NAVAL FUELS IN THE 21ST CENTURY

BY

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ABSTRACT

In 1913 the Royal Commission on Fuels and Engines under the Chairmanship of Lord Fisher, recommended that the Royal Navy should change from coal to oil. It also drew up the specification for the Navy's fuel and recommended the measures necessary to maintain supplies. Following the end of the Second World War, the supply of good quality fuels became more difficult and measures were taken to ensure standards were raised and supply assured. From the late 1960's with the introduction of gas turbine propulsion, there was a gradual change to the use of marine middle distillate fuels for all prime movers and auxiliary engines. The propulsion fuel of choice since that time has been NATO F-76, but we are now seeing another change, equally as far reaching as previous changes, due to global fuel demands, the need to combat climate change, conservation of resources and consideration of alternative renewable energy sources. For the Royal Navy in the 21st Century, this means that we have to interrogate the requirement and adapt to marketplace pressures to ensure the continued supply of readily available good quality fuels.

Introduction

This article discusses the current Naval Service Authority fuel requirements for Royal Navy (RN) and Royal Fleet Auxiliary (RFA) vessels and aircraft, in order to maintain Operational Capability (OC) and interoperability with partner nations now and for the foreseeable future. It addresses recent perturbations within the fuel marketplace and the premiums charged by oil companies for supply of F-76 and the fluctuations in the global cost of fuel. In addition, it specifically addresses future fuels and the changes that are likely to become necessary to both products and equipment.

Fuel Requirements, Use and Procurement

It is essential that fuel used by the RN, RFA and ship borne aircraft deliver the Operational Capability (OC) required by CINCFLEET. The established datum fuels (F-76 and F-44) provide Fleet with the ability to conduct unrestricted world-wide operations, whilst meeting international legislation, maintaining interoperability with allied nations and achieving compatibility with a wide range of prime movers and auxiliary engines.

Naval Fuel Requirements

To deliver OC, the following criteria need to be met:

- A single, readily available, high flash point fuel for ship propulsion to serve multiple types of prime movers and auxiliary engines on board ship, including high performance GT engines, providing appropriate equipment availability and effective logistics;

- A single, separate, readily available, high flash point aviation fuel to serve all types of sea-based military aircraft;

- Fuels suitable for use in a rapid underway-refuelling capability to extend sustainability on station;

- A fuel suitable for use in water-compensated fuel tanks to maintain trim and stability;

- Minimising fire hazards, including under battle conditions;

- Maintaining fuel quality during normal and extended operational storage periods ashore and onboard ships and submarines. (Fuel performance is included in the nuclear submarine safety case);

- Enabling unrestricted operations world-wide;

- Compliance with national and international safety regulations and environmental legislation;

- Ability to share fuels with allies and partner navies.

The Fuels

UK F-76 to Def Stan 91-4[1]

The datum propulsion fuel, which meets the OC for RN use, having amongst others, the following key user requirements:

- High flash point > 61°C for ship safety reasons;

- Pour point (the lowest temperature at which the fuel sample flows under test conditions and an indication of the minimum temperature at which a fuel may be pumped) –6°C max;

- Cloud Point (the temperature at which paraffin wax visibly appears to come out of solution and may cause filter blockage) -1°C max;

- Sulphur content < 0.2% (to meet current EU legislation requirements);

- Good water separability (to ensure that sodium in sea water can be removed by fuel treatment systems to avoid premature gas turbine corrosion);
- Good storage stability (i.e. a fuel that does not form excessive levels of insoluble material that may lead to filter blockage);
- Good lubricity (to prevent excessive wear in fuel pumps: fuel commonly lubricates some fuel pump components);
- Cetane number (a measure of the ignition quality of a fuel for diesel engine use) 45 min;
- Good filterability, i.e. a Filter Blocking Tendency (FBT) of at least 150 ml. in 10 mins measured by the Diesel Fuel Test Kit (DFTK) (to reduce filter usage).

It maintains an advantage over potential alternatives for the following reasons:

- It is proven for use on all RN and RFA diesel and gas turbine engines;
- The logistics infrastructure is in place for RN, NATO partners and other country's navies;
- It has a good energy density (around 44.5 MJ/Kg) and excellent energy per volume (around 37.8GJ/m^3);
- The specification is under the control of MPSIPT MPS216 as the Service Authority for naval fuels and lubricants.

NATO F-76 to STANAG 1385[2]

STANAG 1385 is the guide specification, which establishes the minimum quality requirements for participating nations to develop their own standards to procure fuel to the appropriate NATO Code. F-76 provided by other nations under fuel exchange agreements is, in many respects, identical to the requirements of Def Stan 91-4. The notable differences being a lower cetane requirement (Cetane No 40 min), slightly lower flash point minimum (60°C) and no filterability / cleanliness requirement. STANAG 1385 also allows a higher sulphur limit than Def Stan 91-4 (1 % m/m max compared with 0.2 % m/m max because of world-wide supply concerns) and water separation (demulsibility) is measured by a different method. STANAG 1385 is regularly reviewed within the NATO Naval Fuels & Lubricants Working Party and is amended in consultation with Alliance members.

