1 The Chemical Processing Industry

1.1 Introduction
It is fair to say that few, if any, commercial manufactured goods do not in some way, rely on processed chemicals as a raw material. These chemicals are manufactured goods themselves, having gone through a range of processes from the sources outlined in Chapter 1 of Chemistry of Industrial Products. Table 1.1 lists the 10 most important chemicals (by production level) in the United States in 1998. It would be expected that the equivalent Australian list, if available, would be similar.

**TABLE 1.1 Major chemicals by production levels USA 1998**

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Output (million tonnes)</th>
<th>Chemical</th>
<th>Output (million tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulfuric acid</td>
<td>38.8</td>
<td>Lime (CaO)</td>
<td>14.7</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>23.6</td>
<td>Sodium hydroxide</td>
<td>10.9</td>
</tr>
<tr>
<td>Oxygen</td>
<td>16.8</td>
<td>Phosphoric acid</td>
<td>10.6</td>
</tr>
<tr>
<td>Ethene</td>
<td>16.6</td>
<td>Chlorine</td>
<td>10.3</td>
</tr>
<tr>
<td>Ammonia</td>
<td>15.4</td>
<td>Propene</td>
<td>9.1</td>
</tr>
</tbody>
</table>

**CLASS EXERCISE 1.1**
What do you notice about the top 10 chemicals? Why do you think this is?

**CLASS EXERCISE 1.2**
The table below is a list of the top ten chemical companies in the world, based on sales in 1993. Most are very well known names. Do you know which countries they are based in?

<table>
<thead>
<tr>
<th>Company</th>
<th>Country</th>
<th>Company</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hoechst</td>
<td></td>
<td>Dow</td>
<td></td>
</tr>
<tr>
<td>BASF</td>
<td></td>
<td>Exxon</td>
<td></td>
</tr>
<tr>
<td>DuPont</td>
<td></td>
<td>Shell</td>
<td></td>
</tr>
<tr>
<td>Bayer</td>
<td></td>
<td>Ciba-Geigy</td>
<td></td>
</tr>
<tr>
<td>ICI</td>
<td></td>
<td>Elf-Aquitane</td>
<td></td>
</tr>
</tbody>
</table>
1.2 A History of the Australian Chemical Industry

Industry sectors

The Australian chemical industry began in the 1860s to manufacture phosphate fertiliser for the fast growing agricultural sector. (Though it could be said that the chemical industry began in 1841 in Sydney with the production of gas from coal that co-produce ammonia and aromatic solvents). Several fertiliser manufacturing companies were established using imported phosphate rock that was reacted with sulphuric acid to produce superphosphate fertiliser. These fertiliser plants required sulfuric acid that was made from imported sulfur for reaction with imported phosphate rock. Sulfuric acid was then also used to produce other chemicals including nitric acid.

The first fertiliser plants were established by the Mount Lyell mining company in New South Wales, Victoria and South Australia, by the Cumming Smith and Company at Yarraville, Victoria, the Adelaide Chemical Works Company near Adelaide, South Australia, the Colonial Sugar Refinery (CSR) operations at Balmain near Sydney, New South Wales and by Cresco Fertilisers at Geelong, Victoria. They were small and comparatively inefficient as reflected in high fertiliser prices.

A cooperative of farmers responded to the high price of superphosphate by establishing the Pivot Superphosphate company at Yarraville, Victoria. Resulting in major price reductions, the entry of a large scale and more efficient manufacturers promoted industry rationalisation and in 1929, Pivot's four principal competitors formed the Commonwealth Fertilizers and Chemicals Limited as their own lower cost co-operative.

The first chemical plants were therefore fertiliser manufacturers that supplied Australia's fast growing rural sector. These early plants also used bone material from slaughterworks treated with sulphuric acid to produce a crude form of phosphate fertiliser. The use of by-products from slaughter yards as raw materials for the chemical industry progressed from the use of slaughter yard bone material for the manufacture of fertiliser, to animal-fat derived chemicals. Processed animal fat was reacted with caustic soda to produce soap, glycerine and crude fatty acids (stearin and olein).

