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7. IMPACT OF THE PROPOSED FUEL QUALITY SCENARIOS ON THE AUSTRALIAN REFINING INDUSTRY

Chapter 7 presents a discussion of refining issues associated with the production of improved fuel quality and sets out estimated of costs and greenhouse impacts associated with changes to refinery operation.

The structure of this chapter is as follows:

Section 7.1 presents a discussion of the technologies employed for transport fuel production in Australian refineries and describes existing fuel quality and refinery capacities. Section 7.2 describes the methods available to improve Australian fuel quality. Section 7.3 describes the process used by the refineries to model the refinery changes and predict costs to meet fuel quality requirements. Section 7.4 presents the assessments of costs for the scenarios modelled. Section 7.5 discusses the reasons for differences between cost estimates for different refineries. Section 7.6 summarises the key issues for refiners. Section 7.7 summarises the cost implications for each of the scenarios considered and Section 7.8 identifies the key findings from this chapter.

7.1 AUSTRALIAN REFINING INDUSTRY TECHNOLOGIES

Australian refining industry technologies are outlined in this section as follows:

- The generic process-plant elements of a typical oil refinery; and
- The specific process-plant configurations of Australia’s eight major oil refineries. Depending on process-plant (and viable feedstocks), product qualities differ for the eight refineries.

7.1.1 The Typical Oil Refinery

Refinery Overview

Petroleum is a mixture of crude oil and natural gas, which are extracted from the ground and transported by pipeline and/or ship to refineries, where the petroleum is processed into refined products such as petrol, diesel, lubricating oil, fuel oil and bitumen.

Crude oil quality varies enormously depending on its source. “Crude” may be light or heavy, pale or dark, sweet or sour (low or high in sulfur), paraffinic or naphthenic, and high or low in heavy metals.

The basic petroleum products are typically LPG, petrol, jet-fuel, diesel and fuel oil. Other products may include naphtha (as solvents or petro-chemical feedstock), wax, luboil and bitumen. The product slate (or off-take ratios), and the required qualities of these many products can also vary significantly with location and time.

As refinery technology and operation are tailored to average crude type and product slate, actual refineries differ significantly in both size and process plant detail, and thus have different product quality capabilities and constraints. The age of the plant and the prevailing environmental standards also often influence a refinery's current performance potential.

In general terms however, the typical oil refinery functions as follows:

Crude oil is separated into different fractions by atmospheric distillation. The crude oil is heated to 350 to 400^0C and the vapour and liquid are piped into a distilling column. The vapour rises and the liquid falls to the bottom. Heavier hydrocarbons condense more quickly and settle on the lower trays, and lighter hydrocarbons remain as vapour for longer and condense on the higher trays.

Light fractions are drawn from the trays and removed. The light gases, methane, ethane, propane and butane pass out the top of the column, petrol and naphtha are collected in the top trays, kerosene and gas oils in the middle, and fuel oils at the bottom. The residue drawn out of the bottom may be used as fuel or further processed. (Ref: AIP web page)

Further processing of these fractions is summarised below:

- Light gases are processed to remove impurities and produce LPG;
- Light gasoline is hydrotreated[1] and passed through an isomerisation plant. Isomerisation refers to the chemical rearrangement of straight chain hydrocarbons to produce branches attached to the main chain. This process produces higher octane products, making them better petrol blending components. The product of this process is gasoline;
- Naptha is hydrotreated and then passed through a catalytic reformer[2] to increase octane;
- Kerosene is hydrotreated;
- Light gas oil is hydrotreated and blended to distillate;
- Atmospheric residue may be burned as fuel, processed into lubricating oils, waxes and bitumen or used as feedstock for cracking units.

The main products from crude petroleum are summarised in Table 7-1, from Moeller (1989).

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[1] Hydrotreating is a method of removing impurities form intermediate or final products. The feedstock is mixed with hydrogen and heated to 300 to 380^0C. The oil combined with hydrogen then enters a reactor loaded with a catalyst which promotes reactions to remove sulfur, nitrogen, metals and other impurities.

[2] Reforming is a process which uses heat, pressure and a catalyst (usually containing platinum) to bring about chemical reactions which upgrade naphthas (hydrocarbon mixtures containing many paraffins and naphthenes) to isoparaffins and aromatics, which are used to blend high octane petrol.

Table 7-1 Important Products from Crude Petroleum

	Boiling Range (^{0}C)	**Composition**	**Source**	**Principal Uses**
Natural Gas	-	Mainly methane, some nitrogen	Natural sources	Fuel gas, also reformed to synthesis gas
Liquefied Petroleum Gas (LPG)	-	Propane, butane	Stripped from 'wet' natural gas or from cracking operations	Domestic and industrial fuel – production of coal gas, synthetic materials
Primary Flash Distillate	Varies	Propane and butane dissolved in gasoline-kerosene range of liquids	Preliminary distillation of crude petroleum	Manufacture of synthetic gas
Gasoline	25-175	Complex mixture of materials. Contains additives to improve performance but no sulfur or polymerisable components.	Primary distillation, cracking and reforming processes	Spark ignition internal combustion engines
Kerosene	135-300	Pariffinic hydrocarbons with substantial proportion of aromatics, low sulfur content	Distillation, cracking	Agricultural tractors, lighting, heating and aviation gas turbines
Gas Oil	175-345	Saturated hydrocarbons	Distillation, hydro-desulphurisation	Diesel fuel, heating and furnaces, feed to cracking units
Diesel Fuel	175-375	Saturated hydrocarbons, often with high sulfur	Distillation, cracking	Diesel engines, furnace heating
Fuel Oils	225-425	-	Residue of primary distillation, blended with distillates	Large scale industrial heating
Lubricating Oils	Wide range	Three types: mainly aromatic, mainly aliphatic, or mixed.	Vacuum distillation of primary distillate residue, solvent extraction	Lubrication
Wax	-	Pariffins	Chilling residue from vacuum distillation	Food, candles, petroleum jelly
Bitumen	-	Wide variation	Residue from vacuum distillation or oxidation of residue from primary distillation.	Road surfacing, waterproofing

Residue Conversion Technology.

The most distinguishing feature of any “typical” refinery is its chosen route for upgrading atmospheric residue. The yield of this heavy fraction ranges from about 10 to 70 percent of crude oil, with major quality variations depending on the origin of the crude.

While fractions of some atmospheric residues may be sold with little or no chemical change (as lube oil, fuel oil or bitumen), most have to be chemically “cracked” to smaller molecules to economically match market demand. Globally, three cracker types are widely employed to achieve this: fluid catalytic cracking, hydrocracking or thermal cracking. Capital costs and product qualities differ for each cracker type.

To upgrade bottoms of the lighter crude oils usually processed in Australia, the refineries use either a catalytic cracker, a hydrocracker or a lube oil plant (and sometimes a combination of these). Thermal cracking is not used in Australia. The locally used technologies are briefly discussed below.

Catalytic Cracking

Catalytic cracking is used to breakdown the heavy hydrocarbon fractions under controlled heat and pressure, in the presence of a catalyst. The catalyst is in the form of a very fine powder, which flows like a liquid when agitated by steam, air or vapor. The process yields more useful products, including petrol, LPG, unsaturated olefin compounds, cracked gas oils, cycle oil, light gases and solid coke residue.

Alkylation

Olefins (unsaturated hydrocarbons such as propylene and butylenes) produced by catalytic cracking may be combined with iso-butane (a small branched chain hydrocarbon), to form the larger branched chain molecules (iso-paraffins) that produce high octane petrol. A liquid acid catalyst is used (hydrofluoric acid, HF, or sulfuric acid, H_2SO_4). This process is known as alkylation.

Hydrocracking

Hydrocrackers can upgrade heavy vacuum distillates predominantly to high-quality diesel and jet-fuel (rather than to petrol). The hydrocracking process is a catalytic high temperature, high pressure process for the conversion of petroleum feedstocks in the presence of fresh and recycled hydrogen. (Speight, 1998) The naphtha by-product is further processed on the reformer.

Hydrocracking is a hydrogen addition process, consuming a significant flow of fresh hydrogen feed-gas. Besides cracking and hydrogenating feed molecules, hydrocracking reactors also remove approximately 99% of feed-sulfur as hydrogen sulfide so that all the hydrocracking liquid products are "sweet" (almost sulfur-free).

The main disadvantage of hydrocracking is its high capital cost, due to the extremely heavy steel vessels and other equipment necessary to contain its 150 to 200 bar operating pressures, plus the necessary ancillary hydrogen manufacturing unit.

