APPENDIX 3.3

*(referred to in paragraphs 3.26, 3.27 and 3.28)*

# The technology of petrol production[1]

1. Petrol is one of a range of petroleum products which are jointly produced from the refining of crude oil. The other main products of the refining process are naphtha which, like petrol, is one of the `lighter' or more volatile products, gas oil, derv, jet kerosene and paraffin, which are in the middle of the product range, and heavier residual products including fuel oil and bitumen.

2. Petrol, derv and jet kerosene are used to power transport and there are few economically attractive alternative fuels for these uses. Naphtha, which is a raw low-grade form of petrol, can be further processed to make higher-grade petrol and is also used as a feedstock in petrochemical plants. Gas oil is burnt in small to medium-sized boilers and is also, as derv, used in diesel engines and as a petrochemical feedstock. Fuel oil is used in large boilers in power stations and industry and may be used as a base feedstock to make lubricating oils. In many applications other fuels, such as coal or gas, can be used as alternatives to gas oil and fuel oil, although switching fuels may require additional investment.

3. The simplest refinery is a `hydroskimming' or `topping' refinery. In such a refinery crude oil is passed through a furnace to be heated to a temperature of about 400°C, then passing to a distillation or fractionation column. A temperature gradient is created in the column so that products with different boiling points can be separately collected. At the top petrol and naphtha, with boiling points of typically up to 160°C, condense. Below that, kerosene accumulates with a boiling range of typically 150°C to 250°C and lower down the tower gas oil, with a boiling range of 250°C to 350°C, is collected. At the bottom of the column residues, with boiling points above 350°C, are withdrawn; these include heavy fuel oil, bitumen and lubricant feedstocks. The petrol and naphtha which are produced from simple distillation are not usually of saleable quality. In particular the octane rating of the raw petrol is deficient. To produce saleable material raw naphtha will, after being treated to remove sulphur compounds, be reformed through reaction with a platinum catalyst and hydrogen to produce higher octane petrol.

4. As the demand for petrol has expanded relative to the demand for middle distillates and residues, more sophisticated upgrading processes have been developed to increase petrol yield. The commonest form of upgrading is fluid catalytic cracking (FCCsometimes called `cat cracking'). Here heavy distillates, which have been distilled from the residue stream under vacuum, are passed through a catalyst bed reacting to produce petroleum gases, petrol and gas oil (the carbon-fouled catalyst being continuously recirculated so that excess carbon can be burnt off).[2] Whilst the cracking process reduces the molecular size from the large molecules of fuel oil to the medium-sized molecules of petrol, the refiner may also invest in plant that expands molecule size so that petroleum gases can be transformed to larger molecule petrol. Such plant includes alkylation and polymerisation units. As cat cracking tends to produce significant volumes of petroleum gases such units will normally also be employed in an upgrading refinery. Figure 1 shows a simplified flow diagram for upgrading plant augmenting a simple hydroskimming refinery.

5. The yield of petrol and other petroleum products that the refiner obtains depends both on the type of refinery operated and the type of crude oil refined. Every crude oil has its own characteristics and yields petroleum products in different proportions. Crude oils produced in the North Sea are relatively light, and about a quarter of their distillation yield is petrol or naphtha. Middle East light crude, such as Saudi Light, has a distillation yield of petrol of less than 20 per cent. Apart from these simple yield differences there are also technical differences in the character of crude oils. Such distinctions can be important in determining the refiner's choice of crude; for instance, North Sea crude oil is less suitable for the production of residue for making lubricants than is Middle East crude. North