Until the use of natural gas, the manufacture of gas from coal and later from oil, produced a range of crude chemicals especially phenols and aniline. These by-products became the key raw materials for the Timbrol company who may be described as Australia's first major petrochemical manufacturer.

The production of iron and steel required coke made from coal. The coking process produces a range of useful (aromatic) substances including coal tars, benzene, toluene, xylene (BTX) and naphthalene providing the raw materials for Timbrol, Monsanto and the naphthalene for CSR-Chemicals later ICI Rhodes.

Australia's burgeoning mining industry increasingly required explosives that are hazardous to transport for which shipping companies demanded substantial premiums. The high cost of freight promoted the formation of the Australian Explosive and Chemical Co. Ltd in 1874 initially producing black powder explosive until dynamite was discovered a few years later. In 1897 the company was purchased by the Nobel company that in 1928 became part of the Imperial Chemical Company of the UK. The explosives plant was owned by the ICI subsidiary ICIANZ marking it as the first step of ICT's progressive domination of Australia's chemicals industry.

During the nineteenth century, a rapidly growing local market encouraged the manufacture of pharmaceuticals using eucalyptus oil and other vegetable products found in Australia. Other products included phenol-based antiseptics (phenol was produced at gas works), vitamin A extracted from fish and the scaled up activities of pharmacies.

Australia's pharmaceutical industry began in the latter part of the nineteenth century with the manufacture of distillates and extracts made from eucalyptus trees (used for respiratory treatment, odoriferants and liniments), and many small operations as extensions of pharmacies. Two companies, FH Faulding and Drug Houses of Australia were established.

There was little further investment of any significance until the beginning of World War 2. A world-wide developing shortage of materials (including for antibiotics bolstered by military action in the malaria and disease-prone tropics) and in particular with operating margins reinforced by tariffs.

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and import licensing, promoted a pharmaceutical industry manufacturing active ingredients. One example was Monsanto who progressively diversified to become a substantial manufacturer of commodity chemicals made from benzene.

Another chemical produced in substantial volume was ethanol (ethyl alcohol) produced from 1901 by the Colonial Sugar Refining Company (CSR) by fermenting molasses. Forty years later in 1940, ethanol was to become the basis for their organic chemical plant at Rhodes, New South Wales.

A significant investment was made in 1918 by the Mount Lyell mining company at Yarraville, Victoria with an electrolytic chloralkali plant to produce caustic soda and chlorine. The chlorine later formed the nucleus of a chlorine-based organic chemical industry by ICI to produce pesticide chemicals. Other chemicals produced in the early period of the chemical industry development were explosives, soap co-produced with glycerine, and organic residues and ammonia from coking operations. Using coal to produce town gas and coke for steel, co-produced a range of organic residues that provided the raw materials for Timbrol - the first important Australian-owned organic chemical synthesis plant.

The plastics resins manufacturers are important components of today's chemical industry. The Australian plastics processing industry began about 1917 with the manufacture of phenolic articles made from imported resin powders. In 1928 two manufacturers (Elliotts and Australian Drug Co.) began to synthesise phenolic resins (bakelite) from phenol and formaldehyde. With their superior performance, appearance and ease of manufacture, plastics began to replace the more traditional materials such as wood, metal and leather providing a rapidly growing market.

As typical of other developed countries, Australia's plastic production grew rapidly. For example, while production in 1939 was only about one thousand tonnes per year, over the next five decades it increased more than 900-fold (i.e. to about 900 thousand tonnes today). This rapid growth is reflected in the following chronology of major investments in the chemical industry over just two decades:

- 1939 - casein formaldehyde and cellulose nitrate
- 1946 - phenol and urea formaldehyde resins
- 1949 - urea formaldehyde by ICI at Deer Park - cellulose acetate by CSRC
- 1950 - PVC by ICI at Botany
- 1952 - polystyrene by Monsanto at West Footscray
- 1953 - polyester resin by Monsanto
- 1955 - polystyrene by CSRC
- 1958 - polyethylene at Botany - vinyl acetate by CSRC

