better – an obvious example is mobile phones which have become smaller, lighter and more practical thanks to improvements in micro-technology and plastics.

The world of electronics has advanced to the point where products can entertain and educate, such as sophisticated electronic toys.

Home computers play multiple roles for families, including budgeting, corresponding, playing games and working from home. All these machines depend on plastic housings, circuit boards, components and packaging.

Computer electronics will continue to play a large role in the home – as well as improved appliances, builders have shown that it is possible to build “all-electronic houses” with computers controlling lights, climate control, humidity, security systems, appliances and home entertainment units - again, all this requires plastics that are durable as well as those that are delicate.

A new era for plastic electronics is here, based on inherently conductive polymers (ICPs) and flexible substrates. Products which will use ICPs, which have been developed by Nasa, include anti-static coating, rechargeable batteries, radio frequency identification (RFID) and organic light-emitting diodes (OLEDs) for computers and mobile phones, flexible solar panels that can be laminated to walls and ceilings or used to as a source of energy for portable equipment.

The multifaceted uses of petrochemicals have proven to be a great boon to the electronics sector. The electrical goods and electronic industries will continue to rely heavily on petrochemical products and industries for many



important components and to ensure the products we take for granted constantly improve.

End of life measures for plastics in electronics

In response to concerns about what happens to plastic in obsolete electronics, infrastructure for recycling plastics used in electronics has been, or is being, developed in many countries. This is achieved via government-run schemes, such as those organised by local authorities in Britain and the United States, as well as private companies, such as Envirofone, a European recycler of mobile phones.

End-of-life options for the plastics used in electronics include: feedstock recycling, mechanical recycling, energy recovery (which is becoming more popular in European markets) and safe landfilling.

Technology has advanced to the point where different types of plastics can be detected and

separated at the point of recycling, such as separating those with and without flame retardant.

Governments and businesses are recognising the economic opportunities that can be gleaned from recycling and proper end-of-life protocols for electronics, including the plastic components. Indeed, the Minnesota Office of Environmental Assistance deemed the recycling of electronic thermoplastics as “the single greatest opportunity for adding revenue to the electronics recycling process.”

The market for recovered plastics is growing with many product and industry applications under development. These include: compact disc covers, camera casings, automotive parts, construction, shipping and concrete.

Georgia Lewis is the Deputy Editor of International Systems and Communications.

Types of plastics used in electronics

Different types of plastics perform different roles in the manufacture of electrical products. Here are some common types and their main uses:

- **Acrylonitrile butadiene styrene (ABS)** Computer housings, monitors, keyboards, telephone handsets.
- **Alkyd resins** Circuit breakers, switch gear.
- **Amino resins** Lighting fixtures. Useful because of low conductivity.
- **Epoxy resins** Electrical components.
- **Ethylene vinyl acetate (EVA)** Handle grips, fridge-freezer door seals, vacuum cleaner hoses.
- **Liquid crystal polymer (LCP)** Moulded inter-connect devices. Replaces ceramics in high-performance electrical components used in high-frequency applications.
- **Phenol formaldehyde** Fuseboxes, switches, handles.
- **Polyacetal** Also known as polyoxymethylene (POM), used in electrical appliance housings.

- **Polyamide** Adaptors, food processor bearings.
- **Polycarbonate** Telephones.
- **Polyesters** Switches, electrical insulation.
- **Polyethylene** Electrical insulation.
- **Polymethyl pentane (PMP)** Circuit boards.
- **Polyphenylene oxide (PPO)** TV housings, coffee machines.
- **Polyphenylene sulphide (PPS)** Transformers, hairdryer grilles, element bases, moulded interconnect devices. Replaces ceramics in high-performance electrical components used in high-frequency applications.
- **Polypropylene** Kettles.
- **Polystyrene** Refrigerator trays and linings.
- **Polysulphone** Microwave grilles.
- **Polyvinyl chloride (PVC)** Cable trunking, cable and wire insulation.
- **Styrene acrylonitrile (SAN)** Outer covers of electrical devices, battery housings, air conditioning components.
- **Urea formaldehyde** Fuse boxes, switches.



Transport and automotive uses

By Georgia Lewis

The petroleum industry does more than provide fuel for vehicles.

The petroleum industry has had a very obvious role to play in the world of transport by providing the fuels that power vehicles across the world. While hybrid, hydrogen and electric technology are all improving and becoming more cost-effective, oil will still be used as fuel to power vehicles for many years to come. But oil also has a vital role to play in terms of the petrochemical products which are essential to the modern transport industry. Indeed, the cars, buses, motorcycles, trucks and aeroplanes of today are all heavily

reliant on the use of petrochemical-derived products. Roads, too, are constructed with the assistance of petrochemistry.

Petrochemicals in car production

Automotive bodies and components benefit from the light weight, design flexibility and durability of many petrochemical products. Petrochemical products are generally easy to process and more cost-efficient for the manufacturer because of availability and reduction in vehicle assembly time.

The light weight is a particular bonus because this translates into energy savings for the end user. In a modern car, around 100kg of petrochemical-based plastics can replace 200-300kg of traditional materials. The average car now contains 120kg of plastics, comprising 15-20% of its total weight.

With this increased use of strong, lightweight plastics in cars, the environmental outcomes are impressive – the lighter weight of plastic components means fuel economy can be improved by 25-35% and for every kilogram of weight lost, the car will emit 20kg less of carbon dioxide over its operating life.

An example of a lightweight petrochemical-derived product with multiple uses is Chevron's Ryton PPS. Made from polyphenylene sulphide (PPS), it is a lighter weight, high performance engineering thermoplastic. It is used in parts exposed to high temperatures, automotive fluids and mechanical stress, such as brake systems, fuel systems, transmission systems, coolant systems and induction systems. It is also used in car lighting, for powertrain components and electrical components. Ryton PPS compounds are also used in automotive fluids, such as brake fluid and power steering fluid.

High density polyethylene gasoline tanks have helped prevent countless fires. This is because of their excellent shape-resistance. In the event of a collision, the tank holds its shape, petrol does not leak and a fire cannot start. Other uses for poly-



Plastics have superseded glass in the manufacture of car headlight covers.



The use of butadiene for car tyres has greatly improved safety, especially in wet weather.



Nylon's contribution to car safety is most dramatically demonstrated in the deployment of airbags

ethylene in the manufacture of cars include reservoirs for wiper fluid, brake fluid and coolant, as well as flexible parts, such as suspension dust covers.

Other plastics that are commonly used in car production include dodecyl mercaptan, used for headlight lens covers, and dodecyl disulphide, used for brake light covers.

Petrochemical-derived synthetic rubber tyres have improved car safety with their excellent road-holding abilities, especially in wet conditions. Synthetic rubber is derived from petroleum, as opposed to natural rubber, which is obtained from certain tropical trees and this is commonly used on aircraft and bicycle tyres as well as automotive vehicles and motorcycles. Styrene butadiene-rubber (SBR) is a common synthetic rubber used for tyres, belts and hoses because of its excellent abrasion resistance and durability. Another synthetic rubber widely used in the automotive industry is thermoplastic olefin rubber (TPO). It is used for parts such as interior and exterior trims, door seals, arm- and headrests, consoles, airbag covers and instrument panels. Cyclohexyl mercaptan is used in the automotive world to vulcanise rubber for tyres.

Phenolic resins are used in binders for friction materials in brakes and clutches, and car booster

seats made from petrochemical-based products, such as styrene-based plastics, have been developed to meet crash test standards. Such seats have helped reduce the death rate from motor vehicle occupant-related injuries among children aged 14 and under.

Styrene, a clear liquid, is used to make acrylonitrile butadiene-styrene (ABS), a heat-resistant thermoplastic widely used in automotive parts, including headlight covers and moulded plastic interior parts. Seatbelts and airbags also rely on petrochemical-derived products for their manufacture. Styrene-butadiene latex is used to make carpet backing for vehicles.

Polyalphaolefins (PAOs) are base oils which are not only used to manufacture fluids, oils and lubricants when mixed with other additives, but can also be used in seat covers and other automotive fabrics that require low volatility.

Other fabric-related uses for petrochemicals include cyclohexane, a feedstock for nylon. This is commonly found in seatbelts and carpets, but nylon resins are also used in engine covers, air intake manifolds, airbags, reservoirs and in air conditioning components, such as fans. Paraxylene is a feedstock for polyester, found in seat fabrics, headliners and carpet, as well as radial tyre cord.





In high performance racing cars, where safety is vitally important, plastics are everywhere; from helmets and neck braces to seatbelts and fire-proof clothing.

Products associated with car maintenance also rely heavily on petrochemicals, such as antifreeze and radiator coolant, which is often produced using ethylene glycol. Hydraulic brake fluids and petroleum demulsifiers are also made with ethylene glycol. Other petrochemicals used to make car maintenance products include polysulphides for engine lubricants and sulfolene for transmission fluids and other base oil formulations.

Road construction uses

Roads themselves are also created using petrochemicals. Asphalt, a by-product of crude oil refining, has long been used on roads, motorsport race tracks and footpaths. Companies such as Total have further developed asphalt with additional ingredients to create high-performance surfaces. Total's two flagship asphalt products, Styrefl and Kromatis combine standard asphalt with elastomers to provide road surfaces that are elastic, cohesive and adhere well to the ground. Kromatis, meanwhile, is used for urban roads and it can be cold-mixed or hot-mixed and bulk-

coloured – its use helps mark traffic areas clearly, such as bus lanes, improving safety.

Motorsport uses

Motorsport is heavily reliant on a range of petrochemical-derived products, such as carbon fibre, used to make lightweight body parts. To improve the power-to-weight ratio, carbon fibre and other plastics are used extensively. This is an example of how motorsport technology transfers to passenger cars, which are featuring more plastic components than ever before and, especially at the luxury end of the market, carbon fibre is being used more extensively.

The E20 chassis designed for the Lotus Formula One team uses carbon fibre for the top and bottom wishbones of the suspension and moulded carbon fibre is used in conjunction with an aluminium composite for strength and lightweight efficiency. The car also features a synthetic rubber fuel cell reinforced with Kevlar, another petrochemical-derived product, and a seat made from an anatomically formed carbon composite.



Motorsport teams form close, mutually-beneficial partnerships with oil companies – exemplified by multiple F1 championship winning Red Bull Racing and Total.

Formula One teams, World Rally Championship teams and Moto GP teams form partnerships with oil companies in order to provide high quality fuels, lubricants and other specialised additives for the racecars. For example, in the world of Formula One, Red Bull is in partnership with Total and Ferrari Scuderia is in partnership with Shell. Petrochemical experts are required to create products such as additives for cold resistance, enhanced combustion and efficient, cleaner-burning fuels and lubricants.

Aeronautical uses

Like the automotive and motorsport industries, the aeronautical industry relies heavily on petrochemicals. Composites derived from petrochemicals can save more than 30% of the weight of an aircraft structure. Keeping components light is essential on aircraft and the weight of every item counts, right down to the plastic used in the miniature spirit bottles. Since the 1970s, the use of plastics in the manufacture of aircrafts has increased from 4% to almost 30% and is expected

to reach 50% in 2013. Ethylene and propylene glycols are used in products, similar to car anti-freeze, to help aeroplanes take off in winter weather conditions.

Georgia Lewis is the Deputy Editor of International Systems and Communications.



Kevlar honeycomb exhibits great structural strength while consisting of 90-99% open space, an important consideration in the aerospace industry where weight is at a premium.





Petrochemicals in construction

By Jess Coutts

The construction industry has benefited enormously from petrochemical products with improved cost-effectiveness, durability and sustainability.

Petrochemicals, in particular plastics, have revolutionised the construction industry. After packaging, the construction industry is now the world's second highest user of plastics. This is because of their durability, versatility, excellent strength-to-weight ratio, cost-effectiveness, corrosion resistance and low maintenance.

The use of petrochemical-derived products means the construction industry is not so heavily



High-density polyethylene replacing corroded steel pipework in one of the world's largest oil shale-fired power plants in Estonia.

reliant on traditional materials and methods and opportunities for innovation are offered through substances such as plastics and resins.

The main uses for plastics in construction include seals, windows, doors, pipes, cables, floor coverings and insulation. Indeed, plastic can be used to create entire buildings. This has been used in social housing projects as a means of providing affordable accommodation. For improved sustainability, recycled plastics have been used for construction projects.

Plastics

Pipes and conduits are the largest uses for polymers for the construction industry. Often used in place of copper or lead, which can both be problematic, PVC and polyethylene are generally used for such applications as large pipes for sewage, drainage and potable water, as well as cabling.

Windows and doors were commonly clad and profiled with wood before the rise of the plastics sector but PVC-U has now become a common material for these purposes, as well as coving and skirting. PVC can also be used as a membrane for roofing and linings. Exterior cladding and roofing using phenolic resin rather than timber is also popular. Another advantage these materials have over wood is reduced fire risk.

Insulation, which has great energy conservation advantages, has also advanced thanks to petrochemical developments. It is commonly manufactured from rigid polystyrene foam which can be incorporated into panels or fitted into the construction of walls and roofs. Polystyrene-based insulation is light, strong and easy to install. Crystal polystyrene, such as that manufactured by Total, is one such example.

Another example of a useful plastic are high-density polyethylene materials which are commonly used as housewraps. Products, such as Tyvek, manufactured by DuPont, are strong but easy to cut to size. Such housewraps provide breathable



protection from water for buildings. It is applied between a building's outer cladding and frame.

Elastomer, epoxy and polyurethane

Elastomer is used for seals and gaskets. In construction, these are mostly used for weather strips, aperture seals, gaskets and expansion joints. The polymers used in these items are chloroprene and ethylene propylene diene monomer (EPDM). These are chosen because they are weather-resistant, deformation-resistant and retain elasticity. Vast quantities of polymers are also used in construction as a base for adhesives and sealants.

Epoxy resins are flexible resins made using phenols (aromatic alcohols) 'Epoxy' refers to a chemical group consisting of an oxygen atom bonded to two carbon atoms that are already bonded in some way. They are predominantly used in coatings, adhesives, electrical laminants and composites. This is because of useful properties such as adhesion, strength, chemical resistance and resistance to environmental degradation. It is because of this that as well as being used in construction, they play a major role in the manufacture of aircraft components and boat hulls.

Epoxy resin coatings are also used in other specialist applications in the construction industry. An example of this is non-slip floor coatings, which are commonly used in warehouses, food preparation areas and factories. These coatings are hard-wearing and resistant to abrasion, chemical spillage and impact. Similarly, polyurethane coatings are used on floors in places such as mortuaries, breweries, vehicle maintenance workshops and abattoirs, where floors need to be able to withstand high-temperature cleaning and chemical resistance.

Paints

Paints are used externally and internally in construction and many synthetic-based paints rely on petrochemical products during their production.



A Tyvek SD2 vapour control layer played an important part in the insulation system for the 50,000 m² roof of the Beichen Convention Center in Beijing, home to the international broadcast media during the 2008 Olympic Games.

The film-forming component of paint is known as the binder or vehicle – this helps paint adhere to surfaces and influences the paint's longevity, gloss, strength and flexibility. Synthetic binders include resins such as acrylics, vinyl-acrylics, vinyl acetate/ethylene (VAE), polyurethanes, polyesters, melamine resins and epoxy resins. Emulsion paint (known as latex paint in the US) is a term for all paints that use synthetic polymers such as acrylic, vinyl acrylic and styrene acrylic as binders.

The solvent (or diluent) component of paint serves to dissolve the polymer and adjust the paint's viscosity. Solvent-borne paints, commonly marketed as "oil-based paints" can contain different combinations of organic solvents including aromatics, alcohols and ketones. Specific examples include petroleum distillate, glycol ethers, synthetic resins and esters.

Other petrochemical-based additives for paint can be used to modify surface tension, improve flow, impart anti-freeze properties, change the texture, improve adhesion, reduce levels of glossiness and improve the finished appearance.





Concretes

Concrete – a man-made material that combines cement with aggregate and water – has been an important building material for centuries. There is evidence the ancient Egyptians used a concrete-like material more than 5,000 years ago, using gypsum mortars, mortars of lime and mud mixed with straw to bind bricks when building the pyramids. It is also believed that the ancient Romans used an early form of concrete 2,000 years ago on buildings such as the Coliseum and the Pantheon. Roman concrete consisted of small pieces of gravel and coarse sand mixed with hot lime and water. Additives such as animal blood, fat or milk, for consistency, and horsehair to prevent shrinkage were also used.