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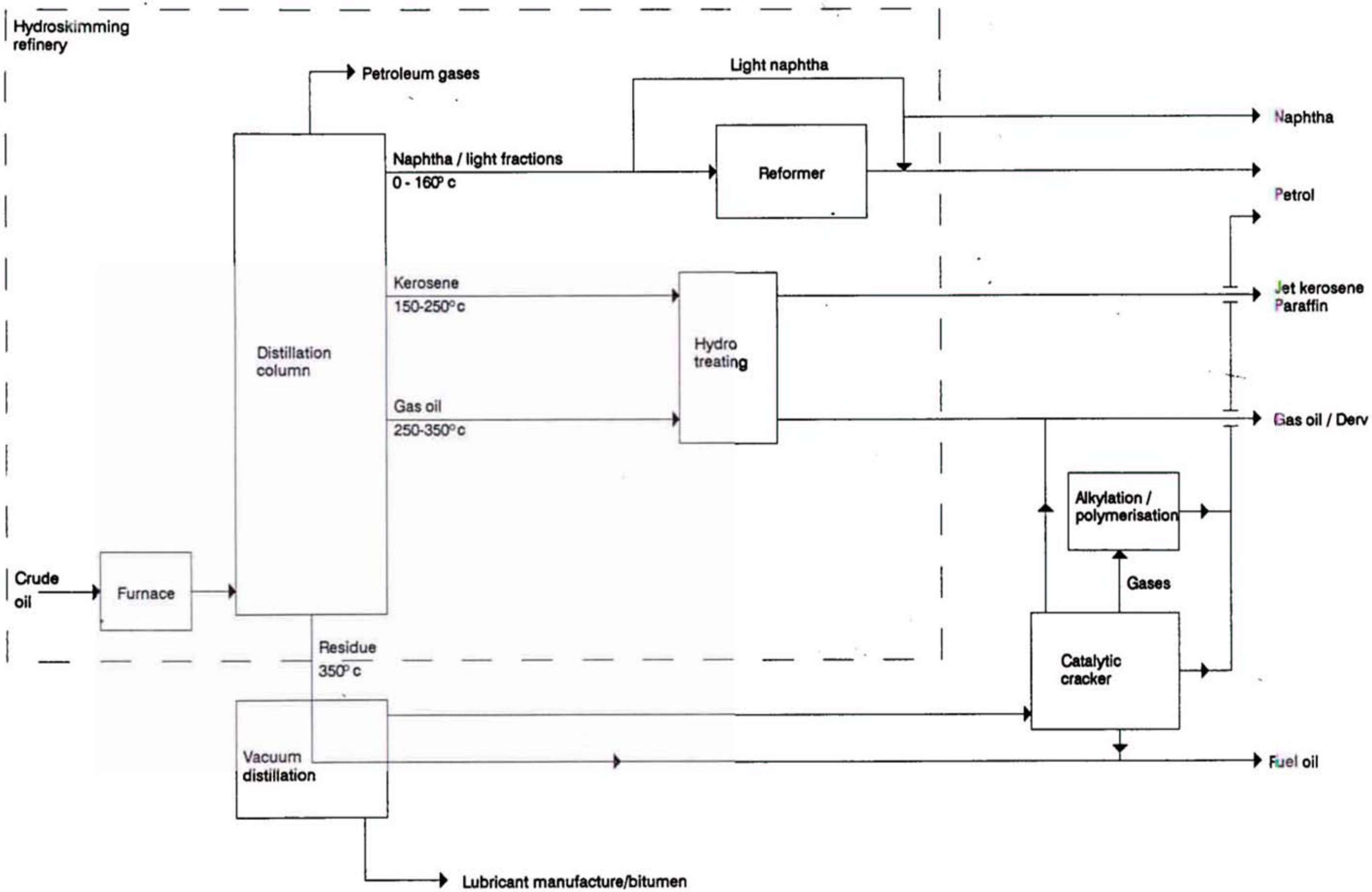
[1]In preparing this appendix we have been greatly assisted by an assessment of refining technology and economics provided by Chem Systems.

[2]This is not the only way of upgrading fuel oil to petrol. The refiner may choose slightly different reactions (including hydrocracking and thermal cracking), though with similar results.

FIGURE 1

**Simplified flow diagram of an oil refinery**




*Source:* MMC study.