International MGO DMA Specification (ISO-F-8217-DMA)[3]

This is the closest commercial grade of MGO to F-76. DMA is produced from the same product stream as F-76, but may contain a proportion of hydrotreated (cracked) stock, which means that it will not meet the storage stability and filterability requirements although it is acceptable to purchase for spot bunkering. It may also contain bio-fuels - Fatty Acid Methyl Esters (FAME), refinery and / or after market additives and contaminants, which could in the longer term affect the operation of the onboard fuel treatment system and in the extreme, cause damage to propulsion machinery.

AVCAT F-44 (JP-5) to Def Stan 91-86[4]

This is the NATO standard high flash point (>61°C) aviation fuel for use on shipboard aircraft, which fully meets the performance and safety requirements. It may be used as a propulsion fuel in an emergency.

AVCAT F-44 (JP-5) as a Single Naval Fuel[5]

The use of F-44 (JP-5) as a single naval fuel at sea is under active consideration by the US. The reduced endurance of ~2% (due to the 2.6 % average decrease in volumetric energy content) that would be experienced by switching to this fuel and the increased cost of approximately 5%, have been assessed by the US as being acceptable as a trade-off against logistic advantage. However, it is recognised that on a global basis, F-44 has limited availability and therefore F-76 or a suitable assured standard of MGO would need to be used as the alternative. For that reason the US is examining worldwide MGO quality. The current US estimate is that it would take 10 years to move to the single naval fuel policy and a further 5 / 10 years to implement. If such a policy were to be implemented, there would be implications for the RN, especially when on collaborative operations with the USN where possibly only F-44 (JP-5) would be supplied from their tankers. The RN would need to examine whether it is practicable to follow the US lead at that time. Consultation and agreement with suppliers will be essential because of the effect of producing large quantities of F-44 on the production of commercial aviation fuel and automotive diesel fuel.

In addition to these fuels currently used in naval service, the following alternatives are available:

Fuel Oils for Agricultural, Domestic and Industrial use to BS2869: 1998 Class A2 (Known as Red Diesel)[6]

Middle Distillate Fuel Class A2 is produced from the same product stream as F-76 and MGO and may have many of the properties that comply with the requirements of F-76, but the minimum flash point is 56°C and water separability or demulsability is not tested.

Automotive Diesel to BS EN590[7]

Although auto diesel and F-76 are fundamentally very similar, auto diesel may have certain properties (listed below) that render it unsuitable for shipboard use on Whole Ship Safety grounds and incompatibility with current RN fuel treatment systems. That said, auto diesel product (Ultra Low Sulphur) with appropriate high flash point, can be offered as MGO, although at a price because high refining costs mean that automotive diesel will always retain a premium over other middle distillate fuels.

- Minimum flash point (>55°C against >61°C for F-76 and 60°C for MGO);

- Water separability is not tested (there is no requirement in BS EN590). The water separability problems associated with road diesel will be exacerbated by the introduction of bio-diesel under the Renewable Transport Fuel Obligation Programme[8];

- Could contain detergents and additives that would also affect water separability;

- BS EN590 is a European specification and although many countries outside of Europe base their diesel fuel specifications on EN590 the quality of auto diesel available worldwide is extremely variable;

- Automotive additive compatibility is an issue.

AVTUR F-34 to Def Stan 91-87[9]

This fuel has a minimum flash point of 38°C and is based on Jet A-1 fuel; used extensively around the world by commercial operators. AVTUR F-34 is the single land battlefield fuel used in ground-based equipment and land-based aircraft. It is proven in the land battle situation because commercial Jet A-1 is widely available at good quality.

However, the use of AVTUR for marine propulsion or shipboard aircraft use is not acceptable on grounds of safety, interoperability, availability, technical considerations and the price is higher than for marine gas oils. Aircraft embarking on board RN Ships fuelled with AVTUR must defuel and refuel with AVCAT before being stored in the hangar on safety grounds. This requires a system for mixing AVTUR with F-76 at a ratio of at least 1:9 so that the defuelled AVTUR can be stored safely and burnt in the propulsion engines.

Fuel Consumption

By using the FLUBCON data, the annual fuel consumption can be plotted for the RN and RFA ships since 1988. The trend is a steady decline in consumption over the period as the number of ships has reduced, with peak usage coinciding with periods of conflict. More recently, the combined annual total of RN and RFA consumption has levelled off at approximately 250,000 cubic metres (cz) with a general rise in consumption by RFA vessels compensating for a decline in consumption by RN ships. AVCAT usage is approximately 14,000 cz per year.