Since ancient times, concrete has come a long way and modern concrete often depends on petrochemical-based additives. Plasticisers, also known as water-reducing admixtures, reduce the quantity of water needed in a concrete mix. Newer water-reducing admixture products are often based

on polycarboxylic ethers, naphthalene formaldehyde condensates or hydroxylated polymers.

Accelerating admixtures are used to speed up the drying time of concretes. While calcium chloride-based accelerators can corrode steel used in concrete reinforcing, triethanolamine can be used instead. Conversely, retarding mixtures are used in hot weather to delay drying times. They can also act as water reducers.

Petrochemicals can play a part in the production of sealers for concrete. Sealers improve the watertightness of concrete, make it easier to clean and protect concrete from damage caused by toxic spills. Film-forming sealers are commonly produced using acrylics, polyurethanes and epoxies. They are easy to use, dry quickly and are cost-effective.

By-products of the refining process can also be used in concrete production, such as fly ash, a by-product from the coal sector. Fly ash can reduce up to 30% of the cement needed in a mix, it improves workability and reduces the heat gener-



A special adhesive was developed to join the precast concrete segments of the Dubai Metro line, able to withstand the country's sometimes extreme climatic conditions as well as the impact caused by the trains.

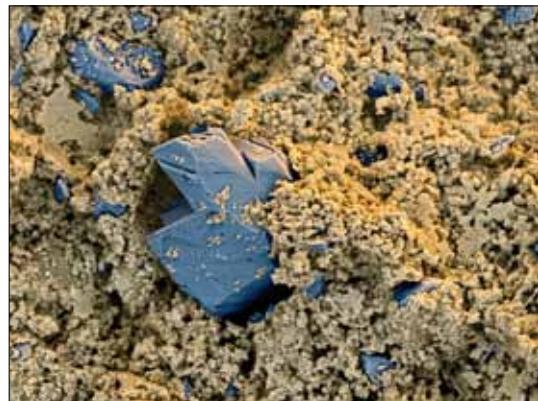


ated by concrete. Ground granulated slag from blast furnaces can also be used like fly ash in concrete production.

Petrochemicals and the future of the construction industry

Economic conditions play a major role in the fortunes of the construction industry. Increased demand for housing along with increased regulations to make the industry more sustainable and energy-efficient will provide opportunities for the petrochemical sector. An example is the growth of "intelligent" buildings and construction methods, which include a move towards more prefabrication in factories rather than work on building sites.

Petrochemicals are used to create a wide range of new materials which will continue to play an important role in sustainable construction projects. Polymeric composites and glass-reinforced plastic materials are two examples. Plastics are advantageous during construction for a number of reasons, such as versatility, resistance to corr-



Nanoscale crystal seeds speed up concrete hardening. BASF's X-Seed hardening accelerator (here magnified 960:1) makes additional heat superfluous and the concrete particularly strong and durable.

osion, light weight, strength and potential for creating more load-bearing structures. As such, their use in construction has a long future.

Jess Coutts is a freelance journalist.



New materials extend the possibilities for the construction industry. The Spyridon Louis stadium built for the 2004 Olympic Games in Athens has a transparent roof made of Makrolon polycarbonate from Bayer MaterialScience.





Fertilisers

By Jess Coutts

Petrochemicals have played an invaluable role in agriculture since the 19th Century and continue to do so, alongside organic products.

Organic fertilisers, such as those produced from fish emulsion or processed animal manure, have grown in popularity in recent years but petrochemical fertilisers still dominate the international market and demand remains strong.

Ongoing high demand for petrochemical fertilisers is fuelled by the world's growing population and also because large developing countries like China and India are moving towards diets with more meat which means more grain needs to be grown to feed livestock.

To understand the role of petrochemicals in fertilisers, it is important to understand the three main nutrients that benefit plants. They are nitrogen (for strong growth), phosphorus (for root growth) and potassium (for improved plant metabolism and disease resistance). Of these, nitrogen is the most important with the world's agricultural sectors needing around 110 million tonnes of it each year along with 33 million tonnes of phosphorus and 30 million tonnes of potassium.

A history of synthetic fertiliser production

The production of nitrogen for fertiliser is based on a process developed by German scientist Fritz

Haber in the late 19th Century in response to a global shortage of nitrate fertiliser. This shortage happened along with the industrialisation of agriculture. In Haber's era, scientists were aware of the nitrogen content in the air we breathe.

Haber invented a way to extract it – into a heated, pressurised container equipped with a catalyst, he injected hydrogen and nitrogen at one end and extracted ammonia at the other. This principle is employed today using natural gas as a fuel and for its hydrogen component. The gas is mixed with air over a catalyst in a heated, pressurised chamber. The resulting ammonia gas chills to form a liquid which is then processed into a number of different nitrogen fertilisers including urea, nitric acid and ammonium nitrate. Also, urea and ammonia can be blended with water to make liquid nitrogen fertiliser. However, in some markets, sales of ammonium nitrate fertiliser is heavily regulated because it can be made to explode.

Gasified coal and gasified petroleum coke can also be used to produce nitrogen fertilisers, but these make up a minority of global synthetic fertiliser production.

Coal was originally gasified in 1792 by pioneering Scottish engineer William Murdoch. He simply heated coal in a retort in the absence of air to partially convert coal to gas with a coke residue also produced. In 1873, the development of a cyclic steam-air process made gasification more efficient and from the 1940s, processes have been further developed to react coal with pure oxygen and steam to produce a gas that can be converted to syngas. In modern synthetic fertiliser production based on coal, there are two common processes used. One is the Winkler process which uses a fluidised bed in which powdered coal is agitated with reactant gases. The other is the Koppers-Totzek process which operates at a higher temperature – powdered coal is reacted while it is entrained in gases passing through a reactor. Ash is removed as molten slag at the bottom of the reactor.





Synthetic versus organic fertilisers

Synthetic fertilisers are chemically identical to organic fertilisers, but fertiliser companies have acknowledged the damage careless use of fertiliser can do, such as causing algae to grow and depleting waterways of oxygen. However, animal manure also contributes to such pollution. Another attraction of petrochemical fertilisers is that they are generally more cost-effective to produce and cheaper to buy than many organic alternatives.

Further issues have been identified with the increased use of nitrogen fertilisers in a bid to meet growing demand for food in a world with a rising population. These include issues related to the homogenisation of many staple crops, such as rice, the use of fertilisers in explosives and the environmental issues.

It has been argued that agriculture is now tied to the petrochemical industry because of the development of high-yield varieties of crops. Many of these crops only respond well to nitrogen fertilisers and this has reduced the variety of crops farmed in many countries. For example, in India, there were around 30,000 varieties of rice prior to the 1940s but only around 10 grown widely today. All these are high-yield types and the narrower genetic base for these crops has made them more susceptible to pests. Therefore, the use of pesti-

cides and insecticides has increased along with nitrogen fertiliser use.

Nitrogen fertilisers can also be explosive and have been used in the making of bombs. As such, many markets now place restrictions on who can buy fertiliser and quantities in which it is purchased.

Debate continues as to whether organic or chemical fertilisers are more environmentally friendly. Dependence on chemical fertilisers can be reduced by combining its use with organic fertilisers. Unlike organic fertilisers, chemical fertilisers can be easily blended to provide more precise levels of nutrients.

Along with more eco-friendly manufacturing processes, many nitrogen fertiliser producers claim they are using ingredients, such as monoethanolamine and potassium carbonate, because of their purity and to ensure that compositions of synthetic fertiliser are accurate so they can be used efficiently.

Looking ahead, petrochemical companies involved in the production of fertiliser, are being encouraged to diversify, to investigate alternative feedstocks and to ensure best practice techniques are used along the entire supply chain to minimise the environmental impact of nitrogen fertiliser production.

Jess Coutts is a freelance journalist.



Modern agricultural production and the petrochemicals industry advance hand-in hand. It is in everyone's best interests to ensure that petrochemical-based fertilisers continue to minimise their impact on the environment.





Petrochemical usage in food

By Ju Piau Khue

Petrochemicals play varied roles in modern food production and preservation.

The petrochemicals used in foods are usually derived from either petroleum (crude oil) or natural gas.

These resulting intermediates and derivatives from the petrochemical processes, such as thermal cracking, catalytic cracking and steam reforming, are used as food additives.

Petrochemicals can take forms as synthetic food additives that are not differentiated from their natural counterparts. Therefore, a widespread lack of consumer awareness is not surprising as current legislation in many markets does not specify the requirement of declaring synthetic food additives that are manufactured from petroleum or natural gas on food labels.

Food additives

According to the European Commission, food additives are defined in the European Union legislation as "any substance not normally consumed as a food in itself and not normally used as a characteristic ingredient of food, whether or not it has nutritive value, the intentional addition of which to food for a technological purpose ... results ... in it or its by-products becoming directly

or indirectly a component of such foods" (Article 1(2) of Directive 89/107/EEC).

Generally, most food additives could be categorised into one or more of these sub-classes: food flavourings, food colourings and food preservatives.

Food flavourings

Since the early ages of mankind, back to 400,000 BC when fire was first used for cooking, humans have been using spices and aromatic plants to season food. But it was only around the 19th Century when humans have started to develop the technology to synthesise artificial food flavourings. Food flavourings are substances that are added to foods to develop tastes and smells.

A widely used petrochemical for artificial food flavouring is butyric acid. Although butyric acid has an unpleasant odour and acrid taste, it can be converted into butyric esters that have pleasant aromas or tastes that are used as fragrant and flavouring agents in food and beverages. Butyric acids are produced industrially via chemical synthesis. This involves the oxidation of butyraldehyde that is produced using propylene derived from crude oil. Despite alternative methods, such as extraction from butter and natural fermentation, chemical synthesis is still the preferred method as it is low in production cost and there is a higher availability of starting materials. Butyric acid is found in a wide range of food products including sweet and savoury biscuits, coffee whitener, chocolate, confectionary and processed dairy products.

Food preservation

Food spoilages are characterised as the deterioration of varying degrees in organoleptic properties (how a food is perceived via the senses, such as taste, touch and smell), nutritional value, safety and aesthetic appeal of foods to an extent that the foods are deemed to be unfit for human consumption. These spoilages can be triggered by many factors, however, the growth of microorg-





anisms remains the main contributor. Through the understanding of how microorganisms are able to proliferate and thrive in our foods, measures can be taken to optimise shelf life.

Food preservatives are substances that are introduced into foods to retard or eliminate the growth of microorganisms. One of the most commonly used petrochemicals in the food industry as a preservative is benzoic acid. Benzoic acid occurs naturally in sources such as cranberries, prunes and plums, or can be synthesised via petroleum-derived intermediates such as phthalic anhydride or toluene.

Benzoic acid and its salts and esters (benzoates) are commonly used in fruit juices and soft drinks in an acidic pH range. Different forms of benzoic acid and benzoates used include benzoic acid (E 210), sodium benzoate (E 211), potassium benzoate (E 212) and calcium benzoate (E 213). The antimicrobial property of benzoic acid is attributed to its ability to be absorbed by the microorganisms. Inside the cell, benzoic acid lowers the pH of the internal environment and inhibits the metabolism of the microorganisms, resulting in

retardation of growth and ultimately death of the microorganism. As benzoic acid produces a sour taste, they are used as food flavourings to some extent. They are used to flavour the pickles used in McDonalds burgers.

Mineral oils are also used as food preservatives. They are manufactured from crude mineral oils though various refining steps and encompass a subgroup of the family of mineral oils and waxes. There are two different types of waxes derived from petroleum that are used in the food industry – paraffin waxes that are distinguished by large, well-formed crystals and microcrystalline waxes (E 905) that have a higher melting point with smaller and irregular crystals.

The microcrystalline wax (E 905) is non-toxic and approved for use internationally for surface treatment of non-chocolate confectionery, chewing gum, melons, papayas, mangoes, and avocado at *quatum satis* (meaning the use of the appropriate concentration needed to achieve the desired results, but not more). The wax coating improves the appearance and shelf life of the foods by inhibiting dehydration and protecting from

►
The preservative benzoic acid, while naturally occurring in fruit including cranberries, can be synthesised from petroleum intermediates.





Microcrystalline wax is an essential ingredient in the production of chewing gum.

oxidation. The protective barrier of wax also attenuates the risks of microbial contamination from the environment. For the European market, the purity requirements of the waxes are defined as per Directive 2009/10/EC. In addition to coatings, microcrystalline wax is also an essential ingredient in the production of chewing gum. Another petrochemical that is used in the manufacture of chewing gum is resin.

One of the many side effects of microbial growth in foods is the secretion of the digestive enzyme lipase that breaks down fats. Unsaturated fats in particular, are susceptible to oxidative damage. The presence of water and oxygen may also cause oxidation of these unsaturated fats. Effects of the oxidation of fats include decreased nutritional quality, increased toxicity, development of rancid flavours and odours, and altered texture and colour. Petrochemicals such as butylated hyd-

oxyanisole (BHA) and butylated hydroxytoluene (BHT) are added to spare the oxidation of fats. As these substances are fat soluble and have antioxidant properties, they are able to extend the shelf-life of these products.

Foods commonly associated with the use of BHA (E 320) and BHT (E 321) are those containing fats such as vegetable oils, animal fats, flavourings, spices, nuts, processed meats and snack products. Despite the similar antioxidant properties of vitamin E, BHA and BHT are preferred for their superior thermal stability. BHA has greater heat tolerance compared to BHT. Since the 1970s, BHA has been steadily replacing BHT due to toxicity studies.

In addition to their functions as antioxidants in food, BHA and BHT are also used in food packaging materials. Antioxidants applied indirectly into foods, for example, via food packaging, are known as secondary antioxidants. In recent years, the use



of packaging materials that exert antimicrobial and anti-oxidative properties has garnered considerable interest. In the USA, cereal industries have been utilising wax paper liners applied with BHA and BHT to contain breakfast cereals and snack food products. BHA- and BHT-treated liners exert anti-oxidative effects on the foods via evaporative migration into the foods.

Plastics have long been used as a protective barrier for foods and are derived from petroleum. The process of manufacturing plastic begins with the distillation of crude oil. Due to the varying lengths of the molecules in crude oil, they can be fractionised at different temperatures. Of these fractionised components, naphtha is the crucial element in the production of plastics. Similar to the manufacture of food additives, naphtha undergoes the cracking process and is broken down into single unit molecules called monomers. These individual units are then linked together in a process called polymerisation, producing a polymer chain. These polymer chains determine the characteristics of the final plastic that is produced. There are two different families of polymers, namely thermoplastic and thermoset.

Thermoplastics soften when heat is applied. This is due to the separation of molecules from one another, enabling them to move easily at high temperatures. Thermoplastics can be melted and remoulded an indefinite number of times. On the other hand, thermosets (also known as thermosetting plastics) form additional chemical bonds between the molecules when they are first moulded. Due to this complex three-dimensional and tightly interconnected network of bonds, a thermoset cannot be re-melted or change its shape. If sufficient heat is applied, chemical degradation takes place. Examples of the different types of plastics that are frequently used in the food industry include polyethylene terephthalate (PET) in food-contact films and high density polyethylene in food containers.

Additives for flavour and preservation

Some petrochemical-derived additives perform more than one role when included in food products.

Glycerol or glycerine is an example of an approved, petrochemical-derived food additive (E 422) that has the combined effect of acting as a food flavouring and food preservative. Glycerine is an odourless, colourless, oily, viscous liquid with a sweet taste. Among its desirable effects in foods are: being used as a humectant (retains moisture), emulsifier for fats, smoothing agent, heat transfer media for frozen foods, solvent for food flavourings and colourings, and as a sweetener.

The multi-step production of synthetic glycerol via the petrochemical propylene is known as the epichlorohydrin process. However, this method was more favourable back in the days before the biodiesel boom in the early years of the 21st century. The biodiesel boom refers to the period where the biofuel industry experienced a rapid and accelerated expansion, resulting in a sharp increase in the availability of glycerine, a by-product of biodiesel production, leading to the "glycerine glut". Consequently, from 2004 onwards, natural routes of glycerol production such as oil and fat processing dominated the industry as synthetic means became economically unviable.