Sea crudes are relatively low in sulphur, producing fuel oils with a sulphur level of less than 1 per cent, whereas Middle East crudes may yield fuel oils with about 4 per cent sulphur. Figure 2 gives a simplified representation of four yields that may be obtained with combinations of two typical crudes, North Sea and Middle East light, and two typical refineries, a simple `hydroskimming' refinery and an upgrading refinery with facilities to crack fuel oil into petrol and middle distillates. The petrol[1] yield shown here varies from 17 per cent from Saudi Light in simple distillation to 33 per cent for North Sea crude run in an upgrading refinery. The yields also allow for some of the residual fuel oil to be consumed within the refinery to fuel the refining process.

6. The yield structures shown in Figure 2 can only be regarded as indicative. The refiner and chemical engineer develop processes and procedures to adjust a refinery to provide the mix of yields that is preferred for their business. Most refiners have a degree of flexibility; traditionally simple refineries have tended to operate different yield patterns in summer and winter to mirror the seasonality of demand. In the case of petrol and naphtha the summer yield may exceed the winter yield by about 6 per cent with winter yields of middle distillates exceeding the summer yield by a similar proportion.

## The impact of changing petrol demand on refining

7. As described in paragraph 3.13, there has been a relatively strong growth in demand for motor spirit in contrast with the demand for some other petroleum products. Between 1974 and 1988 inland deliveries of all petroleum products in the United Kingdom fell by almost 30 per cent whereas petrol consumption rose by 40 per cent. In 1974 petrol accounted for 14 per cent of the output of United Kingdom refineries; in 1988 it accounted for 33 per cent. This change has been facilitated by a large investment by United Kingdom refiners in making their refineries more sophisticated. At the same time refiners have had to rationalise their basic distillation capacity. In 1974 the United Kingdom's simple distillation capacity was slightly less than 150 million tonnes per annum, with refinery throughput of 111 million tonnes. During the 1980s several United Kingdom refineries were closed and by 1988 United Kingdom distillation capacity was around 86 million tonnes with a utilisation rate of 90 per cent. In 1988 the United Kingdom's total cracking and conversion capacity was around 30 million tonnes, about 50 per cent more than in 1988. This investment in upgrading plant and rationalisation of basic distillation capacity reflects a wider trend that has been seen throughout Europe. Changes in the various types of refinery capacity between 1980 and 1988 are set out in Table 1. This shows similar rates of closure of primary distillation capacity in the United Kingdom and the rest of North-West Europe but a greater increase in cat cracking capacity in the United Kingdom.