Luboil Plant

Luboil Plant (LOP) capacities are expressed as output of lube product, rather than as intake of plant-feed. Using mainly a series of physical separation processes, a typical LOP complex yields only around 30% finished lube-stock on atmospheric residue feedstock. The remaining 70% of LOP feed emerges as vacuum distillates and residues which the refinery still has to either upgrade (eg. as fluid catalytic cracking feed and bitumen) or export (eg. as low price heavy fuel oil).

Blending of Road Transport Fuels

Petrol

The typical petrol blend components are:

- Butane (C_4-LPG, excellent octane, but very high volatility)
- Light naphtha (C_5/C_6 light naphtha, low octane)
- Isomerate (light naphtha converted to high octane branched paraffins, benzene-free)
- Naphtha (reformer feed, usually hydrotreated, low octane)
- Reformate (very low in sulfur, aromatics-rich, high octane);
- Alkylate (sweet, high-octane, low volatility, converted from LPG);
- Poly-gasoline (similar to alkylate, but with low motor octane number); and
- Catalytic cracked gasoline (olefins-rich, relatively high sulfur).

The two main components of a petrol blend are reformate and catalytic cracked gasoline (CCG). Most of the aromatics (including benzene) in a petrol blend come from reformate. However, virtually all the sulfur and olefins come from CCG. The percentage of sulfur in CCG is closely related to the percentage of sulfur in the fluid catalytic converter feed, and is most concentrated at the heavy end of CCG.

Diesel

Light gas oil and light cycle oil are by far the main components of diesel. However, a more comprehensive list of typical on-road diesel blend components includes:

- Kerosene (or "heavy naphtha", direct from the crude distillation unit);
- Straight run light gas oil, (off the crude distillation unit, without hydrotreating);
- Hydrotreated light gas oil, (light gas oil from more-sour crude oils, hydrotreated for approximately 90 % sulfur removal);

- Hydrotreated light cycle oil, (fluid catalytic cracked light cycle oil with poor cetane, hydrotreating lowers sulfur and olefinic gums);
- Hydrocracked gas oil (a low sulfur, high cetane component); and
- Hydrotreated vacuum gas oil, (from the vacuum distillation unit, if *pour point* is low. Pour point is the temperature below which the gasoil becomes waxy and no longer pours easily).

Fluid catalytic cracked light cycle oil is the poorest quality diesel component above, degrading overall blend parameters of storage stability, sulfur, cetane, and PAHs. To minimize these negative effects (particularly fuel stability), light cycle oil should always be hydrotreated via a hydro-desulfuriser unit before blending. In practice, the degree of hydrotreating often varies per refinery.

7.1.2 Australia's Eight Major Refineries.

Refinery Plant Size and Fuel Quality Data.

Table 7-2 shows total refinery intake is almost 40 million tonnes per year (Mtpa). Thus average refinery production is about 5 Mtpa, ranging 3.6 to 6.4 Mtpa.

Individual plant capacities are given as *% of CDU capacity* in Table 7-2. (Note that actual plant utilization may be much less than the plant capacity shown in Table 7-2, and equal-sized plants may differ in technology and so give different product qualities). This, together with variations in average crude quality, helps to explain petrol and diesel quality differences between the eight Australian refineries. This data illustrates the chemistry and plant changes needed to meet future fuel-quality goals.

The abbreviations used in the Table 7-2 are summarised below:

CDU	Crude Distillation Unit
$C_{5/6}$	Pentane / Hexane
HF	Hydrofluoric Acid
H_2SO_4	Sulfuric Acid

Table 7-2 Refinery Crude Capacity and Relative Plant Sizes, 1997 (AIP, 1998)

	Caltex		**BP**		**Mobil**		**Shell**	
Location - Major Refinery	Lytton QLD	Kurnell NSW	Bulwer Island QLD	Kwinana WA	Altona VIC	Port Stanvac SA	Geelong VIC	Clyde NSW
Refinery Capacity Mtpa (Total = 38 million tpa)	**4.6**	**5.4**	**3.4**	**6.4**	**5.3**	**3.6**	**5.3**	**4.0**
Crude Distillation Unit/s (×1000 barrels, per day) (Total = 812,000 barrels per day)	100	116	74	138	110	78	110	86
Relative Plant Sizes % CDU Atmospheric CDU %	100	100	100	100	100	100	100	100
Hydrotreating (of $C_{5/6}$, Kerosene) %	-	-	-	9	-	-	30	23
Isomerisation, Isosiv* (of $C_{5/6}$) %	8	8	0	11	0	13	7	0
Reforming (of hydrotreated naphtha) %	**26**	**26**	**18**	**16**	**32**	**33**	**28**	**23**
Fluid Catalytic Cracking	**33**	**39**	**28**	**24**	**21**	**-**	**36**	**41**
Alkylation, with HF or H_2SO_4 %	3.3	3.6	3.3	2.4	2.6	-	4.1	3.5
Catalytic Polymerisation %	1.6	1.4	-	1.5	-	-	2.5	1.4
Hydro-desulfurisation, (gasoil) %	9	14	13	13			13	12
Hydro-desulfurisation (gasoil, kerosene and naphtha) %					48	78		
Sulfur Recovery Unit %	**~0.2**	**0.16**	**0.35**	**0.37**	**0.06**	**0.28**	**0.86**	**0.90**
Vacuum distillation (including luboil) %	-	16	-	14	30	33	9	24
Luboil plant – Output Capacity %	-	3.3	-	2.6	-	8.0	2.7	-

Table 7-3 Australian Refineries – 1997 Average Pool Qualities of Petrol and Diesel (AIP, 1998b)

	All	**Caltex**		**BP**		**Mobil**		**Shell**	
Refinery Location **Petrol**	Aust Avg.	Lytton QLD	Kurnell NSW	Bulwer Island QLD	Kwinana WA	Altona VIC	Port Stanvac SA	Geelong VIC	Clyde NSW
Production Mtpa	13.1	1.9	2.3	1.1	1.6	1.8	1.0	1.7	1.6
RON-0	92.3	92.1	92.0	92.0	93.0	92.3	92.0	92.8	93.4
MON-0	82.6	82.6	82.4	82.3	82.9	83.1	83.7	82.4	82.3
Benzene % vol	2.9	2.4	2.4	2.9	2.1	4.3	3.4	2.9	2.7
Aromatics % vol	31	30.6	34.1	30.6	33.3	31.6	30.9	25.8	28.4
Olefins % vol	13	12.6	16.5	10.5	8.9	12.6	1.0	12.6	17.0
Sulfur ppm	193	70	181	350	292	216	22	90	224
RVP, Nov to Feb kPa	73	75.5	72.7	73.3	71.1	70.5	66.9	72.9	77.8
Density kg/m^3	734	736	734	732	729	737	740	729	740
Final boiling point deg.C	192	186	201	191	184	187	193	176	217
On-road Diesel :									
Production Mtpa	10.2	1.4	1.2	0.9	2.1	1.2	0.8	1.6	1.1
Sulfur ppm	1500	380	1400	2100	2100	1000	900	1600	2200
Cetane Index	51.1	50.2	50.0	50.4	49.5	51.9	58.8	48.6	51.0
PAH % m	3.5	n/a	n/a	2.2	4.0	n/a	n/a	n/a	n/a
T-95 deg.C	349	339	343	n/a	n/a	357	366	n/a	n/a
Viscosity at 40 °C, mm^2/s	3.2	3.1	3.2	n/a	1.9	3.2	3.2	2.9	3.5
Density kg/m^3	847	843	852	842	845	847	835	850	855

MON – Motor Octane Number, test method to measure gasoline octane number
RON – Research Octane Number, test method to measure gasoline octane number
RVP – Reid vapor pressure, measure of volatility
PAH – polycyclic aromatic hydrocarbons
T-95 – Temperature at which 95% of the gasoline distills
NOTE: Fuel parameters are discussed in Section 2.2.1 of this report.

Links between Fuel Quality and Process Plant

The data presented in Tables 7-2 and 7-3 above are discussed in further detail below.

- **Lytton**. Lytton's gasoline is quite low in sulfur (70 ppm), despite the large size of the fluid catalytic cracker. This may be due partly to the low sulfur content of the crude, but also to a relatively low final boiling point on cat-cracked gasoline, which excludes much of the sulfur in cat-cracked gasoline. In 1997, Lytton's average diesel had only 380 ppm sulfur, the lowest in Australia. This may be due to Lytton's 1995 large hydro-desulfuriser unit.

- **Kurnell.** Kurnell and Clyde gasolines have about 17% olefins, the highest in Australia. This is a result of these refineries having Australia's largest fluid catalytic cracking units.