Plastics have long seen use as food packaging materials.





Petrochemical-derived astaxanthin, fed to farmed salmon, both improves their health and imparts the characteristic redness of their wild counterparts.

Food colouring

The earliest discovery of petrochemicals as synthetic dyes dates back to 1856, when William Henry Perkin unintentionally discovered the purple dye, mauve, from coal tar when he was trying to synthesise the anti-malarial drug, quinine. The discovery of mauvein initiated a race to discover other synthetic dyes that are present in the myriad of chemicals in coal tar. Dyes from coal tar were quickly adopted to colour food, drugs and cosmetics. Food dyes in the present, however, are derived from petroleum.

As food consumers, we are attracted to products that are aesthetically pleasing. We form judgments using colours to perceive the quality and attractiveness of a product that is being marketed to us. Consumers associate colouration with superior flavour. Hence, most food manufacturers incorporate food colourings or food dyes in order to enhance the visual quality of their products. In the USA, data collected by the United States Food and Drug Administration (FDA) have shown a dramatic five-fold increase in the consumption of dyes since 1955, with three synthetic dyes – Red 40, Yellow 5 and Yellow 6 – accounting for 90% of all dye usage.

While some of these dyes are derived from natural sources, the majority are manufactured

synthetically. This is because synthetic dyes are cheaper to produce, more stable and produce brighter colours than most natural colourings. The prevalence of petroleum-derived food dyes is such that they are used in products including breakfast cereals, candy, snacks, beverages, vitamins, and even on the skin of citrus fruits.

Nevertheless, the preconception that synthetic food colourings are limited to the use in manufactured food products is seriously flawed. The flesh of wild salmon from oceans and rivers is often red, pink or orange in varying degrees. This colouration depends on the carotenoid content in the wild salmon's diet, with astaxanthin being the most common carotenoid obtained from natural occurring sources such as small crustaceans or other fish. As farmed salmon do not have access to these naturally occurring sources, petrochemical-derived astaxanthin is incorporated into the diet of farmed salmon.

The addition of astaxanthin promotes the desired redness of the flesh, functions as a precursor of Vitamin A, and is important for the growth, reproduction, metabolism and health of the salmon. The use of astaxanthin is approved by the European Commission. In some countries, such as Scotland, Ireland, Chile and Canada, cantaxanthin (E 161g), is used in combination with astaxanthin





in salmon feeds. However, the use of cantaxanthin is not approved in Australia and New Zealand. In addition to fish feeds, cantaxanthin is also a supplement in poultry feeds in order to modify yolk and skin pigmentation.

Alternatives to the use of petrochemicals

Notwithstanding the many advantages of using petrochemicals in the food industry, there have been rising concerns over the safety and long-term consumption effects on human health. A clear cut consensus on the usage of the different petrochemicals cannot be made, but efforts and measures have been taken by relevant government bodies to regulate levels of usage.

With the increasing demand for organic foods, some manufacturers have opted for natural substitutes. As with most petrochemicals used in the food industry, similar substances could be found in naturally occurring sources. However, due to efficiency, availability and cost issues, this can then result in increased costs being

passed on to consumers. Further, natural sources lack stability and there are still certain properties of synthetic sources that are unrivalled, such as brighter colours from dyes and heat stable antioxidants.

Furthermore, in the area of plastics, researchers have been looking into substituting petroleum-derived plastics with plant-based plastics. However, there is still a lack of technological advances to ensure that naturally sourced plastics are on par with petroleum-derived plastics in terms of effectiveness, cost and production efficiency.

There are many natural substitutes for most petroleum-derived substances. However, the market forces associated with consumer perception and acceptability of increased costs and decreased product quality will ultimately determine which products are used by the food industries and whether alternatives are viable.

Ju Piau Khue is a graduate in Food Science and Human Nutrition from the University of Newcastle.



Heiko Schneller, a BASF laboratory worker, checking the quality of beta-carotene powder. Nature-identical beta-carotene gives soft drinks, ice cream, custard and many other foods an attractive yellow to reddish-orange colour.





Textile industry uses

By Georgia Lewis

The petrochemicals industry has revolutionised the production of textiles.

Without petrochemicals, we would not have the advances that have allowed for affordable mass production of clothes, durable fabrics for a wide range of uses, the variety of fabric dyes we have available and fabrics that are easier to care for than natural fibres, such as cotton and silk. Synthetic fibres often possess qualities that are not easily found in natural fibres. The synthetic textiles industry has also offered economic benefits to many countries. While there is controversy over the ecological impact of synthetic fabrics, there are



When viewed under a microscope, synthetic fabric's resemblance to plastic is striking.

companies who are working to manufacture such textiles in a sustainable and responsible manner.

It is important to make the distinction between synthetic and man-made fabrics. While all synthetics are man-made using petrochemical-derived polymers, other man-made fibres can be composed of a range of materials, including silk, cotton and wool as well as plant polymers, such as cellulose.

Synthetic fibres have a wide variety of uses that go beyond familiar items of clothing, such as nylon stockings. This includes industrial uses, such as tyre cord and flame-proof linings, as well as home furnishing textiles, automotive textiles and sports and leisure uses, such as wetsuits and waterproof tents.

Sources and processes

When magnified, synthetic fabrics look like plastic that has been spun together. Generally, synthetic fabrics are made from chemically produced fibres. The chemicals used to make these fibres include sodium hydroxide and carbon di-sulphide, which are derived from coal, oil or natural gas. Polyester, acrylic and nylon are all examples of fabrics that come from these sources. Viscose, however, can be sourced from either pine trees or petrochemicals.

Initially, the fibre-forming polymers are solid. The solids are converted into a liquid state. This is done by melting if the polymers are thermoplastic synthetics (i.e: they soften and melt when heated), or dissolving them in a solvent if they are non-thermoplastic cellulosics. If the polymer cannot be melted or dissolved, they are chemically treated to form soluble or thermoplastic derivatives.

The chemicals in liquid form are then forced through a device called a spinneret in a process called extrusion. At this stage, the liquid is thick and viscous with a consistency similar to cold honey. A spinneret is similar to a bathroom shower head and it may have from one to several hundred holes. As the liquid emerges from the spinnerets and is exposed to air, it cools and forms tiny threads.



The stretchiness of materials such as spandex has revolutionised sportswear.

These threads are dyed before being woven or knitted together to make fabric. This can be done through four methods of spinning: wet, dry, melt and gel-spinning.

Wet spinning is used on fibre-forming substances that have been dissolved in a solvent. The spinnerets are submerged in a chemical bath and as the filaments emerge, they precipitate and solidify. Acrylic, rayon and Spandex are produced via this process.

In dry spinning, solidification is achieved by evaporating the solvent in a stream of air or inert gas. The filaments do not come into contact with a precipitating liquid so there is no need for drying. This process can be used to make acetate, acrylic, Spandex and vynylon.

In melt spinning, the fibre-firming substance is melted for extrusion through the spinneret and then directly solidified by cooling. This process

can be used to make nylon and polyester products. Melt-spun fibres can be extruded from the spinneret in different cross-sectional shapes, such as round, trilobal, pentagonal and octagonal. Trilobal-shaped fibres reflect light to give a sparkling effect to the fabric. Fibres that are spun in a pentagonal shape or are hollow are used in carpets to show less dirt. Hollow fibres also trap air and create insulation. Octagonal-shaped fibres offer glitter-free effects.

Gel-spinning is a process used to make high-strength fibres. In this process, the polymer is not in a true liquid state during extrusion. The polymer chains are bound together at various points in a liquid crystal form instead – this produces strong inter-chain forces in the resulting filaments that can significantly increase the tensile strength of the fibres. Stronger fabrics can also be created by drawing the filaments while they are solidifying or

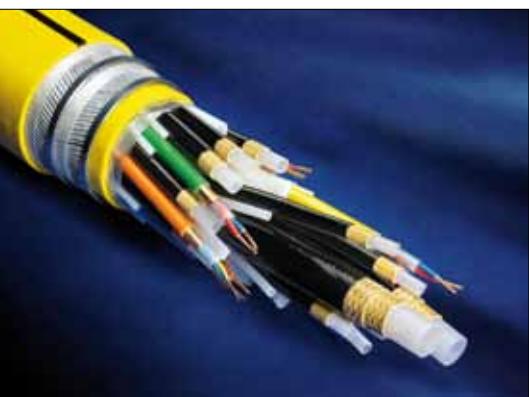




The versatility of synthetics is exemplified by polyester fleece, made from polyethylene terephthalate (PET); the same material used to make plastic bottles.

afterwards – this pulls the molecular chains together and orients them along the fibre axis to create stronger yarns.

Sometimes, additional chemicals can be added to the fabric for specific purposes. Chemicals can make the fabric softer, free of wrinkles, more stretchy, flame-resistant, stain-resistant, waterproof and moth-repellant.



Best known for its use in bulletproof vests, Kevlar's properties of high strength, abrasion and temperature resistance and electrical insulation make it ideal for shielding cables. This umbilical is used by the oil industry in a subsea application for drilling and recovery.

Uses

Textiles created from petrochemicals are many and varied. They include fabrics commonly used in clothing, such as rayon, acetate, nylon, acrylic, polyester, elastane, which is commonly marketed as Lycra or Spandex. Other more specialist materials created from petrochemicals include Kevlar and neoprene. Synthetic fabrics often have multiple uses, some of which cannot be easily achieved with natural fibres alone. Adding further chemicals to synthetic fibres can further improve their versatility.

Fabrics with excellent stretch are commonly used in swimwear, lingerie and hosiery as well as garments that benefit from stretchy fabric, including T-shirts and tracksuits. Synthetics can be mixed with natural fibres to create improved fabrics. For example, polyester, when mixed with cotton, is a common example of a synthetic-natural blend, whereby a garment such as a T-shirt benefits from the cooling, breathable nature of cotton and the stretch, durability, easy care and quick drying properties of polyester. Polyester is also used in raincoats, fleece jackets, children's nightwear, medical textiles and working clothes.

Other blends of natural and synthetic fibres include cotton/Lycra blend, which is especially useful for manufacturing denim which is more comfortable and fits better than 100% cotton jeans, and acrylic/wool blend, which is used to manufacture trousers that are less expensive and easier to care for than 100% wool.

Acrylic is widely used for jumpers, fleece jackets and blankets because it has similar properties to wool, but dries much faster and is more easily washed in machines.

Nylon, commonly marketed under a number of brand names, such as the Invista-owned Tactel, has a wide range of uses, including active sports-wear, fleece jackets, socks, seatbelts, tents and waterproof garments. The combination of warmth, durability and weatherproofing makes it a very



► DuPont vice president Charles Stine announced the development of nylon hosiery at the New York World's Fair in 1938. The first sales were made in Wilmington, Delaware the following year.



versatile textile. It is also easy to clean and does not crease easily.

Neoprene, originally developed by DuPont scientists in 1930, is produced by the polymerisation of 2-chlorobutadiene. This process occurs in an aqueous emulsion. It is a versatile material that is durable, elastic and maintains flexibility over a wide temperature range. As such, it is used on wetsuits, laptop sleeves, orthopaedic braces, electrical insu-

lation, padding for bicycle seats and saddles, and automotive fanbelts.

Kevlar, developed by DuPont in the 1970s, is another synthetic textile which has multiple uses. It is an aramid fibre, that is, a fibre that is an aromatic polyamide. It is also produced under the trade name of Twaron. It can be manufactured in many different grades for a range of clothing, accessories and equipment that is safe and cut-





Nylon fishing nets being prepared to be recycled to produce Biosfera I carpet tiles, extending the useful life of the material.

resistant. Like carbon fibre, which is commonly used on racing cars, Kevlar is both lightweight and strong. Other properties of Kevlar include low density, good impact resistance, good abrasion resistance, good chemical resistance, good resistance to thermal degradation. It is usually yellow in appearance but is frequently coloured, depending on its application, such as camouflaging colours for bullet-proof vests. While the manufacture of bullet-proof vests is probably the best known application for Kevlar, it is a very versatile material with uses that transcend textile uses. Other applications include protective apparel (such as gloves, motorcycle protective clothing, hunting gaiters and chaps; sails for boats), belts and hosing for industrial and automotive applications, aircraft body parts, boat hulls, fibre optic and electromechanical cables, friction linings for clutch plates and brake pads, gaskets for high

temperature and pressure applications, and adhesives and sealants.

As well as producing fabrics, the petrochemicals industry also has a hand in creating products that are related to the textiles industry. Fabric softener, dye fix, dyestuffs, stain removers and fabric brighteners all rely on petrochemicals

Responsible textile manufacturing and alternatives

There has been concern that while these are desirable qualities in fabrics, the fabrics are non-biodegradable so they do not break down in soil if they are discarded. The synthetic textile industry has also come under criticism for the effects on the environment, wildlife and health, especially for those who work to produce these fabrics. Factories have been accused of consuming excessive amounts of water and energy. However,



major companies are leading the way in developing economically and environmentally efficient technologies, considered essential if the industry is to evolve and remain relevant.

Two such companies are BASF Textile Chemicals, based in Germany, and Fong's Industries, based in Hong Kong.

BASF is taking a series of measures to be a more responsible synthetic textile producer, such as a processing system which reduces the use of formaldehyde, including eliminating the use of formaldehyde in the dyeing, pigment dyeing and pigment printing process. Products that are manufactured using fewer chemicals as well as saving water and energy have been another staple of BASF's textile business. For example, Cyclanon ECO is a reducing agent for post-clearing dyeing on polyester, polyester blends and acetate. It is a low-toxicity liquid which destroys unfixed dye particles so waste water leaving the dye house is mostly decolourised. It can also lighten direct dyeing.

The carbon footprint of dyeing has also been reduced with a one-step process of pigment dyeing and finishing – the BASF Color Fast Finish is much shorter than the conventional dyeing process, reducing energy and water consumption and subsequent carbon dioxide emissions. BASF's Ultra-phor SFG liquid fabric brighteners can be applied at lower temperatures for further energy savings.

Fong's Industries, meanwhile, has been setting an example in China and Europe for several years with the textiles part of its business. China is by far the world's leading producer of synthetic textiles, producing 51.8% of the world's man-made fibres with India a distant second at 6.2%. Speaking at the inaugural ITMA Asia +CITME conference in 2008, a major pan-Asian textile industry event, Bill Fong, who oversees the group's business development projects, said of textile companies improving environmental standards: "Action is needed, but the industry cannot do it alone. National and multinational governments should support

the industry with incentive plans to change old technology with modern equipment. Cutting edge technology is available."

Like BASF, Fong Industries have made improvements to their synthetic dyeing processes and the company's water- and energy-saving dyeing machine with an ultra-low liquor ratio has been listed in The 6th Recommendation Directory of Advanced Energy-Saving and Emission-Reduction Technology for China's textile, printing and dyeing industry.

Other textiles companies, such as Interface, are looking to reduce their reliance on using petrochemicals until ultimately they are not used at all. An example of this is Fotosfera, a carpet tile product that is currently sourced from 63% bio-based content, most notably oil from the seeds of castor bean plants. Castor beans grow well in sandy soil, only require water every 25 days and do not compete with food crops, making them a sustainable source of oil for nylon. Fotosfera carpet tiles are installed using another Interface product, TacTiles, which are plastic adhesive patches made from PET polyester and do not require traditional carpet glue – so while the patches are plastic, the adhesive is far less volatile.

Interface has also developed Biosfera I, another carpet tile collection. Biosfera I tiles are made from 100% recycled materials, including nylon from fishing nets. This gives products already created from petrochemicals a longer life, well past their original uses.

Alternatives to synthetic, petrochemical-based textiles that are equally practical, but more sustainable are growing in popularity. An example of a company making great strides in this area is Lenzing, which manufactures fibres from wood rather than oil. Polymers in the form of cellulose wood pulp are converted into fibres known as "man-made cellulosic fibres".

Georgia Lewis is the Deputy Editor of International Systems and Communications.





Sports and leisure

By Georgia Lewis

The world of sports and leisure has been transformed by the use of petrochemicals.

Petrochemicals are especially relevant in the manufacturing process of many items which have become integral to modern sports and leisure activities. For example, plastics are widely used in high-tech sports equipment, which ranges from fairly common items, such as tennis racquets, skis, footballs and running shoes, as well as the kind of sporting equipment that is not quite so commonplace, such as F1 racecars (see page 54) and yachts.