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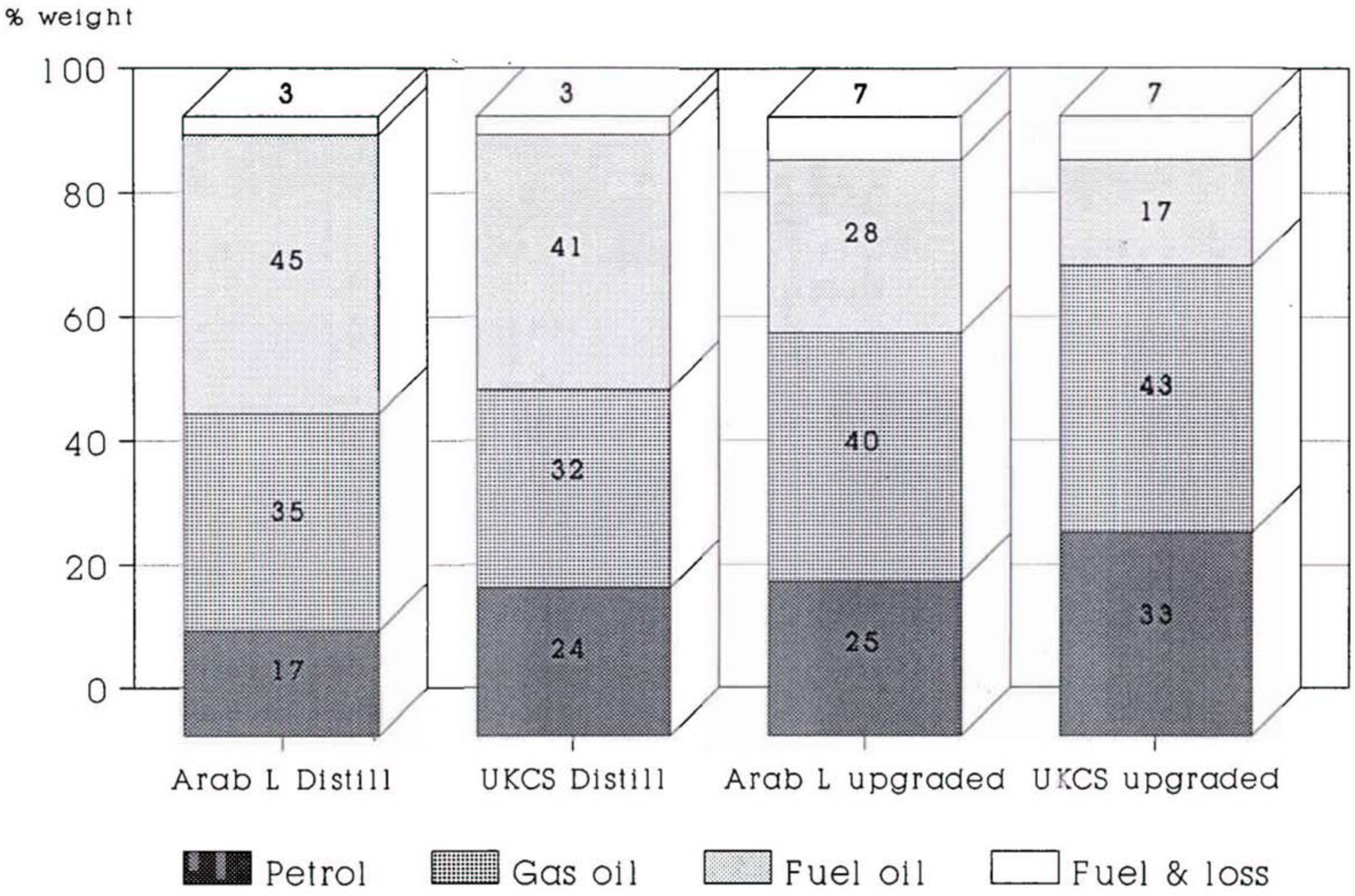
[1] In Figure 2 petrol is used generically to cover all light products including petrol and naphtha.

FIGURE 2

**Product yields with simple and upgraded refinery Arab Light and North Sea crudes, indicative**




*Source:* MMC study.

TABLE 1 **Capacity of processing units**

*million tonnes per year*

| *Process* | *United Kingdom* 1980 | 1988 | % change | *North-West Europe* 1980 | 1988 | % change |
|---|---|---|---|---|---|---|
| Atmospheric (or primary) distillation | 131 | 86 | -34 | 942 | 632 | -33 |
| Fluid catalytic cracking (FCC) | 8.9 | 19.7 | +121 | 54.9 | 87.6 | +60 |
| Hydrocracking | 2.1 | 2.5 | +19 | 9.9 | 18.9 | +91 |
| Thermal cracking | 5.5 | 2.9 | -47 | 25.7 | 24.8 | -4 |
| Visbreaking | 2.2 | 3.0 | +36 | 26.2 | 60.9 | +132 |
| Coking | 2.8 | 3.3 | +18 | 10.1 | 13.9 | +38 |
| Alkylation/polygas | 0.8 | 2.5 | +213 | 3.3 | 6.8 | +106 |
| Naphtha isomerisation | 0.4 | 0.9 | +125 | 3.3 | 5.9 | +79 |

*Source:* Chem Systems.

