CHAPTER 1

WORLD ETHYLENE PRODUCTION BY STEAM CRACKING

The world ethylene production capacity is approximately 120 million tonnes (2008)[1]. The regional break-up is shown in Figure 1.1.

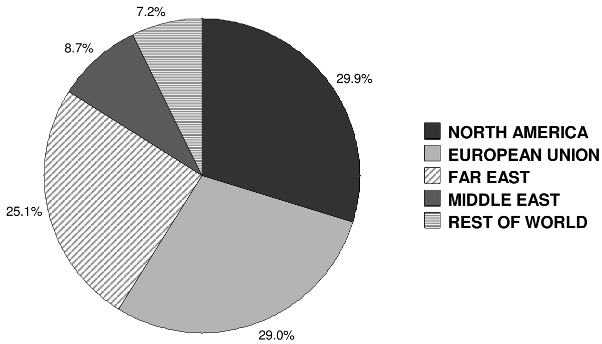

Figure 1.1: World ethylene capacity (120 million tonnes 2008)

In 2008 the ethylene production capacity was still dominated by the developed economies of North America, the European Union and the Far East. The Far East is dominated by Japan and Korea but with significant contributions from the countries of South East Asia. Emerging and rapidly growing regions of olefin production are China and the Middle East.

The following is a selected review of the world's major cracking operations producing olefins and petrochemicals.

North America

USA

The North American production is dominated by the very large cracking operations in the USA reflecting the United States position as the single largest petrochemicals market. It has a large number of fully integrated plants producing a comprehensive range of petrochemicals. In 2008, the US's capacity was almost 29 million tonnes per year (t/y) which is 80% of North America's operations and 24% of the world's total.

Production in the US is on a par with the Far East which has recently overtaken the USA in nameplate capacity. The USA is also slightly larger than the expanded European Union which has major integrated petrochemical operations in Belgium, The Netherlands, Germany and the UK.

Although the USA is geographically large, the petrochemical operations are concentrated in Texas and Louisiana. This gives them easy access to the large oil and gas production facilities in Texas and Oklahoma and the growing production of oil and gas from the Gulf of Mexico. This geographical concentration also facilitates the interchange by pipeline of chemical intermediates (ethylene, etc.) and the development of large open markets for such interchange.

In the past, natural gas liquids – ethane, propane and butane – were the favoured feedstock for ethylene production. Propylene was extracted from the off-gas of some of the world's largest oil refineries in the same region. In recent times, naphtha crackers and flexible fuel crackers have been built (the favoured approach in the Far East and Europe). However, as the following Figure 1.2 illustrates, natural gas liquids (ethane, propane and butane) account for the major portion of the ethylene feedstock.

The product slate from cracking natural gas liquids is dominated by ethylene. Propylene in the US is made from refinery off-gases (REF GAS) and there is a small contribution to ethylene from this source as feed to ethylene cracking operations. Naphtha makes up the balance and

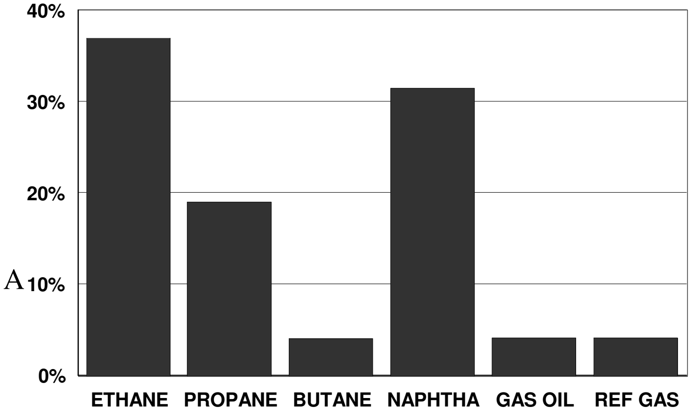

Figure 1.2: US ethylene feedstock (2008)

again much of this is sourced from the natural gasoline fraction of natural gas liquids (condensate).

The approximately 40 cracking operations are owned by various corporate entities. Some have several plants across the US. As well as US majors (Chevron-Phillips, Exxon-Mobil, Dow Chemical, Equistar), several foreign organisations operate crackers in order to have better access to the US market. Notables amongst these are BASF-Fina (EU), Formosa Petrochemical (Taiwan) and Sasol (South Africa).

Of the more than 40 US cracking operations, most are world scale with an average capacity of over 700,000t/y. The US has some of the largest plants in the world with several in excess of 1 million tonnes and one with over 2 million tonnes capacity. Table 1.1 gives a list of the ethylene cracking operations, the operators, their location and nameplate capacity in 2008.

As well large integrated plants for producing olefins and resins, the US chemical complexes can source large volumes of aromatics and other chemicals from the juxtaposed refinery operations. Because these are some of the largest refineries in the world, speciality products can often be simply extracted at a minimum cost. A good example is the production of linear paraffins (for the production alpha-olefins, which are used to produce biodegradable detergents). In most parts of the world this is a costly exercise, but these important intermediates can be extracted in the volumes required from the jet-fuel stream of the large Texas refineries (e.g. Exxon-Mobil's Baytown refinery has a capacity 523,000bbl/d). The large integrated and open market with many competitors, easy access to low cost engineering contractors and equipment, large operations which maximises the economy of scale and access to low cost feedstock has developed the Gulf region of the USA as a centre for low cost production of petrochemicals.

The only issue of concern is the reliance on the ready supply of natural gas liquids and the price of the gas used in their production.

Table 1.1: US Ethylene Plants and Capacity 2008 (tonne/year)

COMPANY	LOCATION	t/y
BASF FINA Petrochemicals	Port Arthur, TX	830000
Chevron Phillips Chemical	Cedar Bayou, TX	794000
Chevron Phillips Chemical	Port Arthur, TX	794000
Chevron Phillips Chemical	Sweeny, TX	923000
Chevron Phillips Chemical	Sweeny, TX	673000
Chevron Phillips Chemical	Sweeny, TX	272000
Dow Chemical	Freeport, TX	630000
Dow Chemical	Freeport, TX	1010000
Dow Chemical	Plaquemine, LA	520000
Dow Chemical	Plaquemine, LA	740000
Dow Chemical	Taft, LA	590000
Dow Chemical	Taft, LA	410000
Du Pont	Orange, TX	680000
Eastman Chemical	Longview, TX	781000
Equistar Chemicals LP	Channelview, TX	875000
Equistar Chemicals LP	Channelview, TX	875000
Equistar Chemicals LP	Chocolate Bayou, TX	544000
Equistar Chemicals LP	Clinton, Iowa	476000
Equistar Chemicals LP	Corpus Christi, TX	771000
Equistar Chemicals LP	Laporte, TX	789000
Equistar Chemicals LP	Morris, ILL	550000
ExxonMobil	Baton Rouge, LA	975000
ExxonMobil	Baytown, TX	2197000
ExxonMobil	Beaumont, TX	816000
ExxonMobil	Houston, TX	102000
Formosa Plastics Corp. USA	Point Comfort, TX	725000

Table 1.1 (continued)

Formosa Plastics Corp. USA	Point Comfort, TX	816000
Huntsman Corp.	Odessa, TX	360000
Huntsman Corp.	Port Arthur, TX	635000
Huntsman Corp.	Port Neches, TX	180000
Ineos Olefins and Polymers	Chocolate Bayou, TX	1752000
Javelina	Corpus Christi, TX	151000
Sasol North America	Lake Charles	453515
Shell Chemicals Ltd.	Deer Park, TX	1426000
Shell Chemicals Ltd..	Norco, LA	900000
Shell Chemicals Ltd..	Norco, LA	656000
Sun Co. Inc.	Marcus Hook, PA	225000
Westlake Petrochemicals	Calvert City, KY	195000
Westlake Petrochemicals	Sulphur, LA	567000
Westlake Petrochemicals	Sulphur, LA	522000
Williams Energy	Geismar, LA	612245

However, since 2000 gas prices have spiralled resulting in increased feedstock costs. In recent times, on an energy basis, the cost of gas in the US has often exceeded the cost of crude oil. This has led to the erosion of operating margins for the large number of plants using gas liquids as feedstock. It has also facilitated exports to the US from low production cost operations elsewhere, such as the Middle East.