Making sporting equipment from synthetics has made mass production of such items easier and made sporting equipment cheaper and more easily accessible to more people. As well as the economic and social benefits, many synthetic materials used in sports and leisure equipment are also more durable than naturally sourced materials, such as leather for footballs.

Hard, shock-absorbing surfaces

Petrochemical-derived synthetics also play an important role in the manufacture of athletics tracks, tennis courts, netball and basketball courts, and artificial turf for football and rugby fields. An example of this is the development of Rebound

Ace, a surface that is essentially a high density, high shock absorption rubber cushion mat that has been combined with multi-layered acrylic surfacing. It has become a popular surface for tennis and netball courts. The rubber is a multi-layered polyurethane combined with fibreglass, and EPDM (Ethylene Propylene Diene Monomer) rubber granule cushioning. This is laid on top of an asphalt or reinforced concrete base.

The main benefit of a shock-absorbing surface, such as Rebound Ace, is that it responds to body impact to reduce fatigue on the legs, ankles and feet of players. This has led to New Zealand's netball governing body claiming that cushioned courts have kept players playing for as many as 10 years beyond what is usually the norm on hard courts. It was also the surface for the Australian Open tennis courts from 1988 until 2007, when it was replaced with another petrochemical-derived surface, Plexicushion. This is another synthetic rubber surface, a blend of latex, synthetic rubber and plastic particles.

Artificial turf

Artificial turf has been refined and developed over the years as a low-maintenance, durable, affordable alternative to grass. It is commonly used on playing fields and tennis courts. It is marketed under many different brand names but first came to prominence in the 1960s when Monsanto developed a product called AstroTurf. This was first installed on a large scale in 1965 at the Astrodome in Houston, Texas. Its use became widespread in the US in the 1970s, predominantly for baseball and American football. At the 1976 Olympics in Montreal, hockey matches were played on a nylon synthetic turf – these days most top-level hockey matches are played on such surfaces and it has changed the sport by making the game faster and adding new playing techniques.

While it is a registered trademark, AstroTurf became a colloquialism for any artificial turf. Orig-i-



AstroTurf's first major installation was at the Houston Astrodome in 1965. Synthetic turf has gone on to find many uses beyond the field of play.



nally, artificial turf was made from short-pile synthetic fibres without infill while second-generation artificial turf used sand as an infill from the 1980s. The latest artificial turfs, developed in the 1990s, tend to use infills made from a blend of sand and recycled rubber.

The basic material for the short-pile turf is polypropylene and polyethylene granules which are melted and extruded to create long yarns or a film that is then cut into individual yarns. The yarns are then tufted into a polypropylene fabric, in a similar technique to that used for domestic carpet – hundreds of needles are positioned on a

beam and every needle pulls a yarn through a base fabric and form a loop. Each loop is then cut so the fibres stand upright.

So commonplace are synthetic turfs in the world of sport that sports governing bodies such as FIFA recommend and approve them, such as Total Petrochemicals' Luminene product.

As well as sporting uses, artificial turf has been used at airports instead of natural grass. It is easier for vehicles to drive over, it doesn't attract wildlife so the risk of wildlife colliding with planes is reduced, it stays green in all weathers so it is easily spotted by pilots and it is easier to maintain.





BASF's Conica track surface was specifically designed for world record attempts and to be easy on athletes' joints.

Athletics tracks

One of the most prominent sporting uses for petrochemical products is on sporting tracks. Leading chemical companies, such as BASF Construction Chemicals Europe and Versalis, have created sporting surfaces using petrochemicals.



A shell coating of DuPont's Surlyn resin prevents chips and ensures the wood-cored pins withstand constant impacts from bowling balls, sidewalls and other pins themselves.

Their tracks are approved by the International Association of Athletics Federations.

BASF's Conica surfaces, for example, have been created to be not too hard or too soft and are made from a three-layer solid plastic. A polyurethane coating is applied before the track is laid and then synthetic rubber granules (EPDM) are used before the topmost polyurethane layer is applied. This surface is also weather-proof.

Versalis, Italy's leading petrochemical company, have also developed a polymer athletics track using their expertise. Marketed as Protopapa, the tracks are made from polyethylene and synthetic rubber, all derived from oil which the company refines at its own plant. The blend of polymers create a durable track that is UV-resistant

Other sporting equipment

Whether it's a more durable material than leather for footballs and rugby balls or wood for tennis racquets, or replacing heavier steels in bicycles, petrochemicals play a major role in the manufacture of many items of modern sporting equipment.

For example, the Lianyungang Shenyang Carbon Bike Company, based in China, manufactures carbon fibre bicycles for the global market. It is affili-



ated with the Yingyou Group, China's biggest carbon fibre producer. Carbon fibre is strong, rust-resistant and light so it is an obvious choice for improving bicycles. DuPont has used ionomer (a polymer with ethylene as the major component and contains covalent and ionic bonds) resins to improve the performance and durability of its golf balls.

Plastics have revolutionised the world of sporting equipment, often replacing traditional materials, such as leather and wood, to create items that are durable, easy to mass-produce and are generally more affordable. Some companies, such

as Marlborough Plastics, a US-based company, supplies moulded plastics which are then turned into a wide range of products for different sports by other manufacturers. Sporting products which can be made from plastics include helmets, archery bows, canoes, tennis racquets, caps and nose plugs for swimmers and divers, bats and balls (especially for children), baskets on ball collecting carts for golf driving ranges and the seats at stadiums.

Georgia Lewis is the Deputy Editor of International Systems and Communications.



Eva Terčelj of Slovenia competing in the 2012 Olympic Slalom Canoeing. Plastics selected for strength and lightness enhance equipment and protect participants in demanding sports.



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Global summary

A round-up of developments and future plans for petrochemical markets from across the world.

While the global petrochemical sector faces challenges, it remains for the foreseeable future, a multi-billion dollar industry. But the status of the sector varies across different markets. The last three decades have seen immense changes to the global petrochemical sector, most significantly, a reduction in the dominance of the United States, western Europe and Japan. In 2010, these three regions accounted for just 37% of the world's petrochemical production.



The dawn of America's shale gas boom has profoundly changed the country's gas and petrochemicals industries.

In the last two decades, Japan's neighbours, including Singapore, South Korea and Taiwan, have expanded petrochemical producing capacity to support their own economies and to export to regions with limited capacity. Three of the fastest growing petrochemicals markets are China, Latin America and the Middle East. China, like Thailand, Malaysia and Indonesia, has expanded due to a desire for self-sufficiency for a fast-growing population. Many emerging markets are also keen to export petrochemical products.

Emerging markets are set to play an ever-increasing role in producing petrochemicals. According to *The Outlook for the US Chemical Industry* report by KPMG, China is expected to take over the US as the largest chemical producer in the world by 2015, by 2025, India will have more than 400 million middle-class consumers (more than the current population of the US), and between 1995 and 2005, more than 95% of world chemical growth was concentrated in developing countries. The increased size and purchasing power of these emerging markets will undoubtedly impact on the petrochemical industry as well as the chemical industry as a whole.

With increased globalisation, many companies have a presence in the petrochemical markets of multiple countries either as sole operators or in partnership with other companies or governments. Halliburton is one such company – while based in North America, it employs 5,600 people in the Asia-Pacific region and has announced a deal with Malaysian national oil company Petronas to extend its capability in the region.

Sasol is another multinational petrochemical producer with truly global reach, While the company is based in South Africa, it exports to 90 countries and has petrochemical operations in the US, Italy, Slovakia, Germany, China, Qatar, Iran, Gabon and Nigeria.

Total Petrochemicals, meanwhile, produces a wide range of petrochemical products, including

those used for household applications, the automotive industry, packaging, medicine, sports and fashion. A major focus of Total's petrochemical and refining business is expansion in the growing markets of Asia and the Middle East.

Here is a region-by-region round-up of the industry.

North America

The shale gas revolution has resulted in major changes to the North American petrochemical market.

United States of America

Stable natural gas prices, along with an abundance of shale gas and a willingness to exploit this resource in many US states, has boosted industry competitiveness.

Low gas prices are helping the US industry in two ways – natural gas has become an important part of the petrochemical industry's energy mix, which keeps costs down, and certain fractions of natural gas, such as ethane, methane and other light hydrocarbons, are vital petrochemical feedstocks.

Low gas prices could have an adverse effect if gas production companies do not make a profit because that could lead to gas resources not being developed. But companies in the US are favouring the production of gas that is rich in petrochemical feedstock material – wet gas rather than dry gas, which is low in feedstock components.

Projects to increase the capacity to produce ethylene from ethane in the US have been announced but it is uncertain which ones will be completed – those that are built will be able to focus on export markets. However, Dow Chemical Company is confident its new ethylene plant in Texas will be completed by 2017 and Celanese expects to complete a methanol production plant in Texas by 2015.

The shale gas boom in America will also continue to bolster the country's petrochemical sec-

tor. Investments by Chevron Phillips Chemical include a world-scale ethane cracker and ethylene facility at its existing operations on the US Gulf Coast. The new facility will exploit feed sources from the development of shale gas reserves.

Ongoing developments in technology are also vital for the growth of the North American petrochemical sector. Honeywell, for example, has announced the launch of a new membrane element to efficiently remove contaminants from natural gas and reduce the amount of valuable methane lost during the decontamination process.

The US petrochemical sector is also bolstered by many of its leading companies expanding internationally, something which many have been doing for decades. ConocoPhillips has been expanding internationally since the 1930s (when it was still trading as Phillips, it merged to form ConocoPhillips in 2001) with forays into countries such as Canada, Venezuela, Mexico, China, Indonesia and Australia.

Canada

In Canada, the industry is very similar to that in the US but with some differences. The American natural gas boom means the US has less need to import gas from Canada. Despite this, plenty of natural gas-derived petrochemical feedstocks in Canada have been earmarked for the export market.

The drop in demand from the US has led to a fall in Canadian natural gas production – and the lack of gas leads to a reduced availability of ethane for feedstock. However, natural gas companies in the Canadian province of Alberta have devised a creative solution – moving ethane to Alberta from a shale formation in the US state of North Dakota, extracting feedstock materials from the by-product off-gases resulting from the bitumen upgrading, as well as extracting incremental quantities of ethane from the gas that is produced in western Canada.

Alberta is Canada's leading producer of petrochemicals with the sector producing more than



While Canada has seen a fall in gas production, development is still ongoing.

\$13.5 billion worth of products in 2011. The main petrochemical products from Alberta are ethylene, polyethylene, ethylene glycol, linear alpha olefins and acetic acid and the two main export markets are the US and Asia. The Joffre and Fort Saskatchewan petrochemical area includes four ethane-cracking plants, two of which are the world's largest.

The government of Alberta amended the Incremental Ethane Extraction Programme to encourage more production of ethane from natural gas and off-gases as a by-product of bitumen refining, with bitumen coming from the area's extensive oil sands.

In eastern Canada, most notably the province of Ontario, the corporate investing landscape was changed with a reduction in corporation tax and initiatives to address regulatory issues – this business-friendly environment should lead to opportunities for growth and investment in natural gas and the ensuing production of petrochemical feedstocks.

Europe

Europe's \$98.5 billion petrochemical industry is primarily derived from feedstocks based on crude oil rather than natural gas, as is the case in other markets, such as the US. As long as oil prices

remain high, European feedstock prices will also remain high.

The economic issues, which have impacted on multiple economies across the European Union, have negatively affected demand for all products, including petrochemicals. However, the European petrochemical industry is strong and advanced so it is expected to emerge successfully from the challenging economic climate. Germany, France and the Netherlands are Europe's three leading petrochemical producers.

Germany

Germany is weathering the Eurozone crisis well and despite a decline in all sectors of the country's chemical industry in 2011, it appears the slump has bottomed out. While there has been a slowdown in exports to the US and an increasingly competitive China, growth prospects for the German petrochemical sector are expected in the production, research and development of high-end specification plastics and speciality chemicals.

An example of an expanded petrochemical plant is that of Evonik Industries, which is building a polybutadiene plant at Marl. BASF has expanded its production of extruded polystyrene by 17%. Also, BASF is ramping up production of nylon engineering plastics and polybutylene terephthalate at its facility in Schwarzheide. Bayer Material-



BASF's plant in Schwarzheide. BASF is one of many German companies increasing production.





Science is developing a toluene diisocyanate plant at Dormagen which is due to come onstream in 2014. This will replace existing facilities at Dormagen and Brunsbuttel.

Growth in the German petrochemical sector is projected to be around 2-2.5% per annum up to 2020.

France

Following a year of zero growth in 2012, the French petrochemical sector is looking to boost research and development and exploit speciality markets in order to strengthen the sector. Propylene, butadiene, the increasingly popular linear low-density polyethylene (LLDPE) and polyethylene terephthalate (PET) are the main petrochemical products made in France. The main areas of demand for French petrochemical products is in aerospace, packaging and food processing.

French producers are looking beyond the traditional markets within the Eurozone, with the US and Asia offering more potential for growth. It is hoped that looking outside of Europe will offset the impact of factors such as low consumer confidence, fiscal cuts, investment limited by space constraints, and unemployment.

Taiwan is an example of a market in which France is keen to expand its petrochemical activities. The Petrochemical Industry Association of Taiwan and the French Institute in Taipei have been holding meetings to discuss sharing technology and knowledge in areas such as environmental protection, energy conservation and manufacturing. French companies slated to be involved in possible partnerships include Elbe Petro, MPR Industries, RB Technologies, SAS, Vulcanic SAS and Bernard Controls.

Russia

A robust petrochemical sector has been an important part of Russia's continued economic growth. Russian petrochemical producers have responded



The Tobolsk-Polymer plant in Russia is scheduled for launch in 2013, producing 510,000 metric tonnes of polypropylene per year.

to the need to compete on a global level, and to offset potential undermining of price competitiveness in the wake of feedstock price liberalisation, by diversifying and building capacity. The diversification of the petrochemical sector has gone hand in hand with growth in the automotive and construction sectors, both of which rely heavily on petrochemical products. Overall production capacities are expected to double by 2017.

Potential availability of naphtha and ethane feedstock is strong because of expansion of refineries and the country's growing gas sector.

Fertiliser is a strong performer for the Russian petrochemical sector with an exportable surplus being produced. Polymers capacity is expected to exceed 10 million tpa by 2017, a three-fold increase from 2008.

Projects slated for completion in Russia by 2014 include plants in the plastics and rubbers sector, including 60,000 tpa of acrylonitrile-butadiene-styrene (ABS) and 3,330,000 tpa of PVC. Other petrochemical products with projected growth in production include polyethylene, polypropylene, polystyrene and polyethylene-terephthalate. This growth mix is expected to coincide with an increase in local demand for plastics.

In 2012, two major Russian players, gas giant Gazprom and petrochemical manufacturer Sibur,





joined forces to sign a long-term contract to supply natural gas liquids (NGLs) from the Surgut Condensate Stabilisation Plant to the Tobolsk-Neftekhim facility up to 2021. The agreement means the annual supply of NGLs will rise from 440,000 mt to 1 million mt by 2016. Hydrocarbon feedstock volumes beyond 2016 will be agreed at a later date.

Rosneft is building a mega petrochemicals complex with 3.4 million tpa capacity in Nakhodka with a 2017 completion date.

Forming international partnerships is another diversification strategy for Russian companies. For example, gas company, Novatek, has signed a 2013 agreement with the Yeochun Naphtha Cracker Center (YNCC), a South Korean petrochemical company, to supply up to 300,000 tonnes of light naphtha, which is produced at the Ust-Luga Gas Condensate Transshipment and Fractionation Complex.

The Netherlands

The petrochemical sector in the Netherlands is well placed to remain competitive despite troubled economic times in Europe. While export growth has slowed, consumer demand is flat, the PVC sector is under pressure from a slump in



A plastomers production site in Geleen, The Netherlands.

housing construction, and the PP sector is under pressure from a slump in automotive production, there is still good news ahead for Dutch petrochemical producers.

The sector is still very competitive in the area of high-value finished products. As such, the sector is still very attractive to foreign investors. Teijin, a Japanese company, opened its first high-performance polyethylene (HPPE) production facility in Emmen in October 2011, as part of the drive towards diversification. Thailand's Indorama Ventures is aiming to increase PTA capacity at its Rotterdam plant by 2014 so it can serve as an important feedstock supplier to PET producers in western Europe.