- **Bulwer Island**. The percentage of sulfur in petrol from this refinery is higher than the industry average, probably due to high sulfur crude oils, and the higher than average final boiling point of cat-cracked gasoline. The sulfur composition of Bulwer's diesel was also high in 1997, at 2100 ppm, indicating that this refinery was not yet deeply desulfurising its light Gasoil and light cycle oil.

- **Kwinana.** Petrol produced at Kwinana has quite low olefins (due to a relatively small fluid catalytic cracking unit) and low benzene (due to a fairly small reformer and a large isomerisation unit). Compared with the Australian average, Kwinana diesel is high in sulfur and low in cetane, most probably due a feed slate rich in high sulfur Middle East crude.

- **Altona**. Altona and Port Stanvac have the biggest reformer ratios (33% of crude distillation unit capacity). Consequently, the benzene composition of petrol is also much higher than average for these two refineries. Sweet Gippsland crude at Altona keeps sulfur in both petrol and diesel lower than the industry average.

- **Port Stanvac.** Gasoline produced at this refinery has extremely low olefins (1%) and low sulfur (22 ppm), and the diesel has the highest cetane-index of all diesel produced at Australian refineries. This is due primarily to the absence of a cat cracker at Port Stanvac. Uniquely among Australian refineries, atmospheric residue is upgraded only by a luboil plant at Port Stanvac.

- **Geelong.** The petrol produced at this refinery has an average of only 90 ppm sulfur, possibly due to hydrotreating much of fluid catalytic cracker feed in Geelong's hydro-desulfuriser unit, which thus avoids high levels of sulfur in the catalyst cracked gasoline.

- **Clyde.** Gasoline pool octane is a full one point higher than the Australian average. This is facilitated by Clyde's super low-pressure CCR (Continuous Catalytic Reformer, 50 psi reactor outlet pressure) which can give higher yields of higher octane reformate than possible with most other reformers. Clyde also has the biggest fluid catalytic cracker capacity (40% of crude distillation unit capacity), which explains why the olefins content of petrol is Australia's highest, at 17%. Clyde diesel has 2200 ppm sulfur (the industry high), due to Clyde's relatively old and undersized hydro-desulfuriser reactor.

7.2 METHODS OF ACHIEVING FUEL QUALITY CHANGES IN AUSTRALIAN REFINERIES

This section describes the processes which can be used to deliver the range of fuel quality improvements called for in the scenarios modelled.

7.2.2 Reduction of Reid Vapour Pressure (RVP) in Petrol

Petrol RVP arises mostly from butanes, whose average RVP is around 350 kPa. Pentanes, with about 17 kPa RVP, also add volatility, but to a much lesser extent.

Butane comes partly with crude intake, but occurs mostly as a by-product of the conversion processes (i.e. naphtha reformers and the various crackers). RVP can be reduced in two basic ways: by removing butane and C_5's (by fractionation or reaction) or by reducing the formation of butane and C_5's (United Oil Producers 1994).

Australia's gasoline-pool RVP situation is outlined in Table 7-3. For Euro 2,3 and 4, the same RVP-range is allowed as a function of "volatility class" (varies with location and season) and petrol E70 (a measure of the proportion of volatile components). Australian conditions would be similar to those in France, Italy and Greece with Class 1 in summer and Class 3 in winter. For average local petrol with 33% E70, (AIP 1998b), Table 7-3 gives the RVP ranges allowed by the European Union. (CONCAWE 1997). Class-1 is the most stringent situation, with the lowest gasoline volatility (or RVP); Class-3 is less demanding, for cooler climatic conditions. Very cold conditions permit classes up to 7 or 8, allowing more volatile petrol blends.

Table 7-4 then shows actual summer and winter national pool RVP's, and the required reduction to meet the adopted target of 60kPa for summertime under the central Scenario 4 conditions (see Table 7-5) with target RVP for other seasons set to be consistent with this value. Under these assumptions the reduction in RVP required would be 13 kPa for all seasons. Table 7-3 lists five summer months, as per USA practice (CONCAWE 1998). Winter is taken as five months.

Under guidelines set out by the World Wide Fuel Charter (WWFC) Australia's typical average summer and winter would be seen basically as Class B and Class-C, based on minimum ambient temperatures, with recommended RVP ranges of 55 to 70 kPa and 65 to 80 kPa respectively. The proposed target RVP's presented are within these spans. WWFC Classes B and C are comparable to CONCAWE's classes 1 and 3.

Table 7-4 Required Reduction in Petrol Reid Vapour Pressure (RVP)

Period	**EU Volatility Class**	**RVP (kPa)**			
		Euro 4 (E70=33%v)	**Adopted Euro 4 Target**	**Australian Average 1997**	**Required Reduction**
Summer: November - March	1	35 – 68	60	73	13
April and Oct			65	78	13
Winter: May - September	3	45 – 78	70	83	13

Source: Concawe (1997)

In Australia the annual petrol pool contains around 800,000 tpa of butane. Butane thus contributes about 35 kPa to the pool's average RVP of 78 kPa. Thus to drop the average RVP of Australia's total annual gasoline pool by approximately 13 kPa would require around 300,000 tpa of petrol's current high-octane butane to be used elsewhere, (with the lost petrol volume and octane replaced by other components).

The technical options to extract and dispose of this 300,000 tpa surplus butane are:

a) Stabilizer column revamps. Refinery "stabilizer columns" (which distill butane from heavier gasoline molecules) still leave 1 to 2% butane in gasoline bottoms to minimize costs. Butane may be partly upgraded (eg. to alkylate), while unconverted butane is blended back into finished gasoline. Advanced fractionation and heat exchange technology can substantially improve the refinery's ability to remove butane products and minimize RVP. (United Oil Producers 1994).

b) Burn butane as refinery fuel gas. This is only to the extent that refinery natural gas imports can be backed out, and usually natural gas imports are quite small. Beyond that level, butane surpluses could only be burned in the refinery by flaring. However, this is considered unacceptable economically and environmentally.

c) Sell butane as fuel for LPG vehicles. With national LPG sales (to all consumers) of around 2 Mtpa, it would not be possible to quickly absorb an extra 0.2 Mtpa of butane into the existing Australian LPG market. Longer term usage of LPG as vehicle fuel will be dependent on government price incentives and the number of LPG-vehicles available on the market.

d) Convert butane to MTBE. In order to produce MTBE, surplus normal-butane must first be converted to iso-butylene and then reacted with methanol to make MTBE. In all, three process plant types (and possibly inter-refinery butane transport) are required. Thus, the overall investment would be relatively large.

e) Alkylate butane to iso-octane. Alkylate has high octane, low RVP and zero aromatics. Surplus normal-butane must be converted partly to iso-butane (in an isomerisation plant) and partly to butylene (in a dehydrogenation plant). These two products are then reacted in a third process plant to make alkylate.

7.2.3 Benzene Reduction in Petrol

Catalytic reformate typically contributes about 80% of benzene in the gasoline pool. This can be reduced in two basic ways (United Oil Producers 1994):

- Minimize benzene formation by removing its precursors in reformer feed. To reach moderate benzene levels (about 2.5%), this can be a minimal cost option.
- Fractionate a benzene-rich light reformate stream for subsequent benzene conversion or extraction. To reach the low levels of benzene adopted for the modeling of Euro 3 and 4 in this study (1%), such more expensive steps would probably be necessary.

Benzene has a very high octane (RON=106, MON=103). Hence its removal lowers the octane rating of the remaining petrol blend, an effect which may then be offset by upgrading the octane of an existing component (eg. light naphtha, by isomerisation) or by adding a new high octane component (eg. MTBE or TAME).

Precursor Removal and Processing

Reformation (which upgrades naphtha by increasing average molecular weight) results in benzene formation from C_5 and C_6 components.

A sharp-cut naphtha splitter is required, to distill a light naphtha (C_5/C_6 top product with negligible C_7 carry-over) from a C_7/C_8^+ bottom product (with minimal C_6) which alone goes to the reformer. The light naphtha may be blended direct to gasoline, or if more pool octane is needed, light naphtha can be sent to an isomerisation unit.

Light Reformate Processing

Some C_7^+ naphtha molecules de-alkylate to benzene in the reformer reactors. Therefore, to achieve very low benzene levels in petrol (less than 1% by volume), it may be necessary to distill the benzene fraction out of reformate product and further process this light reformate.

United Oil Producers (1994) gives four basic options to remove benzene removal from light reformate:

- Saturation. This hydrotreating process converts benzene to cyclo-hexane, but reduces light reformate octane by about 6 points;
- Isomerisation with saturation. This process saturates benzene and isomerises hexanes to give a net RON gain of about 5;
- Alkylation with propylene. This route also increases RON by about 5. It needs no hydrogen, but depends on the availability and price of propylene; and
- Extraction. This requires expensive fractionation, extraction and special storage (for pure toxic benzene) and is chosen only by refiners with a benzene market.