## Trade in petroleum products

8. This structural change in the demand for petrol and other petroleum products and in the capacity of refineries to produce them has had a marked impact upon the overall petroleum product balance of the United Kingdom. In 1973 the United Kingdom was a net importer of oil products, although it had a very large surplus of gas oil of more than 5 million tonnes. At that time the United Kingdom's net imports of petrol were about 2.5 million tonnes, almost 15 per cent of its consumption. Since 1982 the United Kingdom has been a net exporter of petrol and in 1988 net exports of petrol (after deducting imports) amounted to more than 3 million tonnes, equivalent to about 13 per cent of domestic consumption. Figure 3 summarises the United Kingdom trade balances in petroleum products. It will be seen that in 1988 the United Kingdom was a major exporter of petrol and gas oil, a net importer of naphtha (though much of this was for petrochemical use) and was in balance on fuel oil.[1]

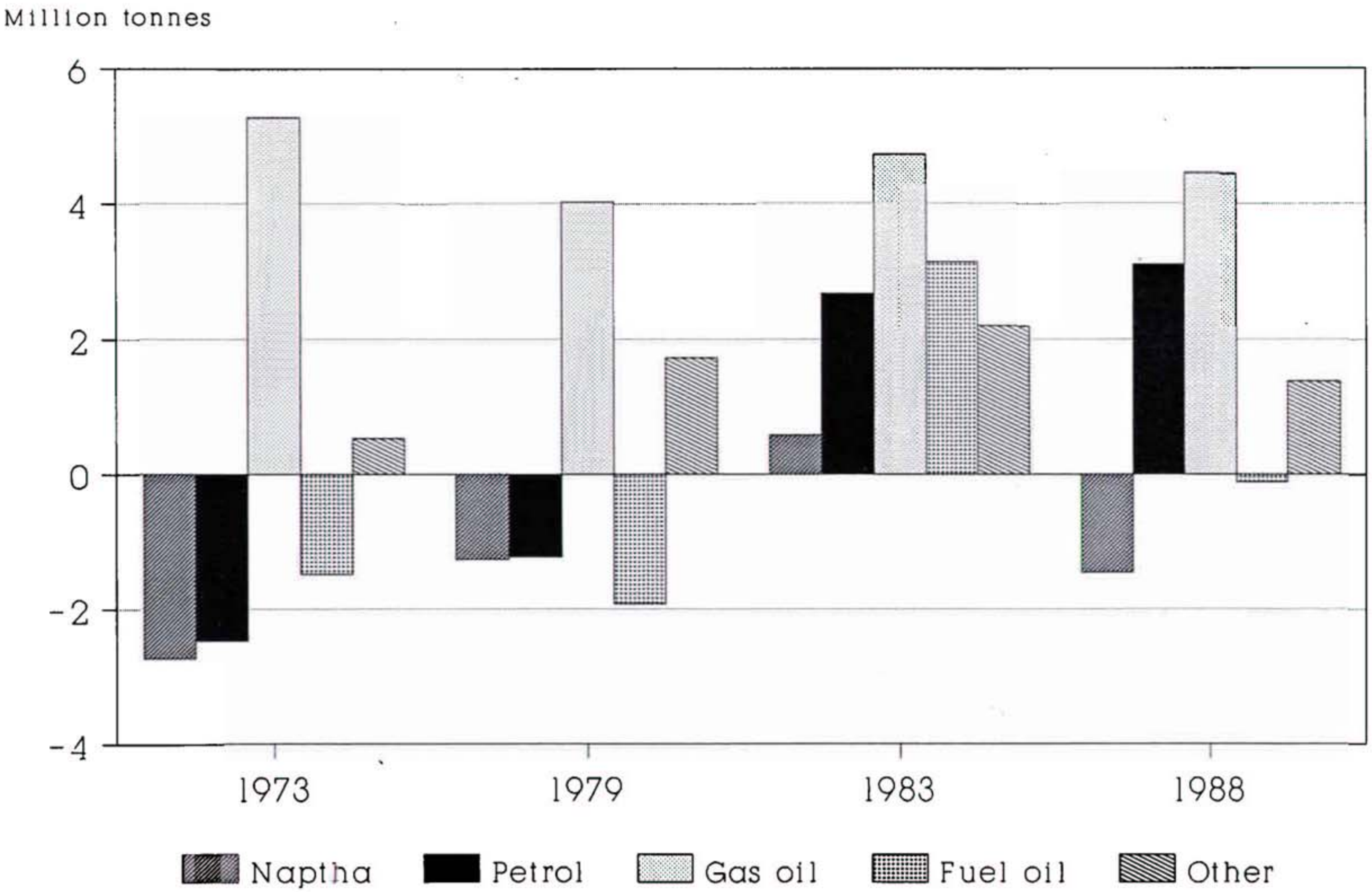
## Petrol quality

9. The efficiency of the petrol engine is related to its compression ratio (which is a measure of the extent to which gases are compressed in the cylinder). The higher the compression ratio, the more work will be derived from a given quantity of fuel and the better the average fuel consumption. However, increases in compression ratios also increase the propensity of the engine to knock. In a spark ignition engine the fuel air mixture is compressed in the cylinder and ignited by a spark. Normally combustion proceeds by a flame initiated at the spark plug which spreads evenly across the chamber until all petrol is burned. If unburnt gases spontaneously ignite ahead of the flame front (causing an excessive pressure rise) a characteristic `knocking' or `pinking' noise is heard. A measure of a fuel's resistance to knocking is its octane rating. Two separate octane ratings are measured for any fuel. The research octane number (RON) relates to mild operating conditions, such as are found during cruising and low-speed driving; knocking under such conditions may be audible to the driver. The motor octane number (MON) relates to more severe driving conditions, typically at higher speeds. This form of knocking may not be audible to the driver but may lead to engine damage and failure. The British Standard Specification for 4-star (premium) petrol is a minimum of 97 RON/86 MON though it is usually marketed at 98 RON. Until recently 2-star (regular) petrol was also marketed at 90 RON/80 MON. This has now been superseded by unleaded petrol at 95 RON/85 MON.

[1]Exports and imports for fuel oil were both over 3 million tonnes and constituted a major element of the United Kingdom's international trade in petroleum products. However, fuel oil is not homogenous; some is traded to achieve a sulphur premium, and other material traded will cover a range of grades varying from upgrading feedstocks to bitumen.