Denmark

The production and export of petrochemicals plays a major role in the Danish economy, with companies such as Novo Nordisk and Haldor Topsøe leading the way. Novo Nordisk runs a high-tech, highly specialised operation with heavy investment in research.

Haldor Topsøe, meanwhile, recorded its best-ever operating profit in 2012 with turnover increasing by 19% to DKK 5,244 million compared to DKK 4,421 million in 2011. This was achieved in spite of increased research and development costs. The company is focusing on expansion and modernisation of chemical production and oil refining to create new opportunities worldwide. Long-term projects for Haldor Topsøe include investment in Pakistan's Fauji Fertiliser Company, in which it holds a majority stake.

Middle East

At the start of the 21st Century, a petrochemicals boom was tipped for the Middle East with extensive hydrocarbon resources in Kuwait, Oman, Qatar, Saudi Arabia and the United Arab Emirates. While petrochemical demand within these countries is fairly limited, world-scale production facil-





ties were developed to cater to export markets with a strong focus on China.

While there were concerns that the new capacity of the Arabian Gulf states would lead to oversupply and lower prices, this has not been the case. The supply-demand balance has been well-managed courtesy of three factors – stronger than anticipated worldwide demand and, interestingly, delays in getting new capacity utilisation rates up, as well as low production costs.

Investment in the Middle Eastern petrochemical market continues, although the pace of investment has slowed.

Kuwait

Thanks to large crude oil reserves – proven reserves of 104 billion barrels – the petroleum industry accounts for nearly half the Gulf state's GDP. As a result of these vast natural resources, the largely government-owned and run petrochemical sector has grown strong, with the assistance of foreign investors.

The five major players in the Kuwaiti petrochemical sector are Equate Petrochemical Company (produces ethylene oxide, ethylene glycol, ethylene and polyethylene), Kuwait Paraxylene Production Company (produces benzene and para-xylene), Petrochemical Industries Company (produces polypropylene), the Kuwait Olefins Company (produces ethylene glycol and ethylene), and The Kuwait Styrene Company (produces styrene).

Dow Chemical Company is a major foreign investor in the Kuwaiti petrochemical sector with 42.5% stakes in Equate Petrochemical Company and the Kuwait Olefins Company. Dow Europe Holding has a 42.5% stake in the Kuwait Styrene Company. The state-owned Qurain Petrochemical Industries Company is another major player with stakes in Equate, Kuwait Paraxylene Production Company and The Kuwait Olefins Company.

Hamad Al-Terkait, CEO of Equate Petrochemical Company, told *Aljarida* newspaper that it is im-

portant for Kuwait to continue to invest in and recognise the value of the country's petrochemical sector. With Gulf states, including Kuwait, looking to move away from relying on oil for energy, the opportunity for Kuwaiti oil resources to continue to be exploited for use in the petrochemical sector is very positive.

Oman

Oman is in the process of stepping up its efforts to capitalise on its hydrocarbons resources and this includes expansion of the petrochemical sector. It is hoped that this will reduce dependence on imports and raise higher export revenues.

The Oman Oil Company (OOC) announced in October 2012 that it was setting up a new petrochemicals facility in the industrial centre of Sohar on the Gulf of Oman. The plant has been budgeted at \$800 million and it will produce purified terephthalic acid (PTA) for polyester fibre, resin and film, and polyethylene terephthalate (PET) for use in plastics.

OOC already has a large downstream petrochemicals portfolio, including Salalah Methanol and the Oman-India Fertiliser Company, as well as a holding in the Oman Refineries and Petroleum



ORPIC's aromatics plant in Sohar, Oman, converts naphtha feedstock into benzene and paraxylene.



Arab Petroleum Investments Corporation



The Arab Petroleum Investments Corporation (APICORP) is a multilateral development bank established to foster the development of the Arab world's oil and gas industries. The organisation was created under the terms of an agreement signed by the 10 member states of the Organisation of Arab Petroleum Exporting Countries (OAPEC) in September 1974. APICORP's vision is to transform the Arab energy industry into a powerful force for the region's economic progress. Driven by this vision, APICORP seeks to make equity investments and provide project loans, trade finance, advisory and research to the industry.

Since its founding, APICORP has made significant contributions to the region's energy industry. APICORP has invested, as an equity owner, in a total of 22 oil and gas joint venture projects worth in excess of \$16 billion. APICORP has also participated in direct and syndicated energy finance transactions worth in excess of \$130 billion. The multilateral development bank's aggregate commitments in these transactions, both in equity and debt, are valued in excess of \$11 billion.

APICORP has a track record of sustainable financial performance since inception. Its consistently strong performance over the past three decades reflects the robust nature of its asset portfolio and its ability to strategically and prudently manage its debt portfolio. In 2012, APICORP's net profits grew 3% from 2011 to reach \$109 million, the highest in its 37 year history. APICORP's total assets rose to over \$5 billion, an increase of 9.6% from 2011 while net asset value per share jumped over 7% to \$1,744.

In October 2012, APICORP's strong fundamentals were endorsed by Moody's upgrade of APICORP's issuer

and senior unsecured rating from A1 to Aa3. Considering the current environment where substantial credit upgrades for financial institutions are rare, the Aa3 rating upgrade of APICORP is considered exceptional.

As part of its current five-year strategy, the multilateral development bank is seeking to broaden its investment and financing portfolios to cover new oil and gas and utility sectors. APICORP is particularly looking at supporting projects that will boost the region's mid-stream and downstream capabilities, which are crucial for Arab countries to maximise economic benefits from energy resources.

Over the last two years, APICORP further stepped up its efforts to support Arab energy industry development through initiatives undertaken in partnership with global organisations. In February 2013, APICORP announced the establishment of the APICORP Petroleum Shipping Fund, a landmark \$150 million Fund aimed at leveraging growth opportunities in the petroleum product tanker charter market, in partnership with Tufton Oceanic, a leading global fund manager in the maritime and energy-related industries. Co-managed by Tufton Oceanic, the Fund is the first investment fund to be established by APICORP and the first fund in the region aimed at a specific vessel category.

Earlier, in May 2012, the organisation signed a trade finance services agreement with global banking leader J.P. Morgan, which enabled it to significantly expand its trade finance services. Another partnership signed with the International Finance Corporation in March 2011 was aimed at enabling APICORP to co-finance developing country energy projects in which Arab countries have made investments.

APICORP

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Qatar Fertiliser Company's Ammonia-Urea plant, QAFCO 4, in Mesaieed.

Industries Company (ORPIC), which operates the country's two refineries, including the one at Sohar that will provide feedstock for the new PTA-PET plant. A project to expand the Sohar refinery is being planned, at a cost of between \$1.5 billion and \$1.8 billion. This is expected to be completed by the first half of 2016 and should have an extra processing capacity of 60,000 barrels per day.

Qatar

The Qatari petrochemical sector, bolstered by enormous natural gas resources and a buoyant economy, continues to experience steady growth despite a slowdown in the Chinese economy and the rapid growth of the petrochemical sector in multiple Asian countries.

A vacuum left by ongoing sanctions against Iran and fully integrated industrial cities at Mesaieed and Ras Laffan have enabled the petrochemical sector to remain strong. Despite the Qatari government imposing a cap of 49% on foreign ownership, many large oil and gas companies continue to invest in the country's hydrocarbons industries.

However, cracker capacity has outstripped gas production and the government has responded by suspending work on new projects until 2014 so sustainable rates of gas production can be ascertained.

Despite this setback, a new carbon dioxide recovery plant is being built by Qatar Fuel Additives Company in Mesaieed Industrial City and it is expected to be operational by 2014. Qatar National Bank Group has financed the project with a corporate loan agreement for \$80 million. Qatar Fertiliser Company, meanwhile, has built another ammonia and urea plant.

Additionally, Qatar Petrochemicals and Shell are building a petrochemical complex in Qatar; and Qatar Petroleum has joined forces with Qatar Petrochemical Company to develop a mega-petrochemical complex in Ras Laffan.

Safety and efficiency improvements are a priority for upstream and downstream sectors of the Qatari oil and gas industry with Qatar Chemical Company, Qatar Petrochemical Company, RasGas and Dolphin Energy all winning Qatar oil and Gas Industry Safety, Excellence and Innovation Awards.

Saudi Arabia

Saudi Arabia's rich oil and gas resources mean the kingdom is well placed to develop a robust petrochemical sector. The government is seeking to diversify and focus on the production of high-performance and speciality-grade petrochemicals with \$150 billion worth of investment between government, companies and joint ventures.

Ethylene and propylene capacities are increasing, largely thanks to the expanding operations of Saudi Kayan Petrochemical Company. Saudi Kayan's Jubail plant is one of the largest in the world.

Diversification will continue to be important to the Saudi petrochemical sector, especially after profits were down among producers in 2012. This was largely attributed to product prices dropping and softening demand from Asia, especially in regard to growth in China and India.

An example of diversifying the sector is the Chevron Phillips Chemical Saudi Arabian joint venture petrochemicals complex at Jubail, which was completed in 2011. The complex was built by



Saudi Polymers Company with the National Petrochemicals Company (Petrochem) and it produces ethylene, propylene, polyethylene, hexane-1 and polystyrene.

Another major player, Saipem (based in Italy), have signed a contract for the expansion of naphtha and aromatics production at the integrated refinery and petrochemicals complex in the city of Rabigh, located north of Jeddah on Saudi Arabia's west coast. The work includes the engineering, procurement and construction of two processing units and it is expected to be completed by the end of 2015.

Sadara Chemical Company, a joint venture between Saudi Aramco and Dow, is increasing monomer capacity with a mixed-feed cracker and aims to produce value-added chemical products and performance plastics. All units are scheduled to be operational by 2016.

United Arab Emirates

Like Saudi Arabia, the petrochemical sector in the United Arab Emirates is exposed to the risk of losing market share to the booming Chinese economy, with China's petrochemical capacity increasing. The UAE will be looking to other markets, such as India – its growing consumption of petrochemicals should offer the UAE a long-term source of export demand.

Expansion is underway in the UAE petrochemical sector, most notably with Borouge – the Borouge 3 project is a significant expansion of the Ruwais plant in the emirate of Abu Dhabi. This is due to be completed by mid-2014. Borouge produces ethylene, polyethylene and polypropylene. Also in Ruwais, Takreer, is expanding its naphtha production which will help with feedstock self-sufficiency for the UAE.

The Tacaamol aromatics project, a joint venture between Abu Dhabi Chemical Company (Chemaweyat) and International Petroleum Investment Company (IPIC) is due onstream in 2016. It is a \$10



Saudi Aramco and Sumitomo Chemical joint venture Petro Rabigh, an integrated oil refinery and petrochemical complex.

billion, three-phase project in Al Gharbia, in the western region of the UAE. As well as production facilities, the project will include export storage tanks, a jetty and loading berths.

Foreign investment is also boosting the UAE petrochemical sector. In 2011, German petrochemical giant Lanxess founded a dedicated company for the Middle East with its headquarters in Dubai. The main products Lanxess supplies to Middle Eastern customers are speciality chemicals, colour pigments for the construction industry and high-end plastics and synthetic rubbers. While a narrow product range and lack of downstream



Part of the current Borouge plant in Ruwais, Abu Dhabi. Capacity will be greatly increased in 2014.





diversification has limited the UAE's petrochemical potential in the past, the expansion projects and foreign investment will boost capabilities and make the sector more competitive in the medium term.

Iran

Despite trade sanctions, Iran has developed a healthy petrochemical sector with solid foreign investment and three petrochemical projects opening in 2012 alone. By expanding range and volume, and investing in research and development, the Iranian petrochemical sector is working towards self-sufficiency for the domestic market.

Foreign companies invested \$1.3 billion in the Iranian petrochemical industry between 2007 and 2012, accounting for 5% of the country's total foreign investment. By 2015, Iran is aiming to implement 47 petrochemical projects, adding 43 million tpa to its capacity, which is currently at 55 million tpa. If all these projects come online, Iran will represent at least 5.3% of global petrochemical output and 36% of Middle Eastern production.

Local companies have also formed partnerships outside of Iran. Petrochemical Commercial Company is one such example – it is a major supplier of Iranian petrochemicals to international markets and has affiliates in Britain, Singapore, China, South Korea, India and Turkey.

The government-owned National Iranian Petrochemical Company, which started with a fertiliser plant in 1964, has become the Middle East's second largest producer and exporter of petrochemicals.

Asia

While Japan has long been a powerhouse for the petrochemical sector in the Asian region, China and India have both experienced rapid growth. Other countries in Asia are also experiencing growth in the petrochemicals sector even in sometimes challenging economic and political conditions.

China

The emerging petrochemical markets of Asia, especially China and India, are growing and are set to continue to do so, along with population growth and a rising middle class.

Petrochemicals have certainly benefited from China's booming economy. Demand and production of petrochemicals have grown at double-digit rates during this century. While China is lacking in traditional feedstocks, the industry makes up for this disadvantage with low labour costs and proximity to emerging markets.

Because of the lack of domestic crude oil and natural gas production for feedstocks, China has become a pioneer in using coal to produce chemicals. Coal makes up 96% of China's total fossil resources – the technologies China is using to exploit this vast coal resource are not necessarily new but China has been placed in a unique position to develop them, whereas the technologies have been superseded by those based on oil or gas in other markets. This use of coal, along with cheap labour and a large population, has led to China having the world's largest chemical industry and consumer market for chemicals.

Joint ventures are also proving to be a popular way to maintain a healthy petrochemical sector in China. Shenhua Group, China's largest coal producer is involved in a 50:50 joint venture with General Electric to form GE Shenhua Gasification Technology Company. This company aims to generate electricity from gasified coal and produce raw materials for the petrochemicals sector.

Zhong Tian He Chuang Energy Company is a joint venture between China Petroleum and Chemical Corporation (Sinopec), China's largest producer and supplier of petrochemical products, and China Coal Group. This joint venture involves plans to build a polypropylene plant in Ordos, Inner Mongolia, with technology licenced from Ineos. The 350,000 tpa plant will produce products to serve China's domestic market.



ExxonMobil partnered with Sinopec, Fujian Province and Saudi Aramco to develop China's first integrated refining and petrochemical facility with foreign participation.

The export market is essential to Sinopec's ongoing growth with more than 150 end-user and distributor companies in more than 100 countries. Major end-users of Sinopec's petrochemical products include DuPont, Proctor & Gamble and Michelin. Its main export products include petroleum coke, paraffin wax, base oil, PET, PVC, soda ash, caustic soda and fertiliser. Sinopec is also involved in a joint venture in Guangdong with Kuwait Petroleum Corporation. This is worth \$9.3 billion and includes a refinery and ethylene plant with a capacity of 1 million tpa. It is expected to come online in 2015.

Numerous US companies have expanded into the Chinese petrochemical market. Air Products has opened a specialist amines plant in Nanjing to complement existing petrochemical development. ExxonMobil is expanding petrochemical operations in China and India, supplying these markets from its global network, including manufacturing facilities in Singapore. Eastman Chemical Company, through its acquisition of Genovique Specialities Corporation, a worldwide producer of specialist chemical products, has acquired a joint venture operation in Wuhan, China with Wuhan Youji. The plant opened in 2007 and it produces Benzoflex, a plasticiser.

China National Petroleum Corporation (CNPC) has a joint venture with Venezuela's Petroleos de

Venezuela in which an integrated refinery plant is being built in Guangdong. CNPC will have a 60% stake and Petroleos de Venezuela will have a 40% stake in the \$9.4 billion project which is expected to open in late 2014.

China's twelfth Five-Year Plan includes new environmental laws to help ensure industries, including petrochemicals, are more sustainable. Under the latest plan, China is evolving its regulatory regime so that industries that are heavy energy users are encouraged to adopt more eco-friendly policies. Stricter controls on proliferating petrochemicals plants have been introduced since 2011 to try and address environmental concerns.

India

Along with China, India is Asia's other growing economic powerhouse. With a population that has already exceeded one billion and set to approach that of China by 2025, the market is enormous. Add to this the growing middle class, with more than 63 million households expected to have an annual income greater than \$6,500 by 2015 and the demand for consumer goods is high, including petrochemical-derived products.