**CLASS EXERCISE 1.3**

*Construct a chronology of the important dates in the Australian chemical industry.*
Key companies

TIMBROL

In 1930, Timbrol Ltd established a plant at Rhodes, New South Wales to process coal tar and residues produced at coking plants using benzene, phenol, naphthalene, toluene, creosote and pyridine. It is important to note that Timbrol, like other manufacturers established over the next forty or so years up to the mid 1970s, were underpinned by two forms of assistance - import licensing that restricted competing imports, and taxes on imports. These taxes called tariffs or import duties were applied to imports deemed to compete with Australian-made goods. By reducing import competition, the prices of Australian chemicals were typically 60 per cent above those of other developed countries enabling a broad range of high-cost activities. The elimination of import licensing in 1960, and the progressive reductions in tariffs beginning 1974, began to expose Australia's protected manufacturing sector to international competition. Falling prices led to closures of many small and high-cost activities and businesses.

It was during that protectionist era that Timbrol, from 1955 as Union Carbide of Australia Ltd, developed into a diversified chemical industry. Using phenol and other coal tar products, in 1937 it used nitric acid to produce anilines and nitrobenzene followed a decade later with chlorine to produce pesticide chemicals including DDT, HCB and 2,4-T. Some innovative and diverse technology was applied by this Australian chemical company. Declining levels of assistance and increasing competition from ICI and Monsanto with new plants in Australia, led to its closure in 1987.

MONSANTO

Phenol, a raw material used by Timbrol, seeded the Monsanto Australia plant at West Footscray, Victoria as the first of many US and European companies to establish in Australia during the protectionist era. Today, nearly all chemical syntheses operations and two-thirds of the chemical formulating activities are undertaken by international companies.

In 1939, Monsanto began to manufacture pharmaceuticals including aspirin and antibiotics required for the war effort as well as phenol-formaldehyde resins and rubber chemicals. Later, using its synthesised phenol, pesticide chemicals were produced in competition with Timbrol and the expertise of its blank company in aromatic chemicals was applied to the manufacture styrene-polymers resins. The West Footscray plant now operates as Huntsman Chemical Corporation using largely imported benzene to produce styrene and styrene polymers. Phenol is still manufactured as a vestige of its origins and surplus styrene (up to 40 per cent of production) is exported.

ICI

World War II led to shortages reinforcing concerns about Australia's self-sufficiency that justified import tariffs and import licensing. High prices for chemicals attracted the Imperial Chemical Industries of the United Kingdom (ICI UK later to become ICIANZ) to invest in Australia with four plants. In 1940, a chloralkali plant was built at Botany, New South Wales to supply caustic soda and chlorine, and a sodium carbonate plant built at Osborne, South Australia. Other ICI investments included a naphthalene plant at Newcastle, New South Wales, an explosives plant at Deer Park, Victoria and a chlorohydrocarbon chemical plant at Yarraville, Victoria.

Botany formed the core of ICI's domination of Australia's chemical industry for the next half century. Their chlorine was initially used to produce halocarbons including carbon tetrachloride and perchlorethylene. In 1957, ICI began to manufacture PVC synthetic resin using acetylene gas made from calcium carbide produced in Tasmania. Polyethylene resin too was introduced, initially from ethylene made by dehydrating ethanol. Not only operating at small scale, the raw materials were expensive in a world that was using petroleum and natural gas as feedstock.

A then substantial scale naphtha cracker was commissioned in 1960 with a production capacity of 60,000 tonnes of ethylene per year. Naphtha was available from nearby oil refineries. Also co-producing the required butenes, six years later ICI formed a joint venture company as Phillips Imperial Chemicals to manufacture synthetic rubber at nearby Kurnell. The venture ceased in 1983 leaving the Australian Synthetic Rubber company (now part of Kemcor Australia) as the only Australian producer of rubber.
The period from about 1940 was a boom period for the world's chemical industry with new polymers and chemicals for new applications and for replacing traditional materials such as metals, leather and wood. Utilising this newly introduced technology, the chemical industry in Australia grew at twice the rate of the economy. At the beginning of that cycle, a sugar grower and producer of ethanol entered Australia's chemical industry to add value to its key product. Ethanol, made from sugar refinery products, could be oxidised to acetic acid and dehydrated to ethylene as two important chemical inputs.