**FIGURE 3**

**United Kingdom net expo.'s of products - selected years**




*Source*: MMC from DEn data.

10. Raw petrol from the distillation column has a RON of about 75. There are a number of ways in which the refiner can increase the octane rating of raw petrol to achieve a saleable product: catalytic reforming (as described above); the addition of lead additives (normally tetra ethyl leadTEL); and by adding petroleum gases, such as butane, to the petrol. Until 1986 petrol in the United Kingdom could contain up to 0.4 grams per litre (g/l) of lead. The effect of this addition was to add about six points to the octane rating.

11. Apart from the methods outlined above for increasing the octane of petrol in a simple refinery, more expensive routes may also be used. Certain alcohols and ethers, collectively referred to as oxygenates, having very high octane numbers can be used as blending components to boost octane quality; methyl tertiary butyl ether (MTBE) is the most widely used. Such blending components are generally more expensive than petrol, consistent with their superior blending properties.

12. Recently there has been a growth in public concern about the addition of lead to petrol. Apart from octane improvement, as discussed above, trace lead also provides a valve lubricant. In the absence of lead it is necessary for engines running on unleaded petrol to have specially hardened valve seats.[1] In 1986 the maximum permitted amount of lead in petrol in the United Kingdom was reduced from 0.4 g/l to 0.15 g/l. In consequence since then refiners have achieved the required octane ratings on petrol by greater use of methods outlined above. This has raised the costs of petrol production, although the impact has been relatively small. In 1989, after fiscal incentives in the 1987 and 1989 Budgets and at a time when environmental concern was being increasingly reflected in consumer decisions, demand for unleaded petrol grew rapidly. Whereas at the end of 1987 4-star petrol accounted for about 90 per cent of petrol used in the United Kingdom and sales of unleaded petrol were less than 1 per cent by the third quarter of 1989 unleaded petrol accounted for about 26 per cent of petrol sold. Unleaded petrol is marketed in accordance with a proposed common European grade of 95 RON/85 MON.[2] With space restrictions for additional forecourt pumps and limitations within the distribution system most refiners in the United Kingdom have decided to phase out 2-star petrol in favour of unleaded which can usually be used instead. Although more processing is required to produce the desired standard of petrol in the absence of lead, the need for this (and its costs) are partially offset by the lower octane rating required for standard unleaded petrol compared with 4-star.[2]