Overall, India's chemical industry is very strong with an estimated \$91 billion of sales in 2011, projected to reach \$134 billion by 2015. The





petrochemical sector is currently valued at around \$40 billion, is expected to grow annually at a rate of 12-15% and employs around one million people.

There are numerous factors which will drive growth in India's petrochemical sector, including large, unexplored reserves of oil and gas and low-cost infrastructure. Indian per capita consumption of polymers is still relatively low but it will increase as the population, labour force, and the middle class grows with it. As long as the sector continues to attract a combination of government, local corporate and foreign investment, this will also drive growth. The Indian government is establishing new petroleum, chemical and petrochemical investment regions in states such as Tamil Nadu and Karnataka.

BASF India is increasing its presence with a \$195.6 million investment in a new chemical production site in western India.

There are challenges ahead for India's petrochemical sector and these must also be addressed to maintain competitiveness, stay cost-effective and continue to attract investment. Procuring raw materials and feedstock from oil- and gas-rich countries needs to be managed efficiently. There is also a growing need for more investment in research and development, new technologies and environmentally friendly initiatives. India's trade and logistics infrastructure will also require more development to cope with the demands of both the domestic and export market.

Japan

The Japanese petrochemical sector has long been an important part of the country's economy but in recent years, changes have been made to cope with increased competition from emerging markets. The March 2011 earthquake and tsunami also had an impact on the petrochemical sector. As a result of this, many locally produced petrochemicals have been used in the reconstruction work in affected areas, such as Fukushima, while

supply of consumer and automotive products was disrupted.

Despite this, Japan has plenty of capacity to meet domestic requirements. The sector continues to grow each year, although growth for 2013 is projected to be 1.2%, compared with 1.5% in 2011. Looking ahead, Japanese petrochemical producers will continue to be challenged by the appreciation of the yen, as well as competition from the Middle East and other Asian countries, and continuously high feedstock prices. In the wake of this, some Japanese petrochemical producers are expected to restructure their operations or even close down some plants.

To overcome these issues, many Japanese companies are also turning their attention to production activities in emerging markets, including China, Saudi Arabia, Singapore and Thailand. These companies include Sumitomo Chemical, Mitsui & Co, Mitsubishi Chemicals, Asahi Kasei and Ube Industries.

Masakazu Tokura, President of Sumitomo Chemical said: "Expansion of overseas operations is necessary for the survival and the development of the petrochemical business. Japan's petrochemical industry faces various challenges, such as the transfer of user industries' production bases abroad, the yen's appreciation and a decline in cost-competitiveness due to higher electricity bills in Japan."

Sumitomo Chemical is going ahead with a joint venture with Saudi Aramco on the Rabigh Phase II project worth \$7 billion. The project will use cost-competitive ethane as part of its feedstock and existing infrastructure from Rabigh Phase I will be used.

Mitsui & Co will also be joining forces with a Saudi Arabian company. Along with a consortium of other Japanese companies, Mitsui & Co has signed a joint venture with Saudi International Petrochemical Company (Sipchem) to set up a plant to produce methanol.

Mitsubishi Chemicals operates a PTA plant in China's Ningbo province and Asahi Kasei is expanding its South Korean operations.





In other parts of Asia, there are also exciting times and new challenges ahead for the petrochemical sector.

Malaysia

Malaysia has evolved since the 1970s from a producer of raw materials to a multi-sector economy and petrochemicals has an important role to play in this mix. Petroleum and its related products make up 10.1% of the economy. A wide range of petrochemicals are produced in Malaysia, including polystyrene, olefins, vinyl chloride monomer and polyvinyl chloride. Investments in the sector are estimated at \$9.28 billion and there are 29 petrochemical plants across Malaysia making 39 types of products. Petronas is the main domestic petrochemical investor. Major international players in the petrochemical industry have a presence in Malaysia, indicating it is a healthy part of the country's economy. These companies include Dow Chemical, BP, Shell, BASF, Eastman Chemicals, Mitsubishi and Lotte Chemical Corp.

The US is the largest source of petrochemical investment for Malaysia, followed by Japan, the United Kingdom, Germany and Taiwan. Partnerships have also been forged with other ASEAN members, including Vietnam, Indonesia and the Malaysia-Thailand Joint Development Area (JDA) for the supply of gas.

The Malaysian petrochemical sector has grown rapidly thanks to abundant oil and gas as feedstock, good infrastructure, cost competitiveness and Malaysia's strategic location with close proximity to other Asian markets. Six gas processing plants in Kertih and Terengganu supply a large proportion of feedstocks while the Peninsular Gas Utilisation (PGU) gas transmission pipeline ensures gas is transported to industries around the country. Kertih is also home to the Petronas Petrochemical Integrated Complex. This links the whole oil and gas value chain, starting with upstream exploration to the final stage of the



The Shell Eastern Petrochemicals Complex on Bukom Island, Singapore.

manufacturing process. The government has also introduced incentives, such as reducing corporate tax to 25% to local- and foreign-owned companies, as well as further tax breaks for new companies.

Malaysia has also introduced the Industrial Master Plan 3 (IMP3) to maintain its competitiveness for manufacturing and services activities. In relation to petrochemicals, the main strategies of the IMP3 include expanding existing capacities, broadening the range of petrochemicals produced, intensified research and development, making feedstock available at competitive prices and improving links with downstream industries, especially plastics. There are also plans to further integrate the petrochemical zones in Kertih, Terengganu, Gebeng, Pahang and Johor, as well as establishing new petrochemical zones in Bintulu, Sarawak, Gurin, Kedah, Tanjung, Pelepas, Johor and Labuan. BASF and Petronas are in an agreement to develop a refinery and petrochemical integrated development (RAPID) complex in Johor.

Mongolia

Mongolia's abundant coal reserves – the world's third largest at more than 150 billion tons – have





led to the early stages of developing a coal-based petrochemicals sector. Coal is already the main source of fuel for the north-west Asian nation and growing local demand for ammonia-based fertilisers and methanol as a feedstock means that investment in coal-based petrochemical production is crucial.

The Mongolian Government's coal policy, according to the Ministry of Fuel and Energy, aims to "provide national security and sustainable development of Mongolia by introducing economic and environmentally friendly clean coal technology and production such as coal liquefaction, coal gasification and coal-chemical industry development." This includes the limiting of fossil fuel imports so that the abundant local coal deposits can be fully utilised, developing transport infrastructure, learning about petrochemical technology from Chinese projects and attracting more foreign investment.

In April 2012, the Mongolian government signed a Memorandum of Understanding with German company ThyssenKrupp to develop a \$2.1 billion coal-to-liquids plant. Prophecy Coal Corporation, a Canadian company, also has significant investment in Mongolia's nascent coal-to-chemicals industry with projects underway in Ulaan Ovoo and Tugalgatai.

Taiwan

Ongoing increases in demand and rising prices of petrochemical products have contributed to solid growth in the Taiwanese petrochemical sector in recent years. At the end of 2011, Taiwan's petrochemical output was at a record-breaking \$65.2 billion, despite challenges faced in the wake of deflation in China, the US debt crisis, weakened global demand, expansion in the Chinese and Middle Eastern petrochemical sectors, and local occupational accidents.

The sector has remained robust even after a major project was aborted in 2011. The Kuo Kuang

petrochemical investment was called off by the central government due to environmental concerns and a negative public response. It was slated to include a refinery, naphtha cracker, aromatic hydrocarbons centre, lower-stream plants and industrial harbour facilities. To offset the possible losses from cancelling this project and to keep the local petrochemical sector competitive, the Taiwanese authorities have announced plans to add value to the sector. The plans include increased spending on research and development, such as centres for the pilot production of new materials.

South Korea

The South Korean petrochemical sector largely serves the automotive and electronics industries. There has been a drop in demand for such products following slowdowns in Asian and European markets, but multiple companies are increasing investment and expanding in South Korea. Aromatics are a particular area of expansion with xylenes capacity set to exceed 10 million tonnes per annum by 2014.

Three companies have major expansion plans for their sites in Yeosu. Lotte Chemical Corp is expanding production capacity for ethylene and propylene at its complex. Kumho Petrochemical is building new Yeosu facilities scheduled to open in 2014. These new facilities will produce styrene butadiene rubber, bisphenol-A, ethylene propylene diene monomer (EPDM) rubber and methylene dipara-phenylene isocyanate (MDI). BASF is also increasing MDI capacity at Yeosu, as well as a new polyethylene terephthalate (PET) facility at Jincheon. Increased PET production can be used to meet demand from China.

Such expansion plans aim to overcome the challenges of chronic overcapacity, low operating rates, and squeezed margins caused by rising crude prices on naphtha, all of which have affected the South Korean petrochemical sector.

A number of South Korean companies have signed up to a global campaign designed to improve the safety and management of chemical products, including petrochemicals. The signing companies include Hanwha Chemical Company, Lotte Chemical Corp, LG, Kumho Petrochemical Company and Samsung Petrochemicals Company.

The Philippines

In the Philippines, there have been mixed fortunes in the chemical industry overall with the value of chemical production increasing just 0.5% in 2012. However, the value of plastics production rose by 11% in the same year. Overall output for the chemical industry was at just 0.6% in 2012 but plastics was up by 7% and rubber by 5.5%.

Adding to the mixed fortunes in the Philippines is a declining automotive sector, which has happened as a result of rising production costs, more competitive regional rivals and a relatively small domestic market. This has hit demand for engineering plastics and rubber. However, PVC consumption is on the increase, thanks largely to a growing construction sector.

Trade liberalisation has increased competition for the Philippines with foreign resins producers and this may negatively impact on the petrochemical sector. However, there are developments that might prove helpful in a challenging commercial environment. In Batangas, JG Summit Holdings is building the country's first naphtha cracker plant and polyethylene facility. Petron, meanwhile, is upgrading its Bataan refinery to include a fluid catalytic cracker.

Indonesia

Indonesia's petrochemical sector also faces challenges and opportunities in the years to come. There are plans for expanding the country's growing polymer resins sector but declining oil production and a constrained refining base may undermine future feedstock supplies. Despite this, growth is

projected as new projects continue to be developed.

The West Java-based Chandra Asri petrochemical joint venture is expanding to increase ethylene and polyethylene production capacity and add a butadiene extraction facility. Indorama Ventures, a Thailand-based company, is developing a plant in Indonesia to make polyester chips and speciality synthetic yarns, coming onstream in 2013. This is part of the company's bid to become a leading vertically integrated polyester value chain producer.

PVC producer Asahimas Chemical has increased production at its caustic soda plant in Cilegon and in the fertiliser segment, PT Pupuk Kalimantan Timur (Kaltim) is building a large-scale nitrogen fertiliser plant at Bontang, East Kalimantan. PT Pupuk Sriwidjaja is planning two urea production plants in East Java.

Saudi Aramco has signed a Memorandum of Understanding with Pertamina, the Indonesian state oil and gas company, for an integrated complex in Tuban, East Java. It will be designed to process 300,000 bpd of crude oil. No completion date has yet been scheduled. South Korean company, Lotte Chemical Corp, will invest up to \$5 billion to set up a petrochemical complex in Cilegon, Banten with completion anticipated by 2016.

Looking ahead, the Indonesian government is seeking to increase investment in the local petrochemicals sector to reduce its reliance of imported feedstock, which cost the country more than \$5 billion in 2011.

Thailand

Thailand's petrochemical industry is expanding with major players signing overseas acquisition and expansion deals, production levels increasing, and two more crackers being commissioned locally, bringing the total number of crackers in Thailand up to seven. Since the 1990s, petrochemical infrastructure construction has been taking place in the kingdom and the sector now represents 5% of



GDP. The overseas joint ventures are commonly being signed in markets where Thai companies already have a solid export sales presences.

The growth has taken place despite three major setbacks. In December 2009, a Thai court ruling ordered that dozens of construction projects on the eastern seaboard be suspended until health, safety and environmental concerns were addressed. Severe flooding struck Thailand in September 2011 and the damage caused to large industrial estates led to a three-month disruption to the supply of Thailand's domestic petrochemical market. Political instability in recent years has impacted overall confidence in investing in the country's economy but there are indications that confidence is returning, such as new joint ventures.

Natural gas feedstock accounts for more than half of Thailand's petrochemical production. Other feedstocks include imported naphtha and naphtha supplies from local refineries.

Companies including Thaioil Company and IRPC Co. of Thailand are among those expanding. Thaioil Company is upping paraxylene production and IRPC is upping styrene monomer capacity.

Singapore

New investments in production have contributed to growth in the Singaporean petrochemical sector. Development has been focused on three sites: the Shell Eastern Petrochemical Complex on Bukom, the ExxonMobil Chemical Complex and the Jurong Aromatics Complex, both on Jurong. Singapore is well located to supply China and the large refining base is another advantage, especially as competition is faced from the Middle East with large feedstock supplies. Sweden's Perstorp has also expanded capacity for hexamethylene derivatives at its Singapore manufacturing site.

The Jurong Aromatics Corporation (JAC) is due to start benzene production at the end of 2014 and this represents the biggest development for Singapore's petrochemical sector.

Vietnam

Vietnam is a new player in the Asian petrochemical marketplace but early steps are being made to add this sector to the country's growing economy. Thailand's Siam Cement Group has set up a joint venture with QPI Vietnam (a subsidiary of Qatar Petroleum International), Petrovietnam and Vinachem to build Vietnam's first petrochemical complex. Siam Cement Group's stake in the venture is 28%.

The plans for the fully integrated \$4.5 billion complex on Long Son Island in Vietnam's Ba Ria-Vung Tau province include a jetty, port, power plant and storage facilities. It is slated to have a capacity of 1.4 million tpa of olefins using ethane, propane and naphtha as feedstock. Downstream petrochemical products will be consumed by Vietnam's domestic market. It is expected to be commercially operational by 2017.

Latin America

Across the Latin American countries, there are mixed fortunes for the petrochemical sector. While there is much investment by both governments and private companies, issues such as feedstock supply continue to be problematic. While some Latin American countries have ample gas or oil resources to be, or potentially be, self-sufficient petrochemical producers, others are reliant on imports.

Brazil

Brazil, with its growing economy, has been dubbed one of the BRIC (Brazil Russia India China) nations, the four countries whose economies have become increasingly competitive – and have attracted much analysis and scrutiny as a result.

However, the Brazilian petrochemical sector has to balance potential for further growth with a slowdown in the national economy. Consumption of plastics in Brazil in 2012 is 32kg per capita, less than one-third the consumption of the US or western Europe, but an increase of 6% on the





previous year, so there is certainly room for growth. Further growth is also expected courtesy of the 2016 Olympic Games in Rio de Janeiro and the 2014 FIFA World Cup.

The fragmentation of the plastics conversion sector is a major concern. Braskem is the monopoly supplier of polymer resins – this company serves more than 11,500 converters that operate with high production costs. The naphtha-based producers are struggling to compete with cheap foreign imports – Brazil became a net importer of oil which made it more vulnerable to both foreign competition and external prices. A difficult regulatory environment and energy supply issues are also challenging the petrochemicals sector.

The good news for the Brazilian market is that the depreciation of the real against the US dollar and a rise in domestic demand should sustain increasing output. Discoveries of new oil and gas in the region have also helped, ensuring raw materials are easily available.

Comperj, a \$8.4 billion petrochemicals complex near Rio de Janeiro, is expected to be completed by Petrobras by the end of 2013.



With the discovery of vast offshore gas reserves, developments in Brazil's petrochemicals sector could be just over the horizon.

Argentina

2010 was a bumper year for the Argentinian petrochemical market with 25% growth reported. However, the sector has faced challenges since then, most notably a lack of feedstock access. The drive towards diversification has suffered because of plant closures and a prioritisation of residential fuel demands which has restricted gas allocations to downstream industries. While the chemical industry overall is very strong in Argentina, averaging annual growth of 10.5% between 2007 and 2011, the petrochemical sector has been limited by a scarcity of raw materials.

But there is some good news for the long-term future of the Argentinian petrochemical sector. A favourable economic climate (the economy is projected to grow by 6% over the next few years, stabilising at 3.5% by 2017) and government policies to reduce poverty have helped increase disposable incomes and food and beverage consumption, which also increases consumer use of plastics. As long as plastics manufacturers find ways to run their businesses efficiently, the high cost of feedstock is an issue that can be overcome.