CSR CHEMICALS
In 1939 CSR Chemicals established at Rhodes, New South Wales next to Timbrol the only other significant Australian-owned company. Initially cellulose acetate resins and vinyl acetate were produced, in part derived from ethanol. For 15 years it even produced polystyrene using imported styrene to compete in Australia's small market with the US-based Monsanto company operating in Victoria.

A quarter century later in 1966, CSR abandoned its sugar-based strategy and began to produce phthalate-based esters used as plasticisers for PVC resin and paints. The required alcohols were produced using newly developed oxo-alcohol technology. Not only was the plant small, it was increasingly overshadowed by ICI. It used feedstocks and raw materials supplied by ICI and produced chemicals for the paint and PVC resin markets that were increasingly dominated by ICI. Not surprisingly therefore, from 1968 ICI progressively acquired CSR's entry into chemical manufacturing. Without ever obtaining a reasonable rate of return, the Rhodes plant was substantially closed in 1992. It now manufactures phthalic anhydride which is reacted with imported alcohols to produce esters. These esters are used principally as plasticisers for PVC resin. With the closure five years earlier of its neighbouring plant that began as Timbrol, the demise of CSR Chemicals ended Australian-owned domination in chemical synthesis activities. There would however be one other major thrust into Australia's chemical industry during its protectionist era that was initiated by two US companies operating a Victorian oil refinery.

ALTONA PETROCHEMICAL COMPLEX
Two decades into an investment surge that saw Monsanto establish at West Footscray with polystyrene polymers, ICI producing polyethylene and polyvinyl chloride resins as well as synthetic rubber at Botany, and CSR producing polystyrene at Rhodes, a new petrochemical complex established in 1961 to directly compete in the small Australian market. Two companies (now known Mobil and Exxon) operating the petroleum refinery at Altona, Victoria, promoted the nearby establishment of a petrochemical complex. They invited three US companies, Dow Chemicals, Union Carbide and BF Goodrich, and later the two German companies, BASF and Hoechst, to produce a range of synthetic resins and chemicals from feedstocks produced at their new joint venture company, the Altona Petrochemical Company (APC). APC was to become one of the most profitable larger chemical companies in Australia.

Though chemicals are synthesised in capital-intensive plants where scale is important for competitiveness, these small-scale (and therefore high cost) operations at Altona were made viable by assistance. Import tariffs ruling then allowed Australian prices to increase between 40 and 50 per cent above open market levels. Obviously exports could only take place at a heavy discount on the Australian price and were therefore only undertaken to absorb surplus production capacity. However there was soon an expression of the consequences of assistance-underpinned activities that crowded out competitive industry with changing circumstances.

Within four years of the formation of the Altona complex, in 1965 Australia's largest oil and gas reserves were discovered in Bass Strait. Though the complex expanded using cheap gas, over the next three decades it failed to capitalise on this windfall to become internationally competitive. Instead price inflating tariffs had only one logical consequence - promoting companies to expand by product range diversion at the expense of scale and international competitiveness. The scale of production was typically no more than one-third that of competing plants in North America and Europe and any exports were at discounted prices. Two attempts at expanding to take advantage of the cheaper feedstock, were pre-empted by ICI's Botany complex though it relied on more expensive feedstocks.
than available at Altona. Despite its feedstock disability, in 1983 ICI commissioned a LPG/naphtha cracker with a production capacity of 250 000 tonnes of ethylene. With surplus production capacity, that $400 million investment restrained the internationalisation of the better positioned complex in Victoria.

By way of summary, Figures 1.1-1.5 show some important aspects of the Australian chemical industry.