Canada

Canada with a nameplate production capacity of 5.53 million tonnes of ethylene is a major player in world petrochemicals. Most of the product is devoted to the US market, particularly the northern states which are remote from the integrated operation of the US Gulf. Most of the operations are large gas based operation based in Alberta: Table 1.2.

Mexico

Mexico has a nameplate ethylene capacity of 1.384 million tonnes. This is produced by three operation owned by Petroeleos Mexicanos. All operations use ethane feedstock.

Table 1.2: Canadian Petrochemical Operations

COMPANY	LOCATION	t/y	FEEDSTOCK
Dow Chemical	Ft. Sask. ALTA	1285000	Ethane
Imperial Oil Products	Sarina, ONT	300000	Ethane LPG
Nova Chemicals	Corunna, ONT	839002	LPG naphtha
Nova Chemicals	Joffre, ALTA (E1)	725624	Ethane
Nova Chemicals	Joffre, ALTA (E2)	816327	Ethane
Nova Chemicals	Joffre, ALTA (E3)	1269841	Ethane
Petromont	Varennes, QUE	295000	LPG naphtha

European Union and Russia

The countries of the European Union (EU) have cracking operations with an annual nameplate capacity of about 26.4 million tonnes of ethylene (2008). The breakdown across the E.U. is shown in Figure 1.3.

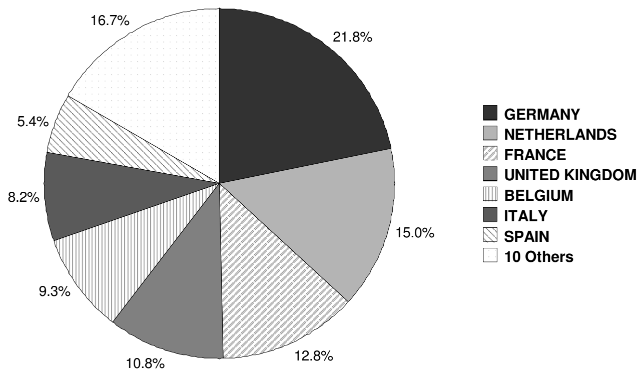

Figure 1.3: EU ethylene capacity (26.4 million tonnes 2008)

The pie chart (Figure 1.3) shows that the major operations are in Germany France, the Benelux countries and the UK. Like the US cracking operations, which are near refineries, oil and gas producing facilities of Texas, Louisiana and the US Gulf, many of the EU petrochemical centres are juxtaposed to refinery operations, North Sea oil & gas producing centres and major ports. This gives them feedstock integration with refinery and natural gas production.

In contrast to the US, most of the feed used in the production of petrochemicals is naphtha with a minor portion coming from natural gas liquids (ethane, propane etc.). There is a minor contribution (just below 10%) from gas oil, much of this being waxy residual fuel oil. The breakdown of feedstock is shown in Figure 1.4.

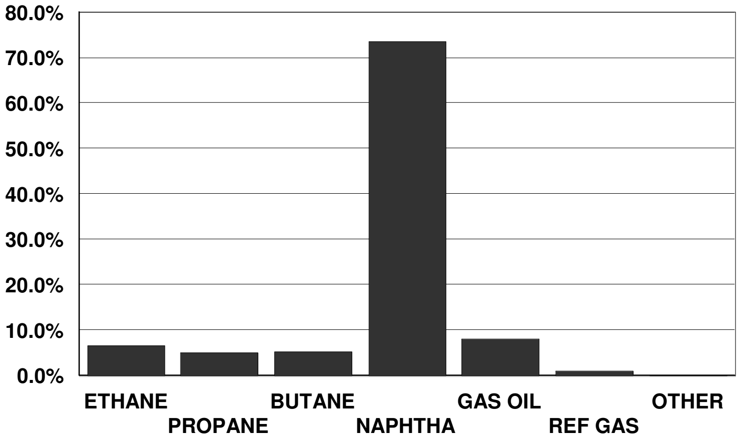

Figure 1.4: E.U. ethylene feedstock (2008)

The individual cracking operations across the countries of the EU and their nameplate capacities are shown in Table 1.3.

Russia

Russia has an annual nameplate ethylene production capacity of 3.49 million tonnes. The plants are scattered across Russia from European Russia to the Far East (Table 1.4). By world standards most plants are small with capacities of 400 kt/y or less. A cross section of feedstocks is used.

Table 1.3 European Cracking Operations (Country, Capacity (t/y), Company, Location)

COUNTRY	TOTAL	COMPANY	LOCATIION	t/y
Austria	500000	OMV AG	Schwechat	500000
Belgium	2460000	BASF Antwerpen NV	Antwerp	1080000
		Benelux FAO	Antwerp	230000
		Benelux FAO	Antwerp	580000
		Benelux FAO	Antwerp	570000
Czech Rep.	485000	Chemopetrol AS	Litvinov	485000
Finland	330000	Borealis	Porvoo	330000
France	3373000	A.P. Feyzin	Feyzin	250000
		ExxonMobil	Notre Dame de Gravenchon	400000
		Naphthachemie	Lavera	740000
		Polimeri Europa France SNC	Dunkerque	370000
		Soc. Du Craqueur de L'Aubette	Berre L'Etang	450000
		Total Petrochemicals	Carling- St. Avoid	568000
		Total Petrochemicals	Gonfreville L'Orcher	520000
		Total Petrochemicals	Lacq	75000
Germany	5757000	Bassell Polyfine GMBH	Wesseling	738000
		Bassell Polyfine GMBH	Wesseling	305000
		BASF AG	Ludwigshafen	620000
		BP	Geisenkirchen	580000
		BP	Geisenkirchen	480000
		INEOS	Dormagen	550000
		INEOS	Dormagen	544000
		LyondellBassell	Munchmunster	320000
		Dow Chemical AG	Bohlen	560000
		OMV Deutschland GMBH	Burghausen	450000
		Shell DEA Mineraloel AG	Heide	110000
		Shell DEA Mineraloel AG	Wesseling	500000
Greece	20000	EKO Chemicals	Thessalonika	20000
Hungary	660000	Tiszai Vegyi Kombinat	Tiszaujvaros	370000
		Tiszai Vegyi Kombinat	Tiszaujvaros	290000
Italy	2170000	Polimeri Europa	Brindisi	440000
		Polimeri Europa	Gela	245000
		Polimeri Europa	Porto Marghera	490000
		Polimeri Europa	Priolo	745000
		Syndial	Porto Torres	250000