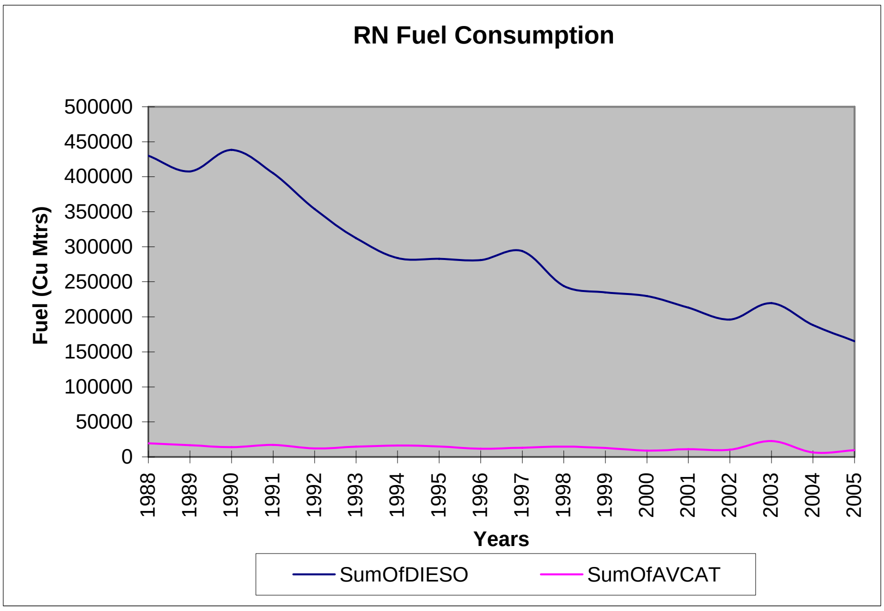

FIG.1 – RN FUEL CONSUMPTION FROM 1988 TO 2005

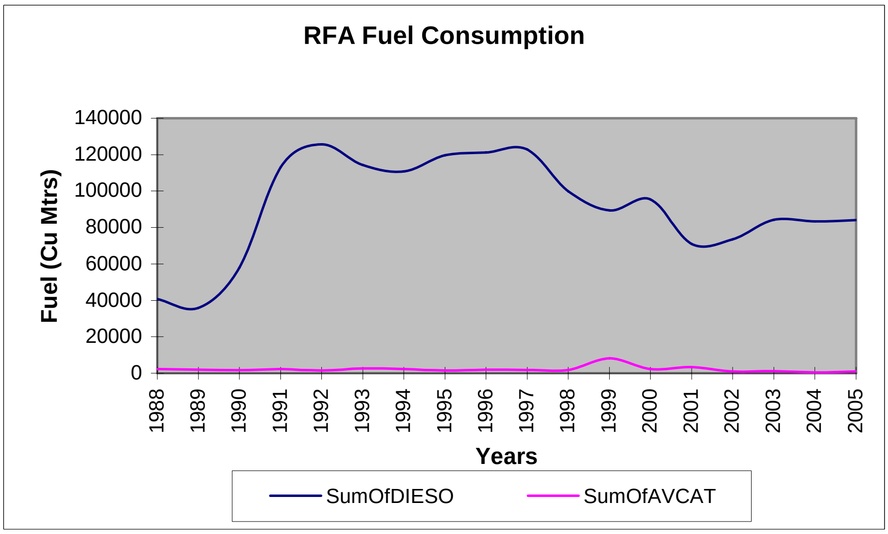

FIG.2 – RFA FUEL CONSUMPTION FROM 1988 TO 2005

Unsurprisingly, when fuel consumption is plotted per class as a ‘snapshot’ over an annual period, it becomes clear that gas turbine engine ships consume the most – over half of all the fuel supplied. However, this does show the effect of propulsion machinery design and configuration on fuel economy. For example, the Type 23 frigates are the most economical to operate due to the CODLAG propulsion system, a Type 23 having approximately 60% of the annual fuel consumption of a Type 22. The least fuel efficient ships are the CVS class, as would be expected with their older design of Olympus gas turbine engines and the need to maintain high speed during flying operations. Such consumption information is invaluable to the platform projects to help predict through life cost and choose options for reducing fleet fuel usage.