7.2.4 Sulfur Reduction in Petrol

In the Australian gasoline pool, unhydrotreated catalytic cracked gasoline (CCG) contributes over 90% of the total sulfur. Thus to lower pool sulfur from 300 ppm down to 50 ppm (as required by Euro-4), refiners have to desulfurise catalytic cracked gasoline only. To achieve this, besides changing to sweeter crude oils, a combination of the following steps can be used in the refinery:

Undercut Catalytic Cracked Gasoline. In many cases, the fluid catalytic cracker's main fractionator can be operated to move the heaviest 15 to 25% of catalytic cracked gasoline to light cycle oil, which alone can eliminate 30 to 50% of gasoline-pool sulfur. While this is a good start (particularly with high diesel demand), it is generally not sufficient to lower petrol pool sulfur to less than 50 ppm.

Cat Feed Hydrotreater (CFH). In removing most of the sulfur from the vacuum gasoil used as fluid catalytic cracker feed, a CFH unit greatly lowers sulfur in all fluid catalytic cracker products. It also lowers sulfur dioxide emissions from the unit chimney stack, and improves total fluid catalytic cracker distillate yield. The CFH process can achieve 50 ppm sulfur from catalyst cracked gasoline. If the full atmospheric residue feed cannot be hydrotreated, then a vacuum distilling unit is also required to first separate vacuum gasoil as feed for the CFH. While technically the best in all cases, the CFH process is also relatively expensive with a large feed rate, high operating pressure (130 to 150 bar) and large hydrogen consumption relative to the alternative of a small hydrotreater for heavy cat-cracked gasoline (HCCG).

Hydro treatment of HCCG. About half of the sulfur is usually in the last (highest boiling point) 10% volume of catalyst cracker gasoline. Sulfur content typically rising steeply in cuts boiling above 200°C. Normally the full-range of catalyst cracked gasoline is not hydrotreated because saturation of olefins would occur, with consequent loss of octane (8 RON, 3 MON) and because hydrogen demand may strain supply. However the heavy end of catalyst cracked gasoline is low in olefins and so this last 10 to 30% fraction of catalyst cracked gasoline can be desulfurised, with minimal octane loss and maximum impact on pool sulfur. This treatment requires a catalyst cracked gasoline splitter (new distillation column) plus a small 50 to 70 bar hydro-desulfuriser unit. If spare capacity exists on an existing gasoil hydro-desulfuriser unit, HCCG can be co-processed there to achieve 99% sulfur removal.

Mercaptan Extraction from LCCG. At low cost and with zero octane loss, the splitter's 70 to 90 % vol cut of light catalyst cracked gasoline (LCCG) can be run through a simple Merox Extraction Unit. This removes 90% of the mercaptan sulfur, equivalent to 20 to 30 % of full-range catalyst cracked gasoline sulfur.

Treating both LCCG and HCCG separately is an efficient way to meet gasoline pool sulfur targets of 30 to 50 ppm. After recombining treated LCCG and HCCG, octane loss is only 1.2 RON and 0.2 MON. To recover this in the pool, reformer severity must be increased by only 1 RON. (United Oil Producers 1998)

7.2.5 Octane Increase in Petrol.

Table 7-2 shows an industry average need for an increase in Motor Octane Number (MON) of 1 to meet 83.4 MON in the unleaded pool. MON and RON (Research Octane Number) are different measures of octane. The target for MON in unleaded pool fuel is 83.4 for the current demand mix for unleaded and premium unleaded petrol. Only Port Stanvac now meets this target, due to its relatively large reformer and isomerisation plants, and the absence of a fluid catalytic cracker which would tend to reduce its pool octane. After pool octane decreases due to lower butane and benzene levels post Euro-4, the overall increase needed will be between +2 MON and +4 MON taking account of the higher percentage of PULP in the gasoline pool. All refineries will have to increase reformer severity (with revamps in some cases), install or revamp Isomerisation units and/or add MTBE to petrol. Oxygenate addition is likely to be the most expensive route. (Zyren, 1996).

7.2.6 Sulfur Reduction in Diesel.

With a sulfur specification of 5000 ppm, today's typical Australian diesel blend would be approximately:

- 50% straight-run light gas oil from sweet crude oils such as Gippsland. With sulfur contents ranging 300 to 700 ppm, this component is needs no desulfurising;
- 20% light gas oil, from sour / heavy crude oils such as Arag Light or Murban. With 7,000 to 13,000 ppm sulfur, such gasoils must be run via an hydro-desulfuriser unit; and
- 30% catalyst cracked light cycle oil. Regardless of sulfur content, this light gas oil component should be hydrotreated to ensure good storage stability of the diesel blend.

Thus, of the 10 Mtpa diesel production shown in Table 7-2, it is roughly estimated that about 5 Mtpa comes from sweet components that have not run through a hydro-desulfuriser unit. The average blend result is on-road diesel with around 2200 ppm sulfur.

To meet the Euro 3 diesel specification of 350 ppm sulfur, since virtually all components will have to be desulfurised, the total additional hydro-desulfuriser capacity required in Australia will be in the order of 5 Mtpa (an average increase of around 1800 tpd per refinery).

To meet the Euro 4 specification of 50 ppm sulfur, the same additional capacity will be required, but with increased desulfurisation capability. Basically, this requires bigger volume, higher pressure, more expensive hydro-desulfuriser reactors. Thus the way to reduce sulfur in diesel from 1500 ppm (the Australian pool average in 1997) to only 50 ppm is technically clear, though expensive (United Oil Producers, 1998). Most refineries will need to install a deep hydro-desulfuriser unit plus ancillary equipment which may include:

- New or revamped naphtha reformer, to make more hydrogen (and octane);
- Steam-Methane Reformer, alternative to make more hydrogen; and
- Sulfur Recovery Unit - additional capacity.

7.3 Modelling The Impacts Of Changes To Fuel Quality

Cost estimates for processes including those described above were assessed by linear program modeling by specialist engineers of Australian refineries, including modeling of new plant and alternative feedstocks for several of the proposed fuel quality scenarios. The results are therefore specific to the location of the refinery and the fuel quality scenario being addressed.

Most of the oil companies participating in this review used their existing operating refinery linear programming (LP) models to validate sophisticated spreadsheet models. Compared with LP-models, these spreadsheet models are easier to modify to reflect the addition of new process plants (with new product yields, qualities and energy demands) and new fuel specifications. The latest spreadsheet models also include advanced optimiser routines.

The modelling of options towards a ‘minimum cost’ response to fuel quality changes is subject to assumptions / perceptions about the external business environment, internal constraints, relative operating and capital costs of competing technologies and corporate financial goals. Therefore, a wide range of equally valid ‘minimum cost solutions’ is to be expected from the modelling process. Increases in operating costs, as well as capital costs, were considered.

7.4 Assessment Of The Cost Implications Of The Proposed Scenarios On The Refining Industry

The following discussion presents consolidated cost data from Australia’s eight major oil refineries. Refinery specific data is presented to the extent allowed by confidentiality undertakings made to the companies who provided the information.

Cost estimates were evaluated relative to Scenario 1, which includes all costs to reduce petrol Reid Vapour Pressure (RVP) to a level which satisfies current tighter Australian volatility specifications. The cost of Scenario 1 is taken notionally as nil.

The central costing estimates presented in this section are the cost increases (relative to the base case) of producing fuel to meet Euro 4 specifications for fuel quality, as defined by Scenario 4.

The oil refinery representatives found it was too complex and impractical (with the resources available) to develop cost estimates for Scenarios 2, 3, 5 and 6 to the same level of detail as Scenario 4. Rather, additional data was indicated as overlays on Scenario 4, where this was seen as being relevant.

The costing variations for Scenarios 2, 3, 5, 6 related only to petrol as all scenarios called for the same diesel quality as Scenario 4 (with the exception of 30 ppm sulfur in diesel for Scenario 6), as discussed in Section 7.4.5.

Therefore, the most complete data provided by refiners was for Scenario 4. Figures 7-2,7-3, and 7-4 have been derived to present consolidated costs of Euro 4 diesel and petrol (relative to base case, Scenario 1). An overview of the core data for Scenario 4 is discussed in Sections 7.3.1 to 7.3.4.

The fuel quality specifications adopted for the modelling process are summarised in Table 7-5. As discussed in Chapter 5, best endeavours cases were included in which elements of fuel quality specification which do not affect engine or control technology performance were relaxed to assess if this would result in significant savings in refining costs. As for the Euro 3 and Euro 4 specification the Best Endeavours Specifications represent limits which would apply to each batch of fuel.