Table 1.3 (continued)

Netherlands	3975000	Dow Chemical Europe	Terneuzen	580000
		Dow Chemical Europe	Terneuzen	585000
		Dow Chemical Europe	Terneuzen	635000
		SABIC Europetrochemicals	Geleen	600000
		SABIC Europetrochemicals	Geleen	675000
		Shell Nederland Chemie	Moerdijk	900000
Norway	550000	Noretyl AS	Rafnes, Bamble	550000
Poland	700000	PKN Orlen	Plock	700000
Portugal	330000	Borealis	Sines	330000
Slovakia	200000	Slovnaft Joint Stock Co.	Bratislava	200000
Spain	1430000	Dow Chemical	Tarragona	580000
		Repsol Petroleo SA	Puertollano	250000
		Repsol Petroleo SA	Tarragona	600000
Sweden	625000	Borealis	Stenungrund	625000
UK	2855000	INEOS	Grangemouth	730000
		INEOS	Grangemouth	340000
		ExxonMobil Chemical CO.	Fawley	120000
		ExxonMobil Chemical CO.	Mossmorran, Fife	800000
		Huntsman	Wilton	865000

Table 1.4: Russian Petrochemical Operations

COMPANY	LOCATION	t/y
Angarskneftorgsintez	Angarsk, Siberia	60000
Angarskneftorgsintez	Angarsk, Siberia	240000
Nizhnekamskneftekhim	Nizhnekamsk	450000
Norsy	Norsy	300000
Omskykauchuyk	Omsk, Siberia	90000
Orgsintez	Kazan	140000
Orgsintez	Kazan	100000
Orgsintez	Kazan	100000
Orgsintez	Orsk	45000
Polimir	Novopolotsk	150000
Salavatneftorgsintez	Salavat	300000
Sibur Himprom	Perm	30000
Sibur Neftechim	Nizhniy Novgorod	300000
Sintezkauchuk	Samara	300000
Stavripolpolymer	Prikumsk	350000
Tomsk PCC	Tomsk	300000
Uraorgsintes	Ufa	235000

Ethylene Production in the Middle East[2]

Over the past decade (to 2008) there has been an enormous expansion in the production of olefins and resins in the Middle East. This has been driven by: (i) the availability of feedstock at low prices as a consequence of the large oil reserves and (ii) the strategic location of the Middle East in being able to supply both the Atlantic and Far East petrochemical demand - in particular the enormous rise in demand from China.

As of 2008 installed capacity based on ethylene is 10.4 million tonnes across five nations of the Middle East as illustrated in Figure 1.5.

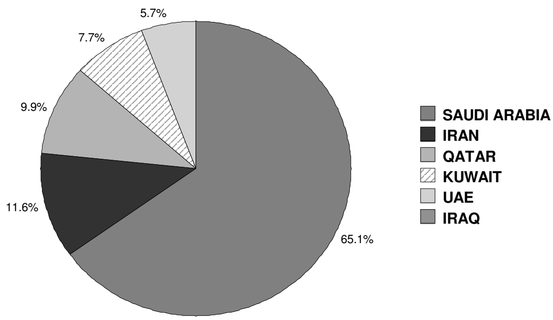

Figure 1.5: Middle East Ethylene Capacity (10.4 million tonnes 2008)

Most capacity is in Saudi Arabia, which has almost 7 million tonnes of ethylene capacity mainly using gas based feedstock[3]. Current capacity in Iran, Qatar and Kuwait stands at about 1 million tonnes each and the UAE has a cracker of 600,000 tonnes. Larger plants are under construction in Iran[4]. The status of the Iraqi petrochemical industry is unknown.

The feedstock used in the Middle East is illustrated in Figure 1.6. What distinguishes cracking operations in the Middle East from those of other regions is the dominance of ethane cracking over other feedstocks.

As is illustrated in the Figure 1.6, ethane is the major feedstock of the region. Along with propane and butane, ethane is extracted from natural gas either as gas associated with oil or from large natural gas fields developed for LNG production, as in Qatar.

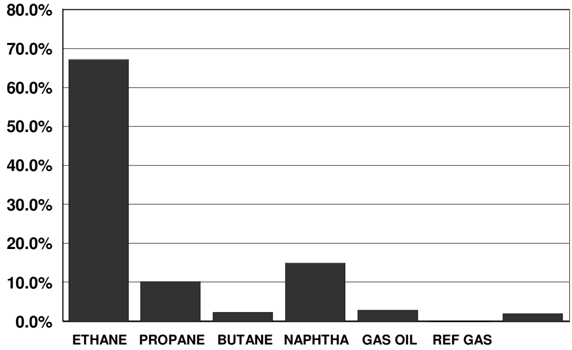

Figure 1.6: Middle East feedstock slate (2008)

A critical factor underpinning the growth in petrochemicals is that the Middle Eastern governments have made the political decision that the pricing of gas and its derivatives (ethane, propane and butane) is not related to the price of crude oil for domestic petrochemical purposes. This distinguishes the Middle East operations from many of those elsewhere such as Europe and USA where the pricing of gas derived feedstock bear a relationship with the prevailing price of crude oil.

When oil price was low (as in the mid 1990s) feedstock costs where broadly similar across the world. However, in a time of high gas and oil prices, the Middle East pricing regime has introduced a large feedstock differential in their favour. This arrangement delivers an enormous competitive advantage to Middle East producers of ethylene which use gas based feedstock. This flows through to the production costs of ethylene derivatives such as polyethylene resins, ethylene glycol, ethanol and acetic acid. The issue of differential feedstock pricing is of increasing concern to the EU where a large part of the downstream products are sold and where domestic EU producers pay much higher prices for feedstock. The issue is a point of contention in the trade between the Middle East and the EU.

Also important in future developments are those cracking operations based on feedstock from the large Qatar North Gas Field[5]. Further gas based plants are planned in Saudi Arabia to come on-stream from 2008. However, one short term issue will be the viability of Iran's industry if the current imbroglio over uranium enrichment results in trade sanctions.

Should these projects come to fruition, the Middle East producers will be the lowest cost producers for a wide range of petrochemicals and derivatives. The major portion of the products would be exported to the world markets and so will impact on the world price. This will be a particular concern to most producers in Europe and the Far East with feedstock (naphtha) linked to the prevailing crude oil price. The cracking operations in the Middle East in 2008 are listed in Table 1.5.