Adding to the optimism for the country's petrochemical sector is the discovery of shale gas – this could enhance polymer production capacities. Significant investment in the Neuquen shale gas play in central-western Argentina has improved prospects. Argentine national energy company YPF (formerly Repsol YPF in conjunction with Spain's Repsol until Argentina nationalised the YPF subsidiary), has exposure to around 3 million of the 7.4 million acres of the Neuquen Basin. As a result, YPF has driven much of the initial appraisal and development work in the area. However, shale gas production is still several years away and, in the short term, Argentina will rely on imported feedstocks.

International investment may offer more opportunities for the Argentine market, such as





Pluspetrol, which is investing \$480 million in exploring and developing new natural gas reserves in Peru's largest natural gas block.

Argentinian manufacturers are also looking to develop biodegradable plastics to counter the depletion of oil and gas reserves for feedstock.

Bolivia

Bolivia's proven oil reserves of 209 million barrels, as well as a claimed 391 million barrels of probable reserves and 255 million barrels of possible reserves. The country also has South America's second-largest proven natural gas reserve at approximately 24 tcf, according to the US Geological Survey. Of this, 85% can be found in the Tarija region in south-eastern Bolivia.

More than half of Bolivia's oil production is driven by two fields – Sábalo (37%) and San Alberto (21%) – and significant operators include Petrobras's Bolivian subsidiary, and YPFB Chaco and YPFB Andina, which are both subsidiaries of the national oil company. The state-owned YPFB Transporte controls most of the country's petroleum transportation network with 2,500km of pipelines capable of carrying crude oil, condensate, natural gas liquids and intermediate products, and connecting centres of production such as Cochabamba, Oruro and La Paz. CLHB S.A Nacionalizada, another part of the national oil company, operates a further 1,500km of pipelines, and an international pipeline in the north connects Bolivia with Chile.

These oil and natural gas resources point to a strong future for the country's petrochemical sector. Bolivia's state oil company, YPFB, is building an ethylene and polyethylene plant in the Tarija region as part of a \$4.2 billion project to exploit natural gas output. It will be using feedstock from the nearby Gran Chaco liquids separation plant. This \$2.3 billion production plant, as well as the Gran Chaco plant, are slated to be operational as soon as 2014.

YPFB has also awarded a \$843 million contract to Samsung to build a new petrochemical fertiliser plant in Bolivia's Cochabamba province. The plant is expected to produce 650,000 tons per year of urea along with an additional ammonia unit with a planned output of 400,000 tons per year. Operations are scheduled to start in mid-2015.

EBIH, Bolivia's state hydrocarbons industrialisation company has outlined \$2.46 billion worth of investments in seven petrochemicals projects from 2013-2017.

Chile

Chile's petrochemical sector has suffered because of low-cost imports, a tough regional export market and a shortfall in gas feedstock. If the country is to overcome these hurdles and rejuvenate the petrochemical sector, the biggest challenge will be addressing upstream supply constraints.

On the economic front, Chilean producers are also facing stiffer competition in the wake of free trade agreements (FTAs), resulting in US producers increasing their market share in recent years. Polymer production has never been able to meet local demand and this trend is forecast to continue.

Falling gas supplies resulted in an estimated methanol output in 2012 of around 500,000 tons. Methanex, Chile's leading methanol producer, says that just one in four of its plants is in operation, and that it is operating at 50% capacity. The company plans to move at least one of its plants out of Chile by the end of 2014, which is an indication of the negative impact low levels of competitively priced gas supplies are having on Chilean petrochemical production.

Overcoming feedstock supply issues will be critical if Chile's petrochemical sector is to recover. Currently, Chile's ethylene production relies very heavily on naphtha, which is provided by local refineries. Naphtha provides 76% of Chile's petrochemical feedstock with 16% from butane and 8% from ethane. At the end of 2011, Chile's refining

capacity stood at 226,800 b/d but a deadline for a state-backed plan to increase the total to 300,000 b/d by the end of 2008 was pushed back owing to project delays.

Energy shortages will also have to be addressed to revitalise Chile's polymer production. A lack of propylene feedstock has resulted in Petroquim failing to produce close to the 150,000 tpa capacity at its polypropylene plant and there are no plans to increase capacity in the foreseeable future.

Mexico

Mexico's petrochemical sector has potential for growth but this will hinge on a number of factors. These include: overcoming its dependence on imports, introducing less bureaucratic regulations, and more investment. The Mexican government is keen to swiftly increase capacities across the value chain through the involvement of the private sector, especially major foreign companies.

In the foreseeable future, Mexico is set to remain an importer of polymers. With the domestic market, sales of linear low-density polyethylene (LLDPE) have equalled that of low-density polyethylene (LDPE) and are set to overtake LDPE, because of LLDPE's higher tensile strength and puncture resistance. It is most likely that Mexico will have to keep importing polyolefins as LLDPE capacity is not expected to rise in line with demand.

However, the Braksem-Grupo Idesa project may help reduce the dependence on imports. This is a joint venture between Brazil's Braksem and Mexico's Grupo Idesa, and the companies have awarded a contract to Technip, a global energy project company. In October 2011, Technip started construction on Ethylene XXI, a \$1 billion plant that will produce ethylene, high-density polyethylene (HDPE) and LDPE. This plant, which will form the core of a petrochemicals complex, is slated for completion by 2015.

Negotiations have also taken place between Mexichem and Occidental Petroleum over build-

ing a \$1 billion ethylene facility. A joint venture with Mexichem and Pemex to produce vinyl chloride monomer (VCM) is also planned.

Peru

Peru's massive natural gas resources, concentrated in the Camisea gas field, mean the country has enormous potential for developing a strong petrochemical sector. These resources offer Peru the potential for at least one world scale cracker and downstream production. Peru also expects to attract around \$53 billion worth of investment in the energy and mining sectors over the next decade. The state news agency, Andina, has reported that investment will be divided between 47 projects, 27 of which are under exploration, 11 of which have environmental impact studies approved, eight of which involve expanding existing projects and one which is still waiting for environmental impact approval. If these oil and gas resources can be exploited via all these projects, Peru would be placed at a distinct competitive advantage compared to many of its neighbours, which rely heavily on imported feedstock.

But the sector is still in its infancy because of a lack of infrastructure and environmental approval for expanding gas production. There is no capacity at present for production of basic petrochemicals, such as ethylene, propylene or polymers. Currently, the investment focus is on LNG exports and fertiliser production. Output is currently insufficient to meet domestic requirements in addition to the feedstock needs of a major petrochemicals facility. As such, it is unlikely that Peru will see olefins and polyolefins capacity coming onstream in the short- to medium term.

A joint venture between PetroPeru, Brazil's Petrobras and Braskem remains at the MoU stage. The plan is to create a facility to produce polyethylene, but the project has been pushed back to 2016 as the investors wait for increased gas supplies to make it viable.

Improve Refinery Profit Using Innovative FCC Cracking Catalysts

by Carl Keeley, V. Komvokis and V. Vergopoulos

"To improve refinery profit, innovative Fluidised-bed Catalytic Cracking Catalysts are needed for all feedstock types and all operating objectives. Our FCC portfolio addresses this need."

BASF – The Chemical Company, we supply chemicals to almost all industries; we combined economic success, social responsibility and environmental protection; In 2012, BASF filed for around 1,170 new patents worldwide; our commitment to innovation enables us to continually provide improved products and solutions to all our customers.

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To improve refinery profit, innovative Fluidised-bed Catalytic Cracking Catalysts are needed for all feedstock types and all operating objectives. Our FCC portfolio addresses this need. We have developed unique FCC Catalyst Platforms¹ to upgrade all feedstock types to distillate and naphtha. Our Maximum Olefin Additive and Maximum Propylene Solution convert naphtha olefins to propylene. Using, for example, our award-winning Distributed Matrix Structures platform with over 150 commercial successes and growing, we have improved selectivity to valuable products with a high

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We invite you to contact us to discover how we can help improve your refinery profitability using innovative FCC Cracking Catalysts and Solutions.

¹ BASF's unique FCC Catalyst Platforms include DMS (Distributed Matrix Structures), Prox-SMZ (Proximal Stable Matrix and Zeolite) and MSRC (Multi Stage Reaction Catalysts).

² A.S. Shackelford et al. Rare Earth Alternative – The Use of Phinesse™ FCC Catalyst at Shell Sarnia, AM-13-02.

³ Y.-J. Jollion et al. Use an innovative cracking catalyst to upgrade residue feedstock, Hydrocarbon Processing Feb 2013.

⁴ V. Vergopoulos, Profit Improvement in FCC Units using Innovative Cracking Catalysts, Middle East Downstream Week 2013, 12-15 May 2013.

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BASF

The Chemical Company



The Future of the petrochemical industry

By Peter Reineck

Continuing innovations are essential to meet increasing global demand.

When considering the current and future importance of petrochemicals and their use of oil reserves, remember they consume only about 8% of the world's oil production versus 92% for fuels. Today, most petrochemical feedstocks are made by upgrading refinery streams made when producing fuels.

Compared to fuels, petrochemicals are a specificity which provides the highest value end-use for oil. They are used in durable applications such as plastics which act as a carbon sink, whereas burning fossil fuels releases carbon dioxide (CO₂, a greenhouse gas) into the atmosphere. Petrochemicals are more sustainable than fuels, and are the preferred end-use for oil.

The chemical industry, including petrochemicals, is central to the pursuit of a sustainable society. Without it, the prospects of sustainably meeting the needs of a growing global population are zero, as construction materials, transportation and telecommunications equipment, clothing and crop fertilisers all depend on chemicals. Talk of 'natural' products which are chemical-free is dishonest, as everything in nature is composed of chemicals.

Petrochemicals are part of the solution and the sector has a bright future. However, the industry faces questions about its reputation and the sustainability of petrochemicals, based on environmental and political considerations related to the supply chain and use of plastics. Unless the industry addresses these concerns, demand may be dampeden.

Specialised plastics made from petrochemicals are used to produce products for essential industries such as healthcare. Public concerns about dwindling petroleum resources have led to speculation about the future supply of such critical products. However, because only a tiny proportion of petrochemicals is used to produce these high value products, the supply chain for oil-based products for healthcare is secure.

It is important to review the impact of market trends and regulation on future demand for petrochemicals and on the supply chain for feedstocks – and the expected changes in feedstock processing and products. It is also essential to examine how long fossil fuels can last, what are the alternatives to petrochemicals, and how the industry can be made more sustainable.

Impact of markets and regulation on future demand

Total production of plastics worldwide in 2009 was 265 million tons (Mt), of which almost 50 Mt was consumed in Europe. By far, the largest application is packaging (38%), followed by a total of 34% used in construction, automotive and electrical & electronics.

Plastics demand is growing with global GDP growth. Packaging demand is growing at above GDP rates as consumers in developing countries increasingly shop at supermarkets instead of markets, and consumers in developed countries buy more convenience foods. In each case, more packaging is required.

Total demand for oil-based plastics and fuels is increasing, but fossil reserves are finite. Disrup-



tions in the supply chain affect the competitive position of petrochemicals relative to alternatives and petrochemicals have a large carbon footprint. There's a need to future-proof the supply chain.

Consumer awareness and government concerns put pressure on brand owners and retailers to replace plastics, in packaging and in other durables. Manufacturers are securing the supply chain, and the EU is following the USA by incentivising the adoption of bio-based products as an alternative for oil-based plastics. Bio-based plastics are produced from plant matter, also known as bio-resources.

Industry estimates call for 10% of bio-based plastics in the EU supply chain by 2025. On this basis, and assuming total plastics demand grows at 2.5% pa to 7 Mt, it is projected that 7 Mt of bio-based plastics will be consumed in the EU market in 2025, of which almost half is expected to be bio-polyethylene (bio-PE).

Despite the rapid growth rate of bio-based plastics, plastics based on oil are projected to grow twice as much in absolute terms. As such, there will be a need for new production capacity for petrochemicals and a need to introduce bio-based feedstocks into the supply chain.

Plastics uses in Europe (2009).

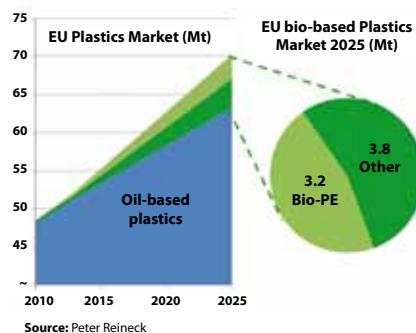


Figure 1.

In terms of volume, PE is the largest plastic, followed by polypropylene (PP) and polyethylene terephthalate (PET). PE is a commodity plastic which is used in a wide variety of applications and is growing at GDP rates. But PP has been growing faster than GDP as it is used in more sophisticated developing markets, as has PET, which is used in packaging. Different growth rates are reflected in the demand for feedstocks. The top three in demand are: ethylene, propylene and paraxylene (used to make PET).

Projected breakdown of the European plastics market to 2025.

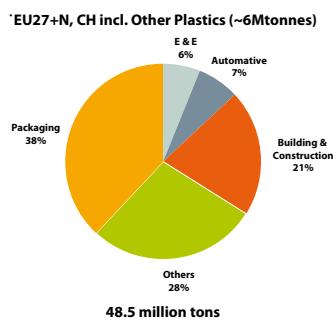


Figure 2.

The future petrochemical feedstocks supply chain

In the second half of the 20th century, oil replaced coal as the source of feedstocks for petrochemical-derived products. These feedstocks are refinery streams which are co-products or by-products of refining oil. The refinery streams are upgraded to produce ethylene, propylene, butadiene, benzene and paraxylene. When ethylene is produced from refinery streams such as naphtha in a steam cracker, propylene is produced at the same time.

Many petrochemical plants are integrated with refineries to add value to refinery streams through conversion to petrochemicals. The price of petrochemicals relative to crude oil is higher than



for fuels, and regulations limit the amount of benzene and other materials that can be blended into gasoline.

Natural Gas Liquids (NGL), a by-product of processing 'wet' natural gas, were first used in the USA in the 1970s as a low-cost feedstock for ethylene. Plants were also built in Western Canada and the Middle East to utilise locally available NGLs but steam cracking NGLs produces no propylene, only ethylene.

In the past few years, there has been a surge in production of unconventional gas. In North America, the abundant supply of shale gas has caused a drop in the market price of gas, which has driven producers to seek customers for NGL. As a result, a number of new ethylene plants to refine shale gas NGL are under construction.

The proportion of ethylene produced from NGL is expected to increase slightly as these new ethylene plants come on stream. These new plants will produce no propylene, and some naphtha crackers now producing propylene may not be able to compete. Since propylene demand is projected to continue to grow faster than ethylene, this will lead to continuing tightness in the propylene market and the need for new propylene capacity.

Propylene demand is an important driver for the increase in the number of methanol-to-olefins (MTO) plants, for which the feedstock is syngas from gasification. Most of these plants are in China and based on coal gasification, but we can expect to see new gasification plants in Europe. The EU plants will be based on biomass, or wood or food waste.

Gasification of biomass and bio-waste is one way in which plastics and petrochemicals producers are expected to future-proof the supply chain and reduce dependency on fossil fuels. Another strategy is fermentation of plant materials to produce ethanol which is then converted to bio-ethylene. Braskem in Brazil is already producing bio-PE by this route.

Other bio-based intermediates now close to commercialisation enable the production of rubber, paints and coatings, adhesives, insulation materials, detergents, solvents and fibres which are wholly or partly bio-based. Several bio-based plastics are already in the market, the largest being polylactic acid (PLA) which is expected to replace oil-based plastics in more than 10% of packaging applications within 15 years.

Future trends

The use of petrochemicals will continue to grow at or above GDP rates. The only alternatives to petrochemicals are chemicals which are identical or functionally similar, produced from other fossil fuels or plant matter. The big trends relate to changes in feedstock, processing and products which are expected to result from making the industry more sustainable.

To date, predictions of 'peak oil' were wrong. However, 'peak cheap oil' occurred at the time of the invasion of Iraq and we are now in an era of 'hard to get oil'. According to the BP Statistical Review of World Energy, June 2012, world crude oil consumption increased by about 1.6% pa since 1986, which is well below growth in global GDP. But in recent years, all net growth came from emerging economies in Asia, South and Central America, and the Middle East, offsetting declines in Europe and North America.