TABLE 7-5 FUEL QUALITY SPECIFICATIONS ADOPTED FOR THE MODELLING

	Euro 3	**Euro 4**	**Euro 3 Best Endeavours[1]**	**Euro 4 Best Endeavours[1]**
Petrol				
RON min	95	95	95	95
MON min	85	85	85	85
RVP (summer) kPa max	60	55	65	62
Distillation:				
Evaporation @ 100^{0}C %v/v min	46		Open	46
Evaporation @ 150^{0}C %v/v min	75		Open	75
Final Boiling Point ^{0}C max	210	205	215	210
Hydrocarbon analysis				
Olefins	18	14	Open	18
Aromatics	42	(35)	48	42
Benzene	1	1	3	2.5
Oxygen content (% m/m max)	2.7	2.7	2.7	2.7
Oxygenates (% v/v max)				
Methanol	3	3	3	3
Ethanol	5	5	5	5
Iso-propyl alcohol	10	10	10	10
Tert-butyl alcohol	7	7	7	7
Iso-butyl alcohol	10	10	10	10
Ether: 5 or more C atoms	15	15	15	15
Other	10	10	10	10
Sulfur content (mg/kg) max	150	(50)	150	50
Lead content (g/L) max	0.005			
Diesel				
Cetane No min	51	55	49	51
Cetane index min	46	52	45	46
Density at 15^{0}C kg/m^3 max	845	845	860	845
95% point ^{0}C max	360	350	370	360
Polycyclic aromatic hydrocarbons %m/m max	11	4	Open	11
Sulfur mg/kg	350	(50)	350	50

NOTE: Numbers in brackets ( ) indicate currently specified elements of Euro 4. The values for the other parameters were agreed as reasonable choices in the absence of formal specifications.

1: Target levels agreed by members of the Australian Institute of Petroleum

Section 7.4.1 states the formula used to calculate the costs to the Australian refineries of meeting fuel quality changes, and provides a discussion of the costs associated with significant parameters, plus an estimate of total costs for Euro 4 standard petrol and diesel.

7.4.1 Formula for Refining Cost of Fuel Quality Changes

Estimates reviewed in the literature are often provided in very different currencies, on different volume units, and from different technical bases. To reduce these diverse results to one common parameter of Australian cents/litre (c/L)[3] and so facilitate comparisons, the following formula is used for this study:

$$D = (C/5 + A) / 12 . F \qquad \textbf{Equation 7-1}$$

where	D = Incremental refining cost	c/L
	C = Capital costs	$ million
	A = Annual operating cost	$ million pa
	F = Fuel production	Mtpa

This formula is founded the following process and economic bases:

- The cost of capital (for interest and capital repayments) has been taken as around 20% pa of capital employed (therefore M$pa cost =C/5). This equates to the annual fixed payment to discharge a capital loan in 7 years at 10% interest rate;
- The annual operating cost includes the usual obvious costs (energy consumption, manpower, maintenance etc) plus the net cost of purchasing more crude or other material (eg MTBE) needed to replace liquid volume or quality downgraded by the selected new conversion process;
- The fuel amount involved in the study is rounded off to three significant figures, approximating 1Mt as 1200ML (rough average conversion for petrol and diesel); and
- Incremental refining cost (c/L) = total cost increase (cents pa) / total liquid fuel (L.pa).

7.4.2 Refinery Costs Associated with Scenario 4

The cost data provided by the refineries were assembled by a chemical engineer with substantial refinery experience. The costings provided by each refinery were compared to assess consistency across refineries and where anomalies were identified the results were challenged. The costing information set out in the following sections reflects the information provided and is considered reasonable.

In the case of petrol significant costs were associated with reduction of sulfur, olefins, aromatics and benzene. These changes are particularly problematic in conjunction with the projected increase for octane demand.

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[3] In this document all references to costs are in 1999 Australian currency unless otherwise noted.

Sulfur in Petrol

Reduction of sulfur content in petrol would generally be achieved by treatment of the catalyst cracked naphtha stream. This process would generally be sufficient to achieve petrol sulfur concentrations as low as 30 ppm.

Olefins

The data provided by the oil refineries indicates that mandating the 14% olefins in Euro 4 (rather than maintaining current 16 to 17% peak-levels) would force two refineries equipped with large fluid catalytic crackers to:

- Increase their combined total capital expenditure by approximately $170 million;
- Increase their petrol costs by an average of 0.9 c/L; and
- Increase total greenhouse gas emissions by approximately 100,000 tpa CO_2.

Aromatics

The information provided by the refineries indicates that the cost of decreasing aromatics from 42% (specified for Euro 3) to 35% (specified for Euro 4) will be very high. To satisfy the projected future increased demand for high octane fuels, existing naphtha reformer severities would normally be increased to make more high-octane aromatics. However, a specification of 35% aromatics would remove this option for increasing the octane content of the fuel, leaving refiners with more expensive options such as new investment (eg. isomerisation and alkylation units) and additives (eg. MTBE and MMT).

One oil refining company has estimated that by 2020, the *additional* cost for their two refineries to lower aromatics from 42% (Scenario-4 in 2005) to 35% (Scenario-4 in 2008) would be 1.0 and 2.1 c/L. The different cost estimates are related to the different site configurations and capacities.

Volatility – Reid Vapor Pressure (RVP)

Experience in Sydney is that it has proven possible to achieve summertime RVP reductions to 67kPa at modest cost (less than 0.1c/L) by removal of butane. Costs will increase for the 2000/2001 summer when summertime RVP is to be limited to 62kPa through an agreement between NSW EPA and the Sydney based refineries.

Depending upon the starting point, initial reductions in RVP can be made cheaply but costs increase for subsequent improvements. Costs to achieve a nominated RVP improvement vary significantly from refinery to refinery. As discussed in Section 7.2.2 removal of butane is the primary mechanism for lowering RVP. The cost associated with this process arise from the additional plant required for the separation of butane from product streams and the losses associated with disposal of the extracted butane. Use in automotive LPG is controlled by demand growth and market factors which differ from refinery to refinery. Replacement of natural gas used to fuel refinery operations is limited by existing gas demand. Storage of butane for subsequent reuse is expensive as large pressurized spheres are required and existing storage facilities are limited. At some refineries it would be necessary to flare excess butane.

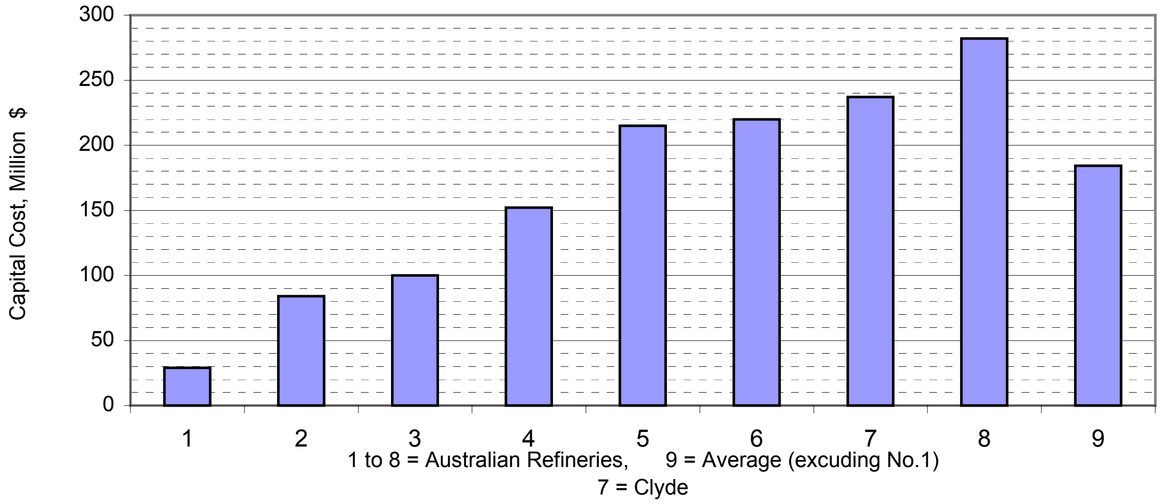
Increase in Octane

Delivering increasing octane demand while simultaneously removing high octane components of fuel was identified by all oil companies as technically challenging and costly. A discussion of this problem is contained in Section 7.2.5.

7.4.2.1 Total Capital Expenditure

The data supplied by Australian oil refineries indicates that the production of Euro 4 diesel and petrol (including 50 ppm sulfur for both fuels) would require Australian oil refineries to invest a total additional **$1320 Million (M)** above what is already planned. At one refinery, a substantial proportion of the work required to achieve Euro 4 diesel and petrol is already committed in existing programs. Excluding this refiner, capital investment per refinery averages $185M. The capital cost range is shown in Figure 7-1.