Table 1.5: Ethylene Producers in the Middle East (2008)

COUNTRY	COMPANY	LOCATION	t/y
Iran	Amir Kaibar Petrochemical Co.	Amir Kabir	520000
	Arak Petrochemical	Arak	247000
	Bandar Imam Petrochemical	Bandar Imam	311000
Kuwait	Equate Petrochemical	Shuaba	800000
Qatar	Qatar Petrochem. Co.	Mesaieed	530000
Saudi Arabia	Al Jubail Petrochemical Co.	Al Jubail	800000
	Arabian Petrochemical	Al Jubail	650000
	Arabian Petrochemical	Al Jubail	800000
	Arabian Petrochemical	Al Jubail	800000
	Al Jubail Petrochemical Co.	Al Jubail	1000000
	Saudi Petrochemical Co.	Al Jubail	1045000
	Yanbu Petrochemical Co.	Yanbu	875000
UAE	Bourouge Abu Dhabi Polymers	Ruwais, Abu Dhabi	600000

One aspect of the developments is that many of the producer organisations have access to the latest technologies. One company, SABIC, owns major petrochemical plants in the EU and has now a strong research and development arm producing new technologies and product improvements.

Cracking Operations in the Far East[6]

The nameplate capacity of ethylene plants in the Far East is now over 28 million tonnes. This corresponds to over 25% of the world's total ethylene capacity. The countries contributing to this total are shown in Figure 1.7.

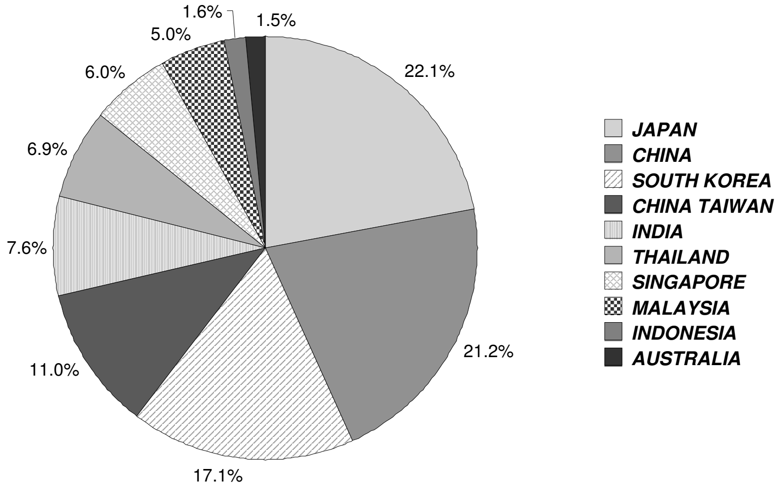

Figure 1.7: Far East Ethylene Capacity (32.9 million tonnes 2008)

Japan remains the country with the highest nameplate capacity with over 22% of the regions total. China and South Korea follow this with about 21% and 17% respectively. Taiwan (11%) and India (8%), Singapore (6%), Malaysia (5%) and Thailand (7%) are significant players in the region. Indonesia and Australia, with their production remaining static, remain outsiders to this growth in the region's ethylene production capacity (each below 2% of the region's production capacity).

Over the past decade, the ethylene capacity in the Far East has grown on average of 9% each year. This is considerably higher than the world growth rate of 5% over the same period. This growth to 2008 is illustrated in Figure 1.8.

Most of this growth has concerned the growth of China and suppliers of commodity resins and chemical intermediates to the rapidly growing Chinese market.

Table 1.6 lists the 2008 nameplate capacities in the Far East by country and the average annual growth over the previous decade.

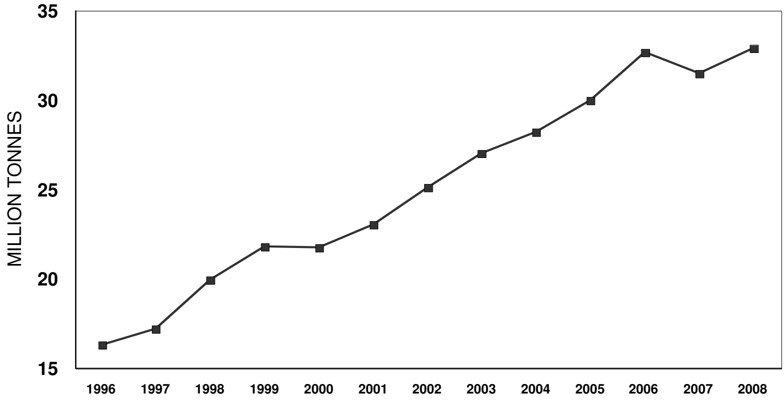

Figure 1.8: Growth in Far East Ethylene Capacity

Table 1.6: Nameplate Capacities for Ethylene Cracking (2008)

COUNTRY	t/y	growth/y
Australia	502000	-0.1%
China	6988000	8.9%
China Taiwan	3621000	25.7%
India	2515000	8.1%
Indonesia	520000	-0.5%
Japan	7265000	-0.1%
Malaysia	1649000	20.0%
Singapore	1980000	34.0%
South Korea	5630000	5.3%
Thailand	2272000	20.3%
TOTAL	32942000	6.5%

Comparing the growth rates we see that there has been a steady annual growth rate in the Far East petrochemical capacity in India and China. Most of the regions growth has been in Taiwan and in the South East Asian nations of Malaysia, Singapore and Thailand which have seen annual average growth rates over 20%. The nameplate capacities of these countries far outstrip local demand. These are export industries which supply the growing markets in India and in particular China whose industries, despite an 8% growth rate, have failed to keep up with rising demand.

Over the decade there has been some increase in capacity in South Korea (5.3%) which is close to the regions average growth rate of 6.5%. Australia, Indonesia and Japan have not changed significantly in capacity, the economies of these nations relying more on imports from South East Asia and the Middle East.

Feedstocks

In the Far East naphtha remains the dominant feedstock. Ethane is used in several countries, where it is available from local natural gas developments. There has been a continued decline in the use of gas oil. LPG is a minor contributor to feedstock in the region. The principal feedstocks used in the Far East are shown in Figure 1.9.

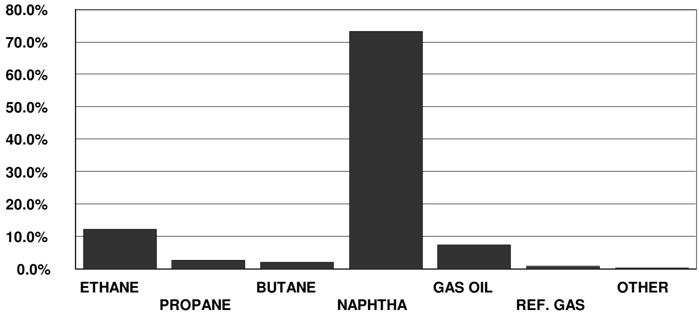

Figure 1.9: Feedstock breakdown in the Far East

However, there is a considerable variation between countries with some almost entirely naphtha and some substantially based on ethane and LPG. The various national breakdowns are shown in Figure 1.10.

Far East Country Survey

Australia (502 kt/y)

There are two major centres one based on Botany Bay near Sydney and the other at Altona in Melbourne. They produce the bulk of the ethylene which is made from ethane, with some supplementary LPG at Altona and naphtha at Botany. A small ethane cracking operation (32 kt/y) at Footscray (Melbourne) produces ethylene for styrene manufacture.