13. Lead is not the only environmental problem with petrol which has been a cause of public concern. A maximum allowable benzene content of 5 volume per cent in petrol has been set by the European Commission. Gaseous emissions (of nitrous oxide, carbon monoxide and unburnt hydrocarbons) have also been the subject of proposed regulations. Such emissions may be limited by the fitting of three-way catalytic converters to the exhaust systems of cars. Such converters are not lead-tolerant and therefore have to be used in conjunction with unleaded fuel.[3] The European Commission is proposing to tighten the rules covering emissions from European motor vehicles; the route by which this will be achieved, whether by lean-burn engines or catalytic converters, is not yet agreed.

14. Other important quality characteristics of petrol are odour, gum-forming tendency and volatility. The first two are readily controllable by suitable treatment processes in the refinery. Volatility refers to the ease of vaporising of petrol. Volatility has to be sufficiently high to permit easy starting and quick warm-up in the cold, but not so high as to cause vapour lock on a warm day. It is controlled by varying the ratio of low and high boiling point components. Petrol volatility is also increased by the addition of butane and other gases as an octane improver. There has been environmental concern about the extent of emissions to the atmosphere of hydrocarbons from evaporation from fuel tanks, particularly when filling the vehicle, and from other parts of the petrol distribution system. These constraints are usually measured as the Reid vapour pressure (RVP). There have been suggestions to reduce the RVP of petroleum products.

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[1]For this reason some engines which can otherwise run on unleaded petrol require a tankful of leaded petrol every fourth or fifth tank filling to provide some such lubrication.

[2]A recent development has been the marketing of unleaded high octane grades at 98 RON (some of which are referred to as `super green'). The production of such unleaded premium petrol requires the blending of very high octane additives into basic petrol (eg MTBE). As such it is relatively more expensive to produce than standard premium unleaded (at 95 RON).

[3]In the United States the principal motivation for the use of unleaded petrol was to achieve tolerance in the catalytic converters so that gaseous emissions could be reduced.

15. Petrol marketed in the United Kingdom is of standardised grade (British Standard 4040 covers leaded petrol and British Standard 7070 covers 92 and 95 octane unleaded), although some refiners, seeking to improve and differentiate their product, include various additives, particularly detergents, in their petrol. There are significant differences in the specification of petrol throughout Europe. Unleaded petrol, with the benefit of an EC directive, has a proposed `eurograde' standard, similar to United Kingdom unleaded, that is not yet generally adopted in other EC markets.[1] Consequently United Kingdom distributors who import European-sourced product may either have to reblend it or, in some instances, face a quality give-away.

[1]As the British Specification for premium petrol is for a minimum of 97 RON it is possible that United Kingdom 4-star petrol could have a lower RON than Germany and other European countries for which 98 RON is specified; in Greece 96 RON is specified and in Italy and Spain 97 RON. Most premium petrol in Europe is restricted to 0.15 g/1 of lead, though the current limit is 0.25 g/l in France, 0.3 g/l in Italy, and 0.4 g/l in Portugal and Spain. A significant proportion of the unleaded petrol marketed in Europe (particularly in Germany) is lower octane than United Kingdom unleaded, approximating to `regular' rating of 91 RON/82.5 MON. More than one grade of unleaded may be marketed in contin- ental markets including a `eurograde' that is similar to United Kingdom unleaded.