Figure 7-1 Total Capital Costs to Provide Euro 4 Diesel and Petrol



The “yet-to-invest” caveat excludes BP’s Queensland refinery where the investment to make Euro-4 fuels has already been approved and construction is well underway. Likewise, to avoid distortions, Bulwer Island data is excluded from the average unit costs reported below. Data for the Shell Clyde refinery is included, though Shell has indicated that they have difficulty seeing a future for the Clyde refinery beyond 2006. The Clyde costs are included in the total, but may not be incurred in Australia due to Shell’s position regarding the future operation of the refinery. The shortfall in supply, should Shell Clyde close, would be met by a combination of increase in production form remaining refineries and imports. If the Shell Clyde refinery were excluded the total cost of production of Euro 4 fuels to the six refineries still to invest would be $1050 million or $175 million per refinery.

Due to refining technology advances, including improvements in catalysts, the above $1.3 billion total is about $700 million less than would have been the case a decade ago. However, in the present global situation of very low gross refiners' margins, $1320 million still represents over 15 years of total after-tax profit for the entire downstream oil industry. Profit was just $ 81 million in 1997. (Financial Review, 18 November 1999). Some local refiners are concerned that Euro 4 investment demands could trigger refinery closures in or before 2006.

7.4.2.2 Total Operating Expenditure

For Australia's eight refineries, operating expenditure would increase by a total of $136 million/year for the production of Euro 4 fuels, an average of $17 million/year per refinery.

Carbon trading permits could add to these costs. However, given the uncertainty regarding the timing and detail of introduction of carbon trading, costs associated with carbon trading are not included in any of the costs presented in this report.

7.4.2.3 Incremental Cost Of Production

Allowing a capital charge at 20% pa, the average extra capital plus operating costs for local refining of Euro 4 fuels would be:

- Euro 4 Diesel 1.5 c/L
- Euro 4 Petrol 1.1 c/L

The bar charts in Figures 7-2 and 7-3 show the capital and operating costs for each Australian refinery, expressed in cents per litre, with refinery names suppressed at oil company request. Costs assessed for the Shell Clyde refinery are identified in Figures 7-2 and 7-3, as Shell has indicated that the future of the Clyde Refinery is uncertain beyond 2006. A range of costs is evident, depending on existing configuration and size for each of the seven refineries represented. A more detailed discussion of the differences in cost estimates form the refineries is provided in Section 7.5. Those sites facing potential costs significantly above the Euro 4 average are at more risk of closure. In a November, 1999 press release Shell indicated

> *… On our present industry outlook, it is difficult to see a future for our Clyde refinery beyond 2006. …*

Costs associated with the production of higher fuel quality were noted as a significant factor in their outlook.

The above Australian cost estimates are comparable with recent European estimates for the costs involved in the production of Euro 4 fuels. As discussed in Section 2.2, CONCAWE (1999) report *EU oil refining industry costs of changing gasoline and diesel fuel characteristics* estimated the average cost for the production of Euro 4 petrol to be 0.9c/L (based on 50ppm sulfur) and 1.6c/L for the production of Euro 4 diesel (average cost in increase cetane number from 51 to 55). Increasing cetane number beyond 56 for the EU as a whole was found to be impractical and a cetane number of 56 was considered a practical upper limit and required the use of a cetane improver additive.

Figure 7- 2
Estimated Cost of Production of Euro 4 Petrol

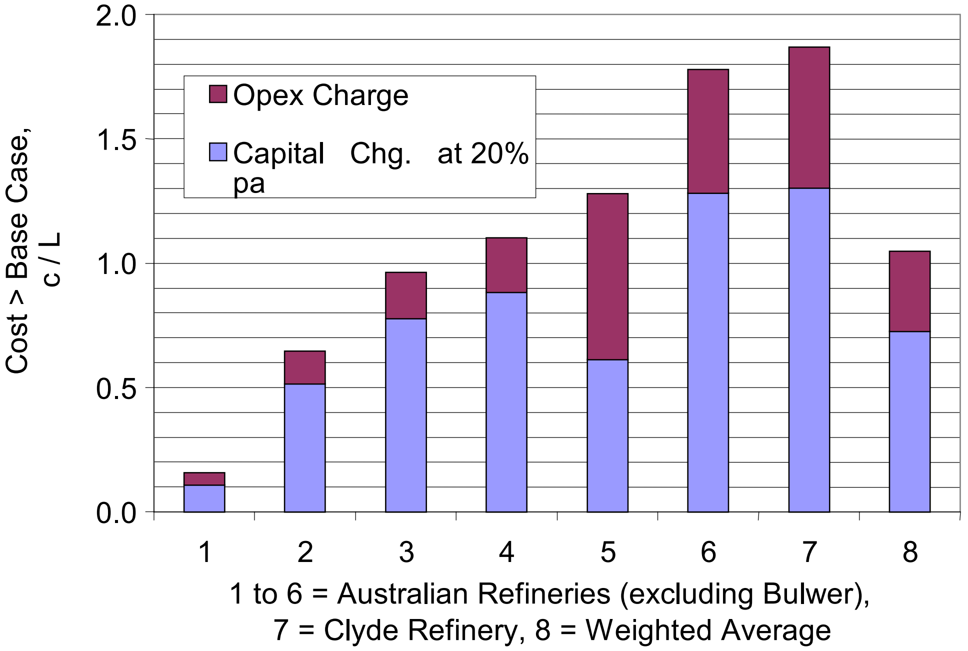
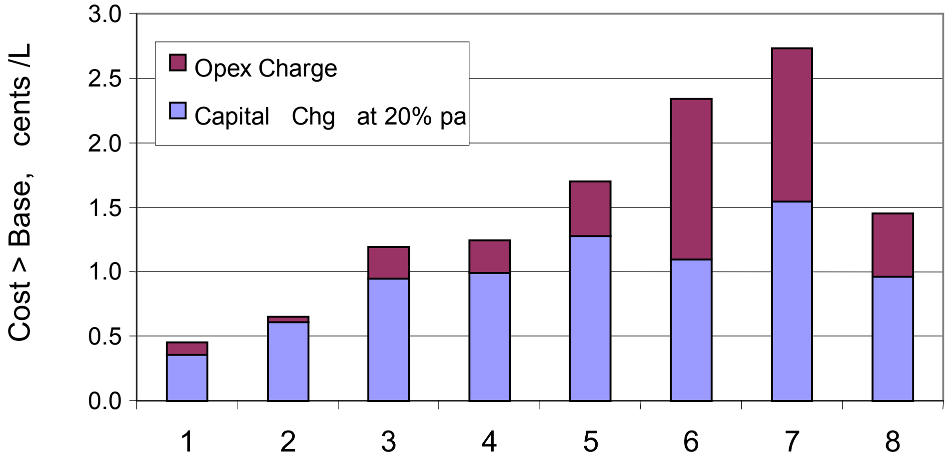


Figure 7- 3
Estimated Cost of Production of Euro 4 Diesel

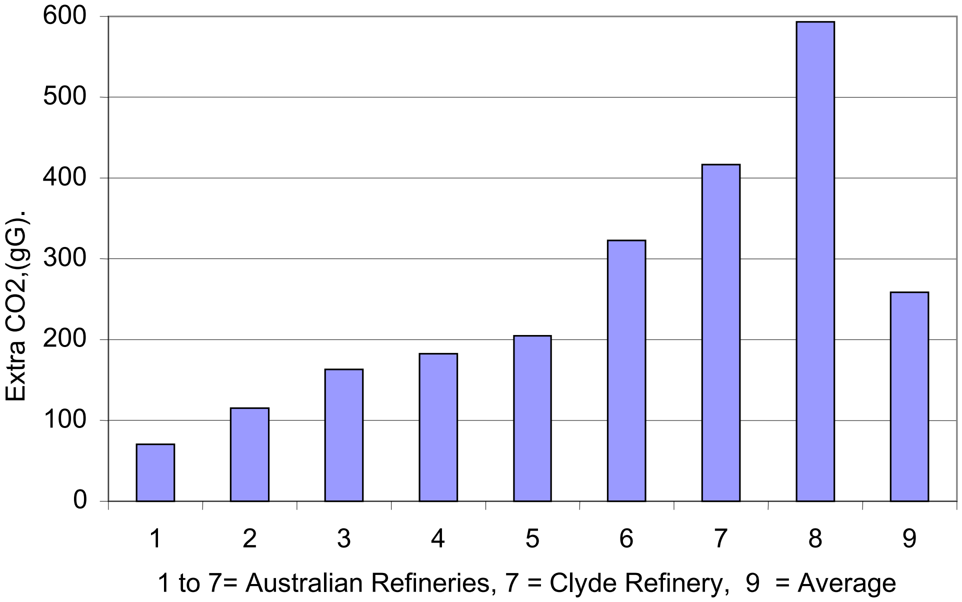


1 to 6 = Australian Refineries (excluding Bulwer), 7 = Clyde Refinery
8 = Weighted average

7.4.2.4 Potential Costs Associated with Increased Greenhouse Emissions

The production of Euro 4 fuels will increase energy consumption in refineries, and therefore increase greenhouse gas emissions. The increased energy consumption will result from direct fuel burning in process furnaces, carbon rejection to make hydrogen and by remote electricity generation. It is estimated that total greenhouse gas emissions from the eight refineries will increase by 2.1 million tonne pa CO_2 equivalent. The estimated increase in greenhouse gas emissions from the eight refineries is illustrated in Figure 7-4.