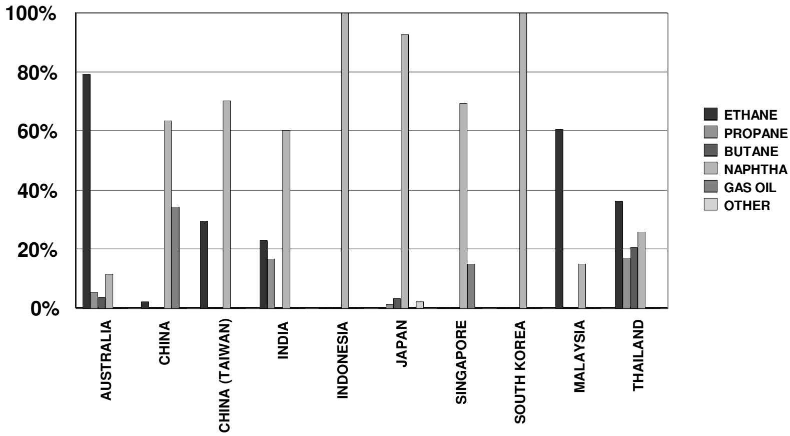

Figure 1.10: Feedstock breakdown by country in the Far East

China (6,9880 kt/y)[7]

The massive expansion of the Chinese economy has had a profound impact on the production and use of commodity plastics in China. The first is the considerable growth in demand for polymer products which have outstripped local supply and as a consequence China is a major importer. This has had the effect of promoting large export oriented plants in other Asian countries, with large parts of their product slate destined for the Chinese market. China is now second to Japan in the amount of ethylene produced in the Far East. The Chinese nameplate capacity is almost 7 million tonnes/year.

The plant locations and capacity are listed in Table 1.7. Most of the Chinese plants are old, with capacities below 200,000 t/y. Many of these plants were designed to use gas-oil and naphtha as feedstock. This takes advantage of some of China's indigenous crude oil, which have high levels of paraffin wax in the gas-oil fractions. In steam cracking, such gas-oils give high yields of ethylene and propylene. Newer plants are larger and tend to be more naphtha based. One plant (Panjin) uses ethane as feedstock.

The large growth in demand has spurred a large number of proposals to increase indigenous capacity. Many of these proposals have fallen by the wayside. Nevertheless, we would expect to see increasing capacity coming on-line over the next decade.

Table 1.7: Chinese Petrochemical Operations

COMPANY	LOCATION	t/y
BASF-YPC Co Ltd.	Nanjing	600000
CNOOC	Daya Bay, Guangdong	800000
CNOOC	Dushanzi	140000
China Petrochem. Industrial	Daqing	320000
Dalian Pet. Chem.	Dalian	4000
Fushan Pet. Chem Cpx.	Fushan	115000
Gaoqiao Petrochem	Gaoqiao	14000
Guangzhou Petrochem	Guangzhou	150000
Jilin Chemical	Jilin	700000
Langzhou Chemical Industrial	Langzhou	240000
Panjin Gas Processing	Panjin	130000
SINOPEC	Beijing	660000
SINOPEC	Guangzhou	140000
SINOPEC	Maoming	380000
SINOPEC	Neijing	650000
SINOPEC	Puyang Henan	180000
SINOPEC	Qilu	720000
SINOPEC	Shanghai #1	145000
SINOPEC	Shanghai #2	700000
SINOPEC	Tianjin	200000

China Taiwan (3,620 kt/y)

China Taiwan has a nameplate ethylene capacity of 3.6 million tonnes a year of ethylene. This makes Taiwan the fourth largest producer of olefins in the Far East. All of the production is from naphtha so that large volumes of propylene, higher olefins and aromatics are also produced. These feedstocks are used to produce a range of polymers, fibre intermediates and petrochemicals in large integrated complexes.

There are only two major players producing olefin monomers: The China Petrochemical Development Corporation (often referred to as CPC, but this can lead to confusion with other Taiwan and mainland Chinese organisations) was the original government owned organisation (now privatised) charged with development of Taiwan's petrochemical industry. It can be regarded as a diversified conglomerate with interest in housing and construction as well as chemicals. The Formosa Petrochemical Corporation (FPC) is a subsidiary of the Formosa Plastics Corporation and has major investments in ethylene and downstream petrochemical operations. The location and size of the current (2008) cracking operations are given in Table 1.8.

Table 1.8: Taiwan Petrochemical Operations

COMPANY	LOCATION	t/y
Chinese Petroleum Corp.	Kaohsiung Linyuan	422000
Chinese Petroleum Corp.	Linyuan	230000
Chinese Petroleum Corp.	Linyuan	419000
Formosa Petrochem. Corp.	Mailiao	450000
Formosa Petrochem. Corp.	Mailiao	900000
Formosa Petrochem. Corp.	Mailiao	1200000

All of the cracking operations use naphtha as feedstock. The future developments of Taiwan's petrochemicals business are linked to developments in the refinery sector which provide the feedstock. Until recently, the supply of petroleum products was in the hands of the government owned Chinese Petroleum Corporation (another CPC!) which operated three refineries and a condensate splitter. These operations supplied the downstream petrochemical plants with naphtha. However, the advent of Taiwan's entry into the WTO has broken this monopoly and FPC has established itself as Taiwan's first private refiner. The FPC refinery was built with the intention of facilitation feed supply to its new crackers. This opening of the petroleum market is allowing the entry of other players and some of the world oil majors have begun to enter the market.

As well as having some of the world's large integrated facilities, Taiwan has major world players in the downstream products and markets. Some of these operations are wholly owned subsidiaries of the major ethylene producing companies. However, there are some major independents that started out in a niche downstream market and have now expanded to become major players in the Far East chemicals industry.

Because many of the companies started in the downstream sector they have been open to further downstream high-tech sector investments. Furthermore, relative to mainland China, Taiwan's labour cost are high and this has seen a slowing of investment in traditional petrochemical operations in favour of placing such investment in the mainland. However, there is a major shift underway into the higher added value engineering plastics, electronic plastics (LCDs) and biotechnology and biomaterials. These future developments in advanced materials are being spurred by Japanese investment in joint ventures.

India (2.515 kt/y)[8]

The past ten years has seen a spectacular growth in the Indian petrochemicals and polymer industries so that today India is a major player in the region. India now has a nominal ethylene capacity of 2.5 million tonnes of ethylene, which places it fifth in terms of capacity in the Far East.

The per capita consumption of polymers at 2.7 kg/y is way below the world average (c. 19 kg/y; compare the developed world >70 kg/y). The demand is growing rapidly at about 12% per annum. This means that most of the new capacity is focused on the increasing domestic demand rather than in the production of export product (compare with Singapore with its export oriented industry). However, in the short term there may be some over-capacity and hence the potential for exports. Most of the plants are on the western side of India. The principal ethylene producing facilities are listed in Table 1.9.

Reliance Industries Ltd (RIL) is a large industrial conglomerate with interests in petrochemicals, refining, textiles, power generation, oil and gas exploration and telecommunications. RIL is one of the world's major manufacturers of plastics and polymers. It has over 50% market share of the Indian market and claims to be the 6th largest PP producer in the world with a capacity of 400,000 t/y. It has a large ethylene cracker (750,000 t/y, naphtha feed) at Hazira and is the majority owner of a very large refinery at Jamnagar, both in Gujarat. The refinery produces large volumes of propylene for PP production.