Nobody knows how long fossil fuels can last, but concerns about carbon footprint and the potential for disruptions in the oil supply chain are leading to future-proofing strategies for the supply chain by reducing oil dependence. The most important trend is the growing use of feedstocks derived from bio-resources and from shale gas and coal.

Another trend is more sustainable processes for producing petrochemicals, such as using novel catalysts to reduce energy requirements and carbon footprint. Another approach is "green chemi-



stry", a philosophy of chemical research and engineering focussed on products and processes that minimise the use and generation of hazardous substances.

Gasification enables more efficient conversion of fossil and bio resources into energy and petrochemicals, and facilitates carbon capture and storage to reduce or eliminate CO₂ emissions.

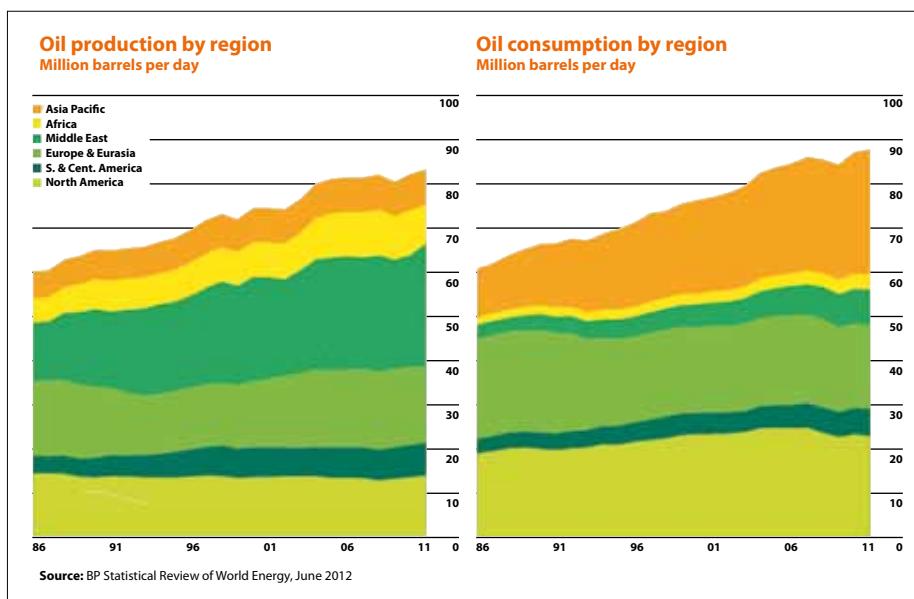
Finally, the market is starting to see new bio-based products that are as cost-effective as oil-based products. This was not the case for the first generation of bio-based plastics, which were often inferior to oil-based plastics, and more costly. Typically, they were sold as 'green' products that could be composted after use, which might not be useful for durable products, such as phone casings.

In future, most plastics will still be based on oil, but bio-based plastics will steadily gain market share. The most attractive applications for bio-based plastics will be those in which recycling is not feasible, such as film packaging which is often

printed and metallised, ready-meal trays which are contaminated with food residues, and automobile trim which is made from multiple materials. For these products, the best end-of-life option is energy recovery. When bio-based content becomes much more valuable than a petro-derived product, the energy recovered is renewable – unlike the petro-derived materials, as there is no net gain of CO₂.

In the 21st century, petrochemicals will continue to play an irreplaceable role. If the industry can satisfy stakeholders' concerns about the sustainability of the supply chain and end-of-life disposal of plastics, its reputation can improve to the point where society looks to the chemical industry for answers to the major challenges of sustainable development.

Peter Reineck provides consultancy services for chemical industry clients. He also founded Nuplas Limited www.nuplas.eu to produce PLA.



Figures 3 and 4.

Petrochemicals glossary of terms

Acetylene Chemical compound with the formula C_2H_2 . It is hydrocarbon that is a colourless gas, widely used as a fuel and chemical building block.

Acetyl A functional group with the formula CH_3CO

Acrylic fibres Fibres where the major raw material is acrylonitrile, a derivative of propylene.

Aliphatic Hydrocarbons characterised by a straight or branched chain. They do not have a ring structure. The simplest aliphatic is methane.

Alkane Any of a group of hydrocarbons that have carbon atoms in changes linked by single bonds. They can be gaseous, liquid or solid and have the general chemical formula C_nH_{2n+2} . Alkanes occur naturally in petroleum and natural gas. They include methane, propane and butane. See also, paraffin.

Ammonia A pungent, colourless gas with the formula NH_3 , often used to manufacture fertilisers and a range of nitrogen-containing organic and inorganic chemicals.

Aromatics Primary petrochemicals which include benzene, toluene and xylenes. Aromatics are very stable and have multiple double bonds and a six-carbon ring structure.

Asphalt A brown-black solid or semi-solid mixture of bitumens which are commonly used in roofing, paving and waterproofing. Derived from either native deposits or as a petroleum by-product.

Benzene (C_6H_6) A colourless, volatile, flammable liquid used as a base structure to which different atoms and molecular structures can be attached. Common uses include medicine, crop protection

chemicals and as a solvent and component in automotive fuels.

BTX A collective abbreviation for benzene, toluene and xylenes.

Butadeine A colourless, flammable hydrocarbon obtained from petroleum with the chemical formula, C_4H_6 . Often used to make synthetic rubber.

Butane Either of two isomers of a gaseous hydrocarbon with the chemical formula C_4H_{10} . It is produced synthetically from petroleum. Its uses include household fuel, as a refrigerant, aerosol propellant and in the manufacture of synthetic rubber.

Butylene A colourless, flammable, liquid gas with a detectable odour. Butylenes have a chemical formula of C_4H_8 and are formed during the cracking of petroleum fractions. Butylene is used in the production of high-octane gasoline, butyl alcohols and synthetic rubber.

Catalytic conversion The catalytic (or relating to a catalyst) oxidation of carbon monoxide and hydrocarbons, especially in automotive exhaust gas to carbon dioxide and water.

Catalytic reforming Catalytic reforming is the chemical process which is used to convert low-octane petroleum refinery naphthas into high-octane liquid products. These products are called reformates and they are components of high-octane petrol.

Coking The process of deriving petroleum coke, a carbonaceous solid, from petroleum using oil refinery coker units or other cracking processes.

Cracking The breaking down of large molecules as part of the refining process.

Cyclisation See dehydrogenation, catalytic reforming.

Dehydrogenation Any process that involves the removal of hydrogen. Frequently used in catalytic reforming processes to convert non-aromatic hydrocarbons to aromatic. Cyclisation – the formation of one or more rings in a hydrocarbon – is also part of the catalytic reforming process.

See also, catalytic reforming.

Derivative products Petrochemical derivative products which can be made in a number of different ways: via intermediates which still contain only carbon and hydrogen; through intermediates that incorporate chlorine, nitrogen or oxygen in the finished derivative. Some derivatives are finished products while further steps are required for others to arrive at the desired composition.

Detergent A cleansing agent, especially a surface-active chemical such as an alkyl sulphonate.

Distillation A method of physically separating mixtures in a boiling liquid mixture.

Dye Substance, either natural or chemical, used to colour materials.

Elastomer A material that can resume its original shape when a deforming force is removed, such as natural or synthetic rubber.

Ethane A colourless, odourless flammable gaseous alkane with the formula, C_2H_6 . It is used as a fuel and also in the manufacture of organic chemicals.

Ethylene A colourless, flammable gas containing only two carbons that are double-bonded to one another. It is an olefin that is used extensively in chemical synthesis and to make many different plastics, such as plastic used for water bottles.

Feedstock The raw material that is needed for some industrial processes. In relation to petrochemicals, feedstocks derived from petroleum are mainly used for the manufacture of chemicals, synthetic rubber and a variety of plastics.

Fraction A component of a mixture that has been separated by a fractional process, such as fractional distillation.

Fractional distillation The process of separating the different parts of a liquid mixture by heating it and separately condensing the parts according to their boiling points.

Hydrocarbon A broad term that refers to organic chemicals that are characterised by

various carbon and hydrogen molecular structures.

Hydrorefining A refining process for treating petroleum in the presence of catalysts and substantial quantities of hydrogen. The process includes desulphurisation and the removal of substances that deactivate catalysts (such as nitrogen compounds). The process is used in the conversion of olefins to paraffins to reduce gum formation in gasoline and in other processes to upgrade the quality of a fraction.

Hydrogen A flammable, colourless gas with the chemical symbol H and H_2 as a molecule of gas. It is the lightest and most abundant element in the universe. As petrochemicals are produced from hydrogen-containing hydrocarbons, hydrogen is involved in nearly all petrochemical processes. The most common application of hydrogen is as a reducing agent in catalytic hydrogenation and hydrorefining.

Inorganic The class of chemicals that does not contain carbons and hydrogens bound together like those in organic compounds. These typically exist as salts, acids and alkaline, as well as some gases and elemental compounds. An inorganic petrochemical is one that does not contain carbon atoms, ammonia being the most common.

Intermediates Petrochemical intermediates are generally produced by chemical conversion of primary petrochemicals to form more complicated derivative products. Common petrochemical intermediate products include vinyl acetate for paint, paper and textile coatings, vinyl chloride for polyvinyl chloride (PVC) resin manufacturing, ethylene glycol for polyester textile fibres and styrene which is used in rubber and plastic manufacturing.

Isobutylene A four-carbon branched olefin, one of the four isomers of butane, with the chemical formula C_4H_8 .

Isomer Any of two or more substances that are composed of the same elements in the same proportions but have differing properties because of differences in how the atoms are arranged.



Isomerisation The conversion of a compound into an isomer of itself. Different processes can be used to achieve isomerisation. For example, in petroleum refining, there are two processes commonly used: a process that uses an aluminium chloride catalyst plus hydrogen chloride; and a process where feedstock is mixed with organic chloride and recycled hydrogen, heated and transferred to a reactor.

Methane A colourless, odourless flammable gas with the chemical formula CH₄. It is the simplest alkane and the main constituent of natural gas.

Methanol A colourless, volatile, poisonous liquid compound with the chemical formula CH₃OH. It is commonly used as a solvent and a fuel. Also known as methyl alcohol or wood alcohol.

Mineral oil See petroleum oil.

Monomer A molecule that can combine with other molecules of the same kind to form a polymer.

Naphtha The collective name for any of the highly volatile flammable liquid mixtures of hydrocarbons which are distilled from petroleum, coal tar and natural gas. Naphtha mixtures are commonly used as solvents, fuel and to make various chemicals.

Natural gas A fossil fuel. Natural gas is a mixture of naturally occurring hydrocarbon gases and it is primarily used a fuel and for making organic compounds. Deposits are found beneath the Earth's surface. Methane is the primary component of natural gas but it also contains varying quantities of ethane, propane, butane and nitrogen.

Olefins Primary petrochemicals which include ethylene, propylene and butadiene. These are unsaturated molecules of carbon and hydrogen that appear as short chains of two, three or four carbons in length. Olefins are produced by steam-cracking natural gas liquids. Also known as alkenes.

Organic Chemical compounds that contain carbon atoms bonded to other carbon

atoms, hydrogen atoms or other substitutes for hydrogen, such as halogens, sulphur and nitrogen.

Paraffin An alkane in liquid or wax form. It consists mainly of alkane hydrocarbons with boiling points in the range of 150°–300°C. Used as an aircraft fuel, in domestic heaters and as a solvent. Also known as kerosene.

Petrochemicals Any substance obtained from petroleum or natural gas.

Petroleum A thick, flammable mixture of gaseous liquid and solid hydrocarbons occurring naturally beneath the Earth's surface. The origins of petroleum are believed to come from accumulated remains of fossilised plants and animals. Petroleum can be separated into fractions including natural gas, gasoline, lubricating oils, naptha, kerosene, paraffin wax and asphalt. It can also be used as raw material for a range of derivative products.

Petroleum coke Often abbreviated to "petcoke" or "pet coke", this is the carbonaceous solid derived from petroleum during a refining process.

Petroleum oil Any light hydrocarbon oil that is a distillate of petroleum. It has a wide range of uses including cosmetics, preservatives, medicines, cleaning and industrial lubrication. Also known as mineral oil.

Plastic A broad term describing any of a large number of synthetic (usually organic) materials that have a polymeric structure and can be moulded while soft and then set. In its finished state, a plastic might contain plasticiser, stabiliser, filler or pigments. See also, thermo-setting plastic and thermoplastic.

Plasticiser A substance added to plastic to make it more pliable.

Polymer A compound, either naturally occurring or synthetic, that has large molecules made up of many relatively simple repeated units (see monomer). All plastics are examples of polymers. A common example of a synthetic

polymer is Perspex. Naturally occurring polymers include DNA, tortoiseshell and cellulose in trees. Major polymer products include PVC and polystyrene (derived from ethylene) and polypropylene (derived from propylene).

Polymerisation The chemical process that combines several monomers to form a polymer or polymeric compound.

Propane A colourless gas which is found in natural gas and petroleum. Widely used as fuel. Its chemical formula is C_3H_8 .

Propylene (C_3H_6) A three-carbon, flammable gaseous molecule containing a double-bond. Propylene is an olefin frequently used in organic synthesis. It is a base chemical used to make polypropylene fibres which are commonly used in carpets and clothing.

Refinery An industrial plant where a crude substance, such as crude oil, natural gas or coal, is purified so it can then be turned into more useful products.

Reformate See Catalytic reforming and conversion.

Solvent A substance, usually liquid, which is dissolved with another substance to form a solution or is capable of dissolving another substance.

Solvent extraction A method used to separate compounds based on their relative solubilities in two different immiscible liquids, usually water and an organic solvent. Also known as "liquid-liquid extraction" and "partitioning".

Steam cracking The high-temperature cracking of petroleum hydrocarbons in the presence of steam as part of the petroleum-refining process. Steam cracking is the main industrial method used for producing olefins. Also referred to as steam-assisted thermal cracking.

Sulfur recovery The process whereby gas is desulfurised. Sulfur can be recovered from raw natural gas and by-product gases containing hydrogen sulphide derived from refining crude

oil and other industrial processes. The Claus process is the most significant gas desulfurisation process. It involves a series of high-temperature reheating processes.

Surfactant A surface-active agent, the basic cleaning agent of petrochemistry.

Synthesis gas A mixture of carbon monoxide and hydrogen. This is mainly used in chemical synthesis to make hydrocarbons.

Synthetic Produced by synthesis, not of natural origin.

Synthetic fibres Manufactured fibres, the most common of which are polyester, a combination of ethylene glycol and terephthalic acid (made from xylylene); and nylon, which has benzene as its most important raw material. See also, acrylic fibres.

Thermal cracking A petroleum refining process that decomposes, rearranges or combines hydrocarbon molecules using the application of heat, without the use of catalysts.

Thermoplastic A synthetic plastic or resin, such as polystyrene, that becomes soft when heated and re-hardens on cooling without any appreciable change of properties.

Thermosetting plastic A plastic that hardens permanently after one application of heat and pressure. Once hardened, a thermosetting plastic cannot be remoulded.

Toluene A liquid aromatic hydrocarbon with a benzene-like structure. However, it is less flammable, toxic and volatile than benzene. It is used in organic synthesis as a solvent and an anti-knock agent in gasoline.

Wax A natural, oily or greasy substance consisting of hydrocarbons or esters of fatty acids that are insoluble in water but soluble in non-polar organic solvents, such as benzene.

Xylene A major aromatic feedstock usually obtained from petroleum or natural gas distillates. Used in the manufacture of plastics and synthetic fibres as a solvent, and in the blending of gasoline.



Acknowledgements

For WPC:

Director General: Dr Pierce Riemer

Director of Communications: Ulrike von Lonski

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Editor: Mark Blacklock

Deputy Editor: Georgia Lewis

Copy & Picture Editor: Adrian Giddings

Publisher: Nigel Ruddin

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Senior Consultants: Jeffrey Fearnside, Michael Gaskell, Karin Hawksley, Jonathan Unsworth

Art and Design Director: Michael Morey

Printed by: Buxton Press Ltd

WPC and ISC would like to express their thanks to the following companies, people and organisations for providing pictures. The credits are listed by article. Where the pictures for an article came from a variety of sources, the appropriate page numbers are given in brackets after each source.

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