Figure 7- 4
Estimated Additional Greenhouse Gas Emissions for the Production of Euro 4 Fuels (Relative to Euro 2 Fuels)



The costs of greenhouse gas emissions may well include carbon trading permits. Refineries will generally not be able to fit the additional emissions into any allocation based on historical emissions and will have to buy additional permits to cover the cost of fuel quality improvements. As the timing and detail of introduction of carbon trading is unclear, possible costs associated with permits for increases in greenhouse gas emissions are not included in the assessment of refining costs.

7.4.3 Refinery Costs Associated With The Production Of Fuels For Scenarios 2,3,5 and 6, Relative to Scenario 4

In developing the refinery costs, Scenario 4 was treated as a central scenario and savings or additional costs associated with Scenarios 2, 3, 5 and 6 were estimated by comparison with Scenario 4. This approach was followed as it was not feasible for the refineries to develop separate costing for each of the scenarios considered. A cost comparison against the baseline (Scenario 1) is presented following the discussion presented below. A description of the development of scenarios modelled is presented in Chapter 5.

7.4.3.1 Refinery Costs Associated with Scenario 2

Scenario 2 (‘MVEC/MBE (Explicit) Option’) includes the tightening of the specifications for petrol to Euro 3 rather than Euro 4. For refineries equipped with large fluid catalytic crackers, this can cut the estimated Scenario 4 capital costs by over $100 M, and operating costs by approximately $10 M pa. The extra unit cost of petrol (in c/L) for such sites would be reduced to about 0.5 c/L.

7.4.3.2 Refinery Costs Associated with Scenario 3

As outlined in Chapter 5, Scenario 3 ('Best Endeavours' – MVEC/MBE (Implicit) Option') includes the introduction of Euro 4 petrol in 2008, with parameters other than sulfur concentration and RVP set on a refinery best endeavours basis. The parameters chosen as estimates of the refinery's 'best endeavours' are summarised in Table 7-5. Euro 4 diesel would be introduced under this scenario in 2006, with specific requirements for 50 ppm sulfur.

Data supplied by the oil refineries for Scenario 3 indicates that capping benzene at 3% (in comparison with the 1% specified in Euro 4, as modelled by Scenario 4) would:

- Reduce industry wide capital costs by approximately $100 million (average capital cost per refinery by about $18 million);
- Reduce petrol costs by 0.2c/L compared to Scenario 4 (over 20% of the total cost increase of 1.1 c/L);
- Reduce refinery greenhouse gas emissions by 500,000 tpa CO_2.

The cost analyses undertaken by the refineries indicated that relaxing summer RVP to 65kPa (compared to 60 kPa for Euro 4) would have little, if any, cost impact on Australian refineries, since essentially all the work to reach the 60 kPa of Euro 4 will be done in Scenario 1.

7.4.3.3 Refinery Costs Associated with Scenario 5

Scenario 5 'Euro 4 transport fuels by 2006' includes the setting of all parameters for petrol and diesel to Euro 4 specifications from 1 January 2006. Scenarios 5 and 6 call for supply of high octane (98 RON) fuel to new vehicles from 2008/2009.

98-RON PULP combined with 35% Aromatics
The Euro 4 specifications lower most of the traditional high-octane components (benzene, aromatics, olefins and butane) in the national gasoline pool. Over the period 2008 to 2020, Scenarios 5 and 6 include an increase in pool-octane by up by 4 points to over 97-RON, with 98-octane Super-PULP rising to 65% of the pool.

All refiners advised that a 98 RON pool of more than 10 to 15% was infeasible without massive amounts of MTBE. One refining company showed that changing from near Scenario 2 petrol (95 RON PULP with 42% aromatics) to Scenario 5,6 petrol (98 RON Super-PULP with 35% aromatics) would raise unit cost of petrol by 3.7 c/L at their two refineries. Relative to Scenario 4 petrol (at 35% aromatics from 2008), the introduction of 98 RON PULP alone in Scenarios 5,6 would eventually raise costs by a further 2.3 c/L. It was estimated that 80% of this cost increase would be from the incremental cost of MTBE purchases, with the balance due to capital charges on large new reformer and isomerisation units.

7.4.3.4 Refinery Costs Associated with Scenario 6

Scenario 6, the ‘most stringent case’, includes the introduction of 30ppm sulfur in petrol and diesel from 2008.

The costing analyses undertaken indicated that lowering the sulfur content of diesel to 30 ppm could usually be done at marginal cost (for a slightly bigger, hotter hydro-desulfuriser-type reactor), typically adding 0.1 to 0.2 c/L to diesel cost.

For most refineries, to lower the sulfur content of gasoline from 50 to 30 ppm required no capital expenditure, just some increase in operating costs for hotter hydrotreating. In some cases, a reactor size increase, or a sulfur guard bed was required, thus raising industry-wide petrol cost by around 0.1 c/L.

7.5 DIFFERENCES IN REFINERY COST ESTIMATES

All four oil companies (BP, Caltex, Mobil and Shell) have plans for 50 ppm sulfur in both fuels. Notably, the companies which delivered the most comprehensive and detailed cost estimates were also usually the ones with the highest cost estimates. They presented very clear strategies and funds for dealing with Euro 4 specifications such as 55 Cetane number diesel and 98-RON petrol. Often companies with lower estimates had smaller problems to solve. For example, low sulfur and low olefins in petrol is easy to achieve without cat-cracked gasoline. Likewise, with existing high capacity for sulfur removal, low sulfur diesel can be less costly.

The cost estimates for each refinery depends strongly on:

1. Existing (or lack of) refinery plant type, technology and size. For example:

    a) Overall refinery capacity – (significant economy of scale effects);
    b) Fluid Catalytic Cracker (makes the olefins which go into petrol and most of the PCA’s in diesel. The poor quality effects of these components are expensive to correct).
    c) Isomerisation Plant- usefully raises octane of straight-run light naphtha;
    d) Alkylation Plant – converts volatile, olefinic LPG to low-RVP / high octane alkylate;
    e) Naphtha Reformer – spare capacity can quickly make more octane-barrels, and more hydrogen;
    f) Hydrogen Manufacturing Unit – may be essential for the removal of sulfur from diesel;
    g) Small gasoil hydro-desulfuriser – suitable for conversion to naphtha hydro-desulfuriser service; and
    h) Utilities infrastructure.

2. Diverse long-term company forecasts of crude and feedstock supply, including:

    a) Light / heavy differential prices (and availability);

- b) High / low sulfur differentials;
- c) Aromatics differentials (eg. can influence decision on a gasoil hydrogenation reactor);
- d) Finished product blending components (to correct sulfur, octane, cetane etc.); and
- e) Low quality product export prices.

3. Company Culture
   - a) Less Conventional – perhaps more innovative / less risk averse.
   - b) Conservative approach, designs cost more but sure to work

4. Models for the increase in demand for high octane fuel

Another key factor which widens the range of estimates is the difficulty (and optional choices) of modelling the increased demand for high octane fuels. While Euro 4 petrol specifications might be mandated in 2008, the actual pool octane required is dictated by the ever changing composition of the national vehicle fleet.

For two or three years, the increased demand for high octane fuel might be addressed at zero capital cost simply by using an additive such as MMT. In due course, investment in isomerisation plant is normally required. Finally, for the long term pool octane specifications of Scenarios 2 to 6, MTBE (or some equivalent blend-stock) would usually be required.

Apart from the six scenarios of this review, most oil companies also have their own internal scenario ideas. Several refiners have observed that the present underlying gasoline volume projections may well become irrelevant should some alternative technology (such as the electric or fuel-cell vehicle) displace the traditional petrol-vehicle.