Table 1.9: Indian Petrochemical Operations

COMPANY	LOCATION	t/y
Gas Authority India	Pata, Utta Pradesh	300000
Haldia Petrochemicals	Haldia, West Bengal	520000
Indian Petrochemicals Corp.	Baroda, Gujarat	130000
Indian Petrochemicals Corp.	Gandhar, Gujarat	300000
Indian Petrochemicals Corp.	Nagothane	400000
National Organic Chemical Ind.	Thane, Maharashtra	75000
Reliance Industries	Hazira, Gujarat	790000

Petrochemical operations are vertically integrated through polyester and fibre intermediates to large textile operations. It is one of the world's largest producers of *para*-xylene and PTA.

Indian Petrochemical Corporation Ltd. (IPCL) is a government owned corporation with the remit to expand the petrochemical and plastics production of India. It has a naphtha based ethylene cracker at Vadodara (132,000 t/y), and large gas based complexes at Nagothane near Mumbai (Bombay; 400,000 t/y) and Dahej near Bharuch in Gujarat (300,000 t/y). The company produces polymers, fibre intermediates, catalysts and absorbents.

Gas Authority of India (GAIL) is a government authority that markets gas produced by various upstream producing consortia. GAIL operates a 300,000 t/y ethylene cracker at Pata in Uttar Pradesh. The ethylene is processed downstream to HDPE and LLDPE.

Haldia Petrochemicals Ltd (HPL) has a large naphtha cracker at Haldia in eastern India (West Bengal). Downstream the company operates LLDPE, HDPE and PP plants.

National Organic Chemical Ind. Ltd (NOCIL) was established in the early 1960s with a series of collaborative agreements with Shell and UOP and was the first company to set up a naphtha based cracker in

India at Thane near Mumbai (Bombay). The plant is small by today's standards with a capacity of 75,000 t/y ethylene. NOCIL produces petrochemicals and rubbers.

Oswal Agro Mills Ltd. is an agricultural company with several fertilizer plants with a small (naphtha) cracker producing 22,000 t/y ethylene near Mumbai (Bombay). Chemplast Sanmar Ltd. (CSL) is a small company focusing on the production of chloro-chemicals. Based in Tamil Nadu, the company has a small ethylene plant which uses ethanol as a feedstock.

Indonesia (520 kt/y)

Indonesia is currently a minor player in the Far East olefins industry. The industry is centred on a single world-scale naphtha cracker at Cilegon in West Java. PT Chandra Asri owns the plant. The feedstock is entirely naphtha. As built, the plant has an ethylene capacity of 515,000 t/y of ethylene and 240,000 t/y propylene which feeds several downstream operations.

Japan (7,265 kt/y)[9]

Japan has a major slice of the ethylene production capacity in the Far East, with nameplate capacity of approximately 23% of the area's total nameplate capacity. Japan has a ethylene production capacity of about 7 million tonnes per year. This nameplate capacity has been stable since the mid-1990s and growth is expected to be modest, mainly by de-bottlenecking operations. This static growth in capacity is in contrast to most of the other countries in the Far East which have seen large increases in capacity since the latter part of the 1990s. This has resulted in Japan's share of capacity in the Far East falling from 41% in 1995 to about 23% today.

The production capacity is in the hands of 10 manufacturing companies. The names, locations and capacities are shown in Table 1.10. Four companies [Mitsubishi, Mitsui (through Ukishima and Keiyo Ethylene), Idemetsu and Showa Denko] hold 68% of the nameplate capacity.

Table 1.10: Japanese Petrochemical Operations

COMPANY	LOCATION	t/y
Asahi Kasei Corp	Kurasiki, Okayama	484000
Idemetsu Petrochem.	Chiba	374000
Idemetsu Petrochem.	Tokuyama	450000
Keiyo Ethylene	Ichihara, Chiba	768000
Maruzen Petrochemicals	Chiba	480000
Mitsubishi Chemical Corp.	Kashima	375000
Mitsubishi Chemical Corp.	Kashima	453000
Mitsubishi Chemical Corp.	Mizushima	450000
Mitsui Chemicals Inc.	Chiba	553000
Mitsui Chemicals Inc	Takaishi City, Osaka	450000
Nippon Petrochemical	Kawasaki	450000
Showa Denko	Oita	600000
Sumitomo Chemical Co. Ltd.	Chiba	380000
Tonen Chemical Corp.	Kawasaki	505000
Tosoh Corp.	Yokkaichi, Mie	493000

Apart from one plant of Keiyo Ethylene (a subsidiary of Mitsui) and one plant of Mitsubishi, all of the producing plants are over 10 years old, most are over 25 years old. This means that most of the capital is fully depreciated and most plants can operate on a basis ignoring capital costs. This helps the Japanese operations to survive periods of depressed ethylene prices.

Of the total ethylene production about 68% is used immediately near the plant by subsidiary companies and affiliates. About 28% is sold on the merchant market and about 4% is exported.

The large merchant trade (about 2 million tonnes per year) is helped by an extensive pipeline system with 88% of ethylene being delivered by pipeline to the end user. The remaining 12% (about 800,000 t/y) is delivered by ship or barge, to the largely coastal petrochemical plants in Japan. The fleet dedicated to intra-Japan trade comprises about 11, mostly refrigerated, vessels with a range of capacities from 440 tonnes to 1700 tonnes of ethylene. Shipping terminals for ethylene facilitate a small import trade in ethylene of about 20,000 t/y.

The dominant feedstock is naphtha, although in some cases hydrogenated natural gas liquids (H-NGL or condensates) are used. However, the choice of condensate is probably restricted to those with a low end point (i.e. they are very similar to naphtha such as A-180 from Saudi Arabia). There is a small use of LPG (butane and propane) in some of the cracking operations.

Like many countries in the Far East, there is a relatively high demand for propylene. To maximise propylene production from naphtha cracking, the process plant is operated at low severity. In order to maintain design levels of ethylene, more naphtha feedstock is required, with the naphtha requirement being about 3.8 times the weight of ethylene produced. This creates a large demand of about 750,000 to 800,000 bbl/d for petrochemical (paraffinic) naphtha.

Most naphtha (65%) is imported, the rest is produced domestically by distilling crude oil in refineries. Due to the large demand and concomitant international trade, it is the Japanese petrochemical market that sets the specification for traded naphtha in the Far East - the so-called “Japanese open spec.”. Most producers of naphtha ensure that their product meets this specification as is illustrated in by the data in Table 1.11.

Table 1.11: Japanese Open Spec and Some Typical Naphtha Compositions

	B.P. (C)	DENSITY (kg/l)	PARAFFINS
Japan Open Specification	24 to 204	0.665 to 0.740	65 Min
Cooper (Australia)	full range	0.729	69.6
Udang (Indonesia)	32 to 191	0.7264	75.5
Khafji (Kuwait)	32 to 190	0.7201	73.4
A-180 (Yanbu, Saudi Arabia)	36 to 154	0.6689	93.8

Naphtha cracking provides about 4.3 million tonnes of propylene per year, which is out of a total demand for propylene in excess of 5.3 million tonnes per year. The difference (about 20%) is made up by propylene extracted from refinery off-gases, particularly FCC operations (used to produce gasoline from heavier feed stocks such as heavy gas-oil or residua).