**FIGURE 1.1** The change in the turnover of the Australian chemical industry and its proportion of GDP

**FIGURE 1.2** Employment in the Australian chemical industry
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**FIGURE 1.3** Sectors in the Australian chemical industry

- Rubber, plastic products & packaging: 43%
- Resins & industrial organics: 15%
- Industrial gases & inorganics: 9%
- Soaps, detergents & cosmetics: 12%
- Paints & inks: 10%
- Fertilisers & pesticides: 8%
- Explosives: 3%

**FIGURE 1.4** Import and export values of the various sectors

*Source: Australian Bureau of Statistics (ABS). Some data not published by ABS.*
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Australia’s chemical industry 1910 -1998

% GDP protectionism and industry response

FIGURE 1.5 Chronology of the Australian chemistry industry (Source: see Footnote 1)

1.2 What does a chemical processing plant do?
In simple terms, a chemical plant does on a very large scale what is done in beakers and flasks in the laboratory:
- separation
- reaction
- purification

Figure 1.6 is a flowchart description of a generic chemical process.

FIGURE 1.6 A generic chemical process
For even the simplest of chemicals, the actual flowchart showing the flow of materials through the equipment used in the various steps is complex. Figure 1.7 shows such a flowchart for the manufacture of vinyl acetate (ethenyl ethanoate), \( \text{CH}_3\text{COOCH}=\text{CH}_2 \), an important monomer, from ethene, ethanoic acid and oxygen.

![Flowchart for the manufacture of vinyl acetate](image)

**FIGURE 1.7** Flowchart for the manufacture of vinyl acetate (from A Heaton (ed.), An Introduction to Industrial Chemistry, Blackie)

**CLASS EXERCISE 1.4**

Carefully examine Figure 1.7, identifying the basic stages of the process (as per Figure 1.6). For the time being, don’t worry about the special symbols used on the flowchart.

**Batch versus continuous processes**

A batch reactor is like a giant washing machine. There is a big vat where all of the reagents are put and a big agitator that keeps them stirring. A batch reactor is great if a company wants to make small amounts of specialty chemicals one “batch” at a time, but not if they want to make the same thing over and over. This is because the reactor must be emptied and cleaned after every batch is made. This takes a lot of time and money, and every batch can be just a little bit different due to small changes in reaction conditions, equipment aging, or because the operator drops a little bit of something foreign into the reactor.

In a continuous process, the reactor is basically a long tube. The raw materials go in one end, react on their way through the tube, not stopping along the way, and the finished product comes out the other end. A continuous process works well, because it can easily make large amounts of a product with little attention from a careless factory worker, and the product usually tends to be of similar quality throughout the process. The downside is, like in the initial production of Butyl rubber, if the tube gets clogged, the whole system has to be shut down for cleaning, which can cost a lot of time and money.
From beaker to tank

Chemical reactions that occur in a particular way in the laboratory don’t automatically scale up to industrial quantities, and still work the same way.

**CLASS EXERCISE 1.5**

*What could change in the scale-up from a beaker to a continuous reactor?*

Chemical manufacturing plants are very expensive to set up, and it would be far too great an economic risk to simply make an educated guess about the design of the plant. Therefore, to simulate the full-scale plant, a *pilot plant* will be designed and built. It will be on a large enough scale to be a good representation of the full-size plant, without costing a fortune. Chemical engineers design, and are involved in the building of the pilot plant, as well as the trialling of the process to establish the optimum conditions.

**ASSIGNMENT**

*When things go seriously wrong at chemical plants, the consequences tend to be catastrophic. There have not been that many disasters in the chemical industry, but those that have occurred are infamous. Find out the specified information on the following accidents, named after the town where the plant was situated.*

**Accidents**

- Texas City
- Seveso
- Flixborough
- Bhopal

**Information**

- date & location
- nature of chemical plant
- description of event
- causes of accident
- effects of accident

**What You Need To Be Able To Do**

- define important terminology
- outline the history of one sector of the Australian chemical industry
- name significant companies in the Australian chemical industry
- list the economically important sectors of the current Australian chemical industry
- draw a flowchart showing the steps in a general chemical process
- describe, using flowcharts, one real chemical process