7.6 KEY ISSUES FOR REFINERS

Some of the key issues that were considered by the oil refining companies in their review of the scenarios and in undertaking the cost estimates are summarised below.

Automotive LPG as a Vital Butane Sink
The Euro 3 summer RVP of 60 kPa will be met largely by sharper, higher cut points in existing gasoline stabilizer columns to remove more butane as top product. In some cases capital expenditure will be needed for column revamps and for increased butane storage plus upgraded LPG distribution facilities.

The refiners have assumed that incremental butane outputs will be readily absorbed into the growing auto-LPG market. In fact, auto-LPG is a major key to refinery viability. Refiners stressed the importance of avoiding lower specifications for olefins or higher excise duties on auto-LPG so as not to constrain this vital butane outlet.

Olefins Level in Euro 4 Petrol

As outlined in Section 7.3.5, Scenario 5, mandating olefins at 14% (rather than 18% of Euro 3) would require industry capital expenditure of \$170 million. The literature review undertaken for this project does not indicate a clear corresponding benefit in terms of reduced motor vehicle emissions.

Aromatics level in Euro 4 Petrol

As also shown in Section 7.3.5, lowering aromatics from 42% to 35% will add 0.6 c/L to the long term cost of making Euro 4 petrol.

Reduction in aromatic content will also force refiners to blend octane enhancers such as MTBE or MMT into gasoline to meet octane requirements. In the case of MTBE fuel efficiency is reduced because of the lower calorific content.

Gasoline Pooling

The idea behind pooling is to achieve a nominated fuel quality averaged over time or grades. This concept would apply to parameters such as benzene, olefin and aromatic content as these parameters do not affect vehicle engine or control systems. The idea is that emissions would vary with time or for different fuel grades (say unleaded fuel and premium unleaded fuel) but the average emission rate would be same as if fuel quality did not change. This would allow some quality parameters to be relaxed at some times or in some grades to reduce production costs while maintaining a particular emissions outcome.

One pooling concept put forward was to meet benzene aromatic and olefin requirement, on average, across the range of octane grades supplied. The specified values would be exceeded for high octane grades (95RON and 98RON) and this would be offset by a corresponding reduction for low octane grade petrol (unleaded). This would allow the emissions impacts to be controlled, while reducing costs for production of high octane fuels. This was seen as a transitional arrangement as, over time, it is expected that the bulk of petrol supplies would be premium unleaded (95RON).

Treatment of imported fuel in an equitable way under a pooling scheme would be problematic and would need to involve some form of averaging over multiple shipments.

MTBE / MMT Octane Extenders

While some refiners prefer not to use these if possible, if increased demand for high octane fuels is coupled with extreme reductions of aromatics and olefins, they may eventually have no choice.

International Fuel Studies

The CONCAWE 1999 report ‘Fuel Quality, Vehicle Technology and their Interactions’ emphasises that the real benefits from fuel quality changes come when they ‘enable’ new motor vehicle technologies. It was also stated that fuel properties should be specified only where there is a clear link to vehicle performance or emissions, and that fuel effects on economy and CO2 emissions must be considered on a ‘well to wheel’ basis.

Australian oil refiners consider that Euro 4 specifications should not be mandated in Australia until the European debate on the Euro 4 specifications is resolved.

7.7 SUMMARY OF THE ESTIMATED AVERAGE COST IMPLICATIONS OF THE PROPOSED SCENARIOS ON THE REFINING INDUSTRY (RELATIVE TO SCENARIO 1)

Table 7-6 summarises the estimated average cost implications of the proposed fuel quality scenarios on the refining industry.

Table 7-6
Summary of Average Fuel Cost Increases (Compared with Scenario 1)

Scenario	Increase in operating costs per refinery	Increase in capital cost per refinery (2008 cf. base)	Increase in petrol production cost by (c/L)		Increase in diesel price (c/L)
			2008	2020	
1	0	0	0		0
2	$7M pa	$85M	0.5	0.8	1.5
3	$7M pa	$167M	0.9	1.2	1.5
4	$17M pa	$185M	1.1	2.1	1.5
5	$79M pa	$260M	1.4	5.3	1.5
6	$79M pa	$260M	1.4	5.3	1.6 to 1.7

Notes:

1. The above c/L sums are the oil refining company’s incremental production costs (not prices). The actual price increases at the bowser may be impacted by imports of overseas surplus petrol and diesel.
2. Scenario-5 costs are virtually the same as Scenario-6 costs, since both have the same tighter specifications on olefins and the introduction of 98 RON PULP. They differ only marginally in timing, and the reduction of sulfur in petrol from 50 to 30 ppm.
3. For Scenarios 5 and 6, (relative to Scenario-4), the average increase in capital and operating costs are:
   a) for olefins, about $25 M for capital costs and $3M pa for operating costs, resulting in a cost increase of 0.3 c/L from 2008, plus
   b) for 98 RON PULP, about $50M for capital costs and $60M pa increased operating costs, resulting in a further cost increase of 2.9 c/L by 2020;
   Therefore, the total increased cost for Scenario 6 in 2020 is approximately 5.3 c/L.
4. Due to the range of viable operating and plant change options available, and also due to the multiple interactions and synergies between nearly all refinery plant investments, it is impossible to precisely identify, isolate and quantify costs pertaining to just one particular fuel quality change (eg. aromatics or olefins). The numbers in the table above are estimates only.
5. Costs are relative to Scenario 1. The cost of Scenario 1 was taken as zero, as the refinery models were developed on the basis that operations and projects required for ‘business as usual’ are already in place.

7.8 SUMMARY OF KEY ISSUES

Refinery costs associated with delivery of a range of fuel quality scenarios were assessed. In the case of diesel fuel quality, all scenarios except the base case (Scenario 1) assessed the cost to reduce sulfur content to 50ppm. For Scenario 6 the most stringent of the scenarios considered sulfur content reduction to 30ppm in 2008. The reduction of sulfur level in petrol to 50ppm was addressed in most of the scenarios. This is consistent with the European Euro 4 petrol standard.

The cost to the Australian refining industry of improved fuel quality standards will be significant. Capital costs associated with introduction of Euro 4 fuel standards for petrol and diesel are estimated at $1320 million. This figure does not include capital programs already committed which will deliver significant fuel quality improvements.

Operating costs increases for production petrol and diesel meeting Euro 4 fuel standards are estimated at $136 million Australia wide. These costs do not include additional operating costs which would arise from programs already committed.

Taking account of capital and operating costs, the increase in the cost of production to produce Euro 4 fuel standards over Australia is 1.1 c/L for petrol and 1.5 c/L for diesel. The costs of meeting Euro 4 standards would varies substantially from refinery to refinery depending upon the existing refinery configurations and crude sources.

Increases in greenhouse emissions of 2.1 Mtpa of carbon dioxide from Australian refineries are predicted in 2010 for Scenarios 4, 5 and 6. If petrol specifications were limited to meeting 50ppm sulfur and other parameters met the Euro 4 ‘best endeavours’ criteria adopted for this study then the increase in greenhouse emissions from refineries is predicted to be 1.6 Mtpa in 2010. A discussion greenhouse emissions is presented in Chapter 6.

Cost Sensitivities

Reduction in olefin level from 18% which is currently specified for Euro 3 fuel to 14% which was adopted for the definition of Euro 4 fuel used in this report (olefin content is currently unspecified in the European standard) would result in production cost increases of the order of 0.9 c/L by 2020.

Estimated production costs were sensitive to the assumptions in relation to octane demand. Substantial production cost increases were assessed if a large proportion of the petrol vehicle fleet were to be supplied with 98 RON petrol coupled with tight constraints on olefin and aromatic content. Should 98 RON petrol be required relaxation of the limits on olefin and aromatic content may need to be considered and use of octane enhancers such as MTBE and MMT may be required. This will be particularly important in regions were octane enhancement additives (such as MTBE) are excluded by State regulators for environmental reasons.

Costs for achieving reductions to petrol volatility (RVP) are strongly influenced by the availability of a productive means of for using butane. Cost effective achievement of further reductions in RVP are linked to growth in the market for LPG which represents a productive use for butane with potential to absorb substantial volume.

Following commissioning of plant to achieve petrol with sulfur content of 50ppm reduction of sulfur concentration from 50ppm to 30ppm could be achieved at modest cost by the oil industry. Recent indications are that emerging advanced vehicle emission control technology may depend upon very low sulfur levels in petrol and diesel. Reductions below 10ppm in petrol would involve substantial capital expenditure as treatment of a wide range of blend stocks would be required. Reduction to 30ppm could generally be achieved by treatment of the catalyst cracked gasoline stream alone.