Korea (5,630 kt/y)

South Korea is a major player in the Far East olefins and poly-olefins markets with 17% of the regions total ethylene capacity of 32 million tonnes /year.

The current (2008) total nameplate capacity of the South Korean petrochemical industry is 5.63 million tonnes. The major players, location and nameplate capacity (2008) are shown in Table 1.12.

Table 1.12: South Korean Petrochemical Industry

COMPANY	LOCATION	t/y
Honam Peterochemical	Yeochun	700000
LG Daesan Petrochemical	Daesan	450000
Lotte Daesan Petrochemical	Daesan	600000
Korea Petrochem Ind.	Ulsan	320000
LG Petrochemical Co.	Yeosu City	760000
Samsung General Chemicals	Daesan	820000
SK Corp.	Ulsan	185000
SK Corp.	Ulsan	545000
Yeochon	Yeochun	420000
Yeochon	Yeochun	480000
Yeochon	Yeochun	350000

All of the plants use naphtha as feed and so produce a broad range of olefins and by-products enabling the production of a large range of products in large integrated complexes. The domestic demand is less than 50% of the production that is the petrochemical operations are export oriented. One aspect of the reliance of the Korean petrochemical sector on exports is the suspicion that during the depths of the petrochemical business cycles, the plants operate on a cash-cost basis. This allows them to undercut rivals having to service debt.

The financial crisis in the Far East during the late 1990s exposed the high debt levels of the petrochemical operations, which were not being serviced. This has forced restructuring of the industry in order to reduce debt levels. For instance some companies had debt/equity ratios of well over 300%. Since restructuring, these levels have been reduced, but are still typically in the 200% region. However, there has been some criticism of the restructure as involving too much financial engineering with total debt still similar to 1997 levels. How these operations will fare in the current crisis of 2009 is moot.

North Korea

As a consequence of the recent political events on the Korean peninsula, there is increasing interest in how the North Korean economy can be integrated into the economies in the Far East. North Korea has permitted some foreign investment in recent years and North Korea has recently asked the World Bank for guidance in establishing a market economy.

North Korea has a nominal ethylene capacity of 60,000 t/y at a plant in Pyongyang. This very small operation could expand should oil be discovered in offshore blocks currently being explored by western companies including Australia's Beach Petroleum.

A more promising basis for the development of chemical and petrochemical plants in the north might come as a consequence of any trans-Korean gas-pipeline developments from the very large Russian Kovylta gas fields at Irkutsk. This might provide both energy and feedstock (ethane) for future petrochemical developments.

Malaysia (1,649 kt/y)[10]

Although currently a minor player on the Far East petrochemicals scene, Malaysia has a strong and growing petrochemical sector with a nameplate ethylene capacity approaching 1.7 million tonnes per year. Led by Petronas (the national oil company), Malaysia has attracted over US$ 7.6 billion since 1997 and a further US$ 5 billion is committed from 2001.

There are three major ethylene plants that feed downstream operations. All are based on the Malaya Peninsula: Table 1.13.

The oldest plant and largest integrated petrochemical plant is at Kertih in Terengganu State. This complex uses gas from the major oil and gas fields off the eastern cost of the Peninsula.

Table 1.13: Malaysian Petrochemical Operations

COMPANY	LOCATION	t/y
Ethylene Malaysia	Kerith	400000
Optimal Olefins	Kerith	600000
Titan Petrochemicals	Pasir Gudang, Jahor	249000
Titan Petrochemicals	Pasir Gudang, Jahor	400000

The other major olefins plants are at Pasir Gudang in Jahor operated by the Titan Group. These plants utilise naphtha or LPG as feedstock that can be imported via the large Jahor port. Initially built around providing feed to poly-olefins plants, these facilities have expanded to produce aromatics. Clearly there is the potential for these developments to offer synergy with the large complexes in Singapore. Many of the downstream operations involve multinational corporations in a leading role.

Other chemicals operations are in Sarawak. Offshore gas feeds a large methanol plant (660 kt/y) on Labuan Island and an ammonia plant at Bintulu. Also at Bintulu is the large Shell Gas to Liquids plant, which produces high valued linear-paraffins and wax as by-products. The naphtha fraction from the GTL plant is used as petrochemical naphtha.

The petrochemical complexes in Malaysia are export driven. The competitive advantages lie in low priced gas feedstock and large integrated plants based on naphtha. The resulting complexes are able to deliver chemical intermediates throughout the Far East.

Singapore (1,980 kt/y)

The petrochemical operations in Singapore are based on Jurong Island. From a cluster of small islands in 1995, the site has been transformed by massive civil engineering to create a large flat land base dedicated to the production of petrochemicals and the integrated downstream industries. These infrastructure works alone have cost the Singapore government in excess of US$ 6,000 million to date. These developments are continuing and Singapore continues to attract private investment lured by the benefits of manufacturing chemicals on a world-scale fully integrated site in the Far East. The petrochemical operations are based around two major naphtha cracking operations. ExxonMobil Singapore (capacity 900 kt/y ethylene) is now complete and operational and Petrochemical Corporation of Singapore (PCS) has recently been expanded to over a million tonnes of ethylene. Another world-scale cracker is reported to be under consideration by Shell.

Cracker feedstock for the Island is entirely imported. Two large oil refineries (ExxonMobil Singapore Pte. Ltd. (227,000bbl/d) and Singapore Refining Company (285,000bbl/d)) supply naphtha to the main cracking operations and additional feedstock supply can be obtained from other Singapore refineries (Shell Eastern Petroleum (405,000bbl/d) on Pulau Bukom and ExxonMobil Oil Singapore (255,000bbl/d) on the mainland near Jurong). Undersea pipelines integrate all these facilities.

Juxtaposed to these main facilities are clustered a large number of chemical processing companies producing intermediates and finished petrochemical products. In order to achieve the greatest benefits, an integrated site requires the sharing of utility services. This minimises the capital requirements for investment by eliminating the need for power, steam, gas, shipping terminals etc. required for stand-alone facilities. Jurong Island's integration is achieved by the existence of a series of service industries dedicated to providing supporting services and utilities to the chemical plants.

Thailand (2,272 kt/y)[11]

There are four main olefins plants at Map Ta Phut in Rayong Province just south of Bangkok. These plants have a capacity of over 2 million tonnes of ethylene (Table 1.14), making Thailand a major player in Far East petrochemicals.

Table 1.14: Thai Petrochemical Industry

COMPANY	LOCATION	t/y	FEEDSTOCK
PTT Chemical	Map Ta Phut	437000	Ethane LPG
Rayong Olefins Co. Ltd..	Map Ta Phut	800000	LPG naphtha
PTT Chemical	Map Ta Phut	350000	Ethane
PTT Chemical	Map Ta Phut	385000	LPG naphtha
PTT Chemical	Map Ta Phut	300000	Ethane

South America

Although South America is a smaller player in the world petrochemical industry, three countries have significant and growing operations. The largest is Brazil (3.5 million tonnes) in six world scale operations. Feedstock for five of these is naphtha with the other based on ethane and LPG. Argentina has a nameplate capacity of 838 kt/y. Three of these plants are small local operations. Venezuela has a nameplate capacity of 600 kt/y in two operations. The operations, locations and feedstock are detailed in Table 1.15.

Table 1.15: Some South American Petrochemical Operations

COUNTRY	COMPANY	LOCATION	t/y	FEEDSTOCK
Brazil	Braskem SA	Camacari Bahia	600000	Naphtha
	Braskem SA	Camacari Bahia	680000	Ethane LPG
	Copesul	Triunfo, RS	700000	Naphtha
	Copesul	Triunfo, RS	500000	Naphtha
	Petroquimica Uniao SA	Santo Andre, SP	500000	Naphtha
	Rio Polimeros	Duques De Caxais	520000	Naphtha
Argentina	Dow Chemical	Bahia Blanca	275000	Ethane
	Dow Chemical	Bahia Blanca	490000	Ethane
	Huntsman Corp.	San Lorenzo	21000	Propane/ Naphtha
	Petrobas Energia	Puerto San Martin	32500	Propane
	Petrobas Energia	San Lorenzo	20000	Propane
Venezuela	Pequiven – Petrochima	El Tablazo, Zulia	250000	Ethane Propane
	Pequiven – Petrochima	El Tablazo, Zulia	350000	Ethane

Africa

There are only a small number of cracking operations in Africa. The main producers are Egypt, Libya and Nigeria each with a capacity of about 300,000 t/y and South Africa with a capacity of 585,000 t/y. The latter production is integrated with the large coal and gas to liquids operations of Sasol.

Feedstock and Carbon Emissions

Based on nameplate capacity, the relative amounts of feedstock used are shown in Figure 1.11. This graph illustrates that the two largest feedstocks are ethane and naphtha with naphtha accounting for over 50% of the required feedstock. LPG (propane, butane) and gas oil make a contribution, but in total this is less than 20%.

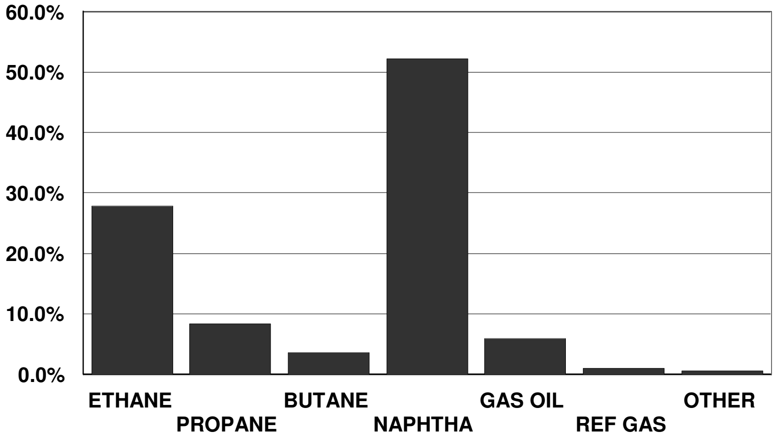

Figure 1.11: World ethylene feedstock

A typical naphtha cracking operation will use approximately 3.3 tonne naphtha per tonne of ethylene. Using this as a basis, the world demand for petrochemical naphtha is almost 200 million tonnes per year or almost 5 million barrels of naphtha per day. The ethane required is typically 1.3 tonnes of ethane per tonne of ethylene. This translates into 41 million tonnes of ethane per year. Most of this is derived from natural gas which (on a weight basis) contains about 10% ethane, hence some 400 million tonnes of natural gas is required to be processed to provide the world's petrochemical ethane or about 63 bcf/d of raw natural gas.

Ethylene cracking operations produce carbon dioxide emissions from fuel oil consumed in furnace operations and losses as a consequence of operational issues (flaring). Using the above data, the estimate of the world's emissions is 255 million tonnes of carbon dioxide. The breakdown by feedstock is shown in Figure 1.12.

Ethane and LPG cracking give little product other than ethylene and propylene. However, naphtha and gas oil produce large quantities of by-products such as pyrolysis gasoline. Assigning some of the carbon dioxide produced to these by-products lowers the carbon dioxide emission attributable to the olefins. Although naphtha produces much higher levels of carbon dioxide than ethane, distributing the emission over all the products produced lowers the total emission from naphtha to appoint where it its lower than for ethane cracking.

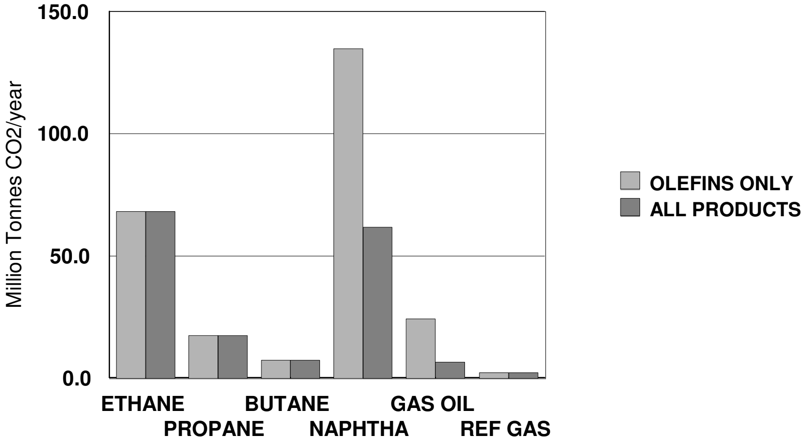

Figure 1.12: World carbon dioxide emissions from ethylene production

One of the issues facing the world petrochemical industry is the issue of placing some sort of emissions charge on carbon dioxide emitting industries, this is especially true for the developed economies which generally use naphtha feedstock. The application of a carbon emission charge would encourage the relocation and investment in many of the developing countries with emerging petrochemical industries. Many of these countries, especially in the Middle East, use ethane as the feedstock and as illustrated such a move may not necessarily result in lower overall emissions.

[1] *Oil & Gas Journal*, "International Survey of Ethylene from Steam Crackers", July 2008; see also W. Sedriks, *ibid*., Nov. 5, 2001, p. 58

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[3] A. M. Aitani, *Oil & Gas Journal,* Jul. 29, 2002; A.Al-Sa'doun, *ibid*., Jan 2, 2006, p. 52 and Jan 9, 2006, p. 48

[4] M.H. Buffeboir, J.M. Aubury, X. Hurstel, *, Oil & Gas Journal,* Jan. 19, 2004, p. 60; A. Aik, S. Adibi, *ibid.* Mar. 26, 2007, p. 48

[5] T. Chang*, Oil & Gas Journal*, Aug 20, 2001, p. 72

[6] See also G. Kin, *Hydrocarbon Asia*, Jul/Aug 2006, p. 48

[7] Wang Yong, *Hydrocarbon Asia*, Sep. 2002, p.16

[8] J. W. King*, Oil & Gs Journal*, Feb. 11, 2002, p. 58

[9] Anon.*, Hydrocarbon Asia*, Jul/Aug 2005, p. 16; *idem*., Nov/Dec 2002, p. 30

[10] Anon.*, Oil & Gas Journal*, Sep. 18, 2000, p. 58; Anon.*, Hydrocarbon Asia*, Nov/Dec 2005, p. 8

[11] Anon., *Hydrocarbon Asia*, Sep/Oct. 2005, p. 10