TOTAL FUEL CONSUMED (CUBIC METRES) DEC 03 - NOV 04

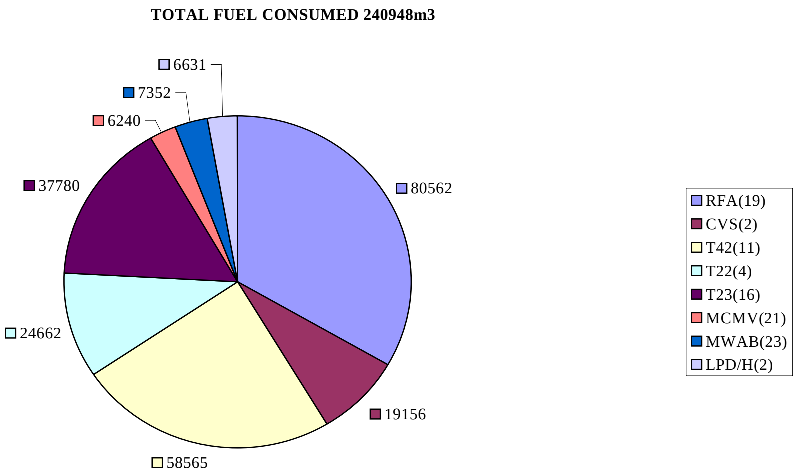

FIG.3 – TOTAL FUEL CONSUMPTION RN & RFA DEC 03 TO NOV 04

Purchasing Issues

Although F-76 to Def Stan 91-4[1] is the datum propulsion fuel for RN use, it is produced to order by a limited number of refineries as it has fairly unique fuel property requirements and, in refinery terms, is needed in very low volumes – making it unattractive to produce. For this reason it may not prove to be cost effective for the MoD Defence Fuels Group (DFG) to continue to supply F-76 to the current edition of the Defence Standard. Therefore, a Purchase Guide[10] has been written in conjunction with the DFG to enable cost effective procurement of bulk fuel that meets the minimum quality requirements of STANAG 1385[2] and for fuel purchased by ships away from base port or on deployment (spot bunkering). The Purchase Guide is considered a ‘stop gap’ measure and it is planned to revise Def Stan 91-4 to enable more flexible purchasing arrangements to be made. The intent of the Purchase Guide is illustrated in (FIG.4).

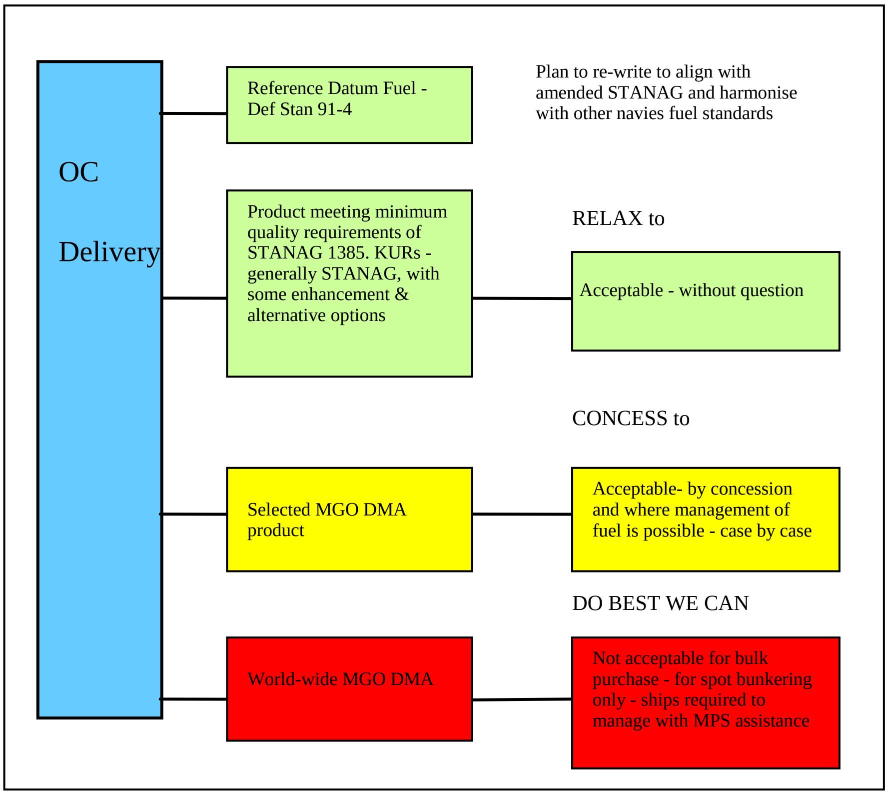

FIG.4 – INTENT OF PURCHASE GUIDE

Marketplace Influences

The marketplace is driven by the need to provide readily available transport fuel (auto diesel, petrol (gasoline) and aviation kerosene) at a competitive price. Crude oil is expected to become increasingly scarce during the 21st century and other primary energy sources to either replace or supplement it are being sought. That said, the primary source of energy for the foreseeable future will continue to be derived from petroleum based sources. It can be seen from the trend data provided by BP in (FIG.5) below that since 1987, more than 40 years of usable reserves have been available with no sign yet of a decline. It can also be seen that most of these reserves are in the Middle East, Central and South America and Africa outside the industrialised regions of the world, leading to concerns about security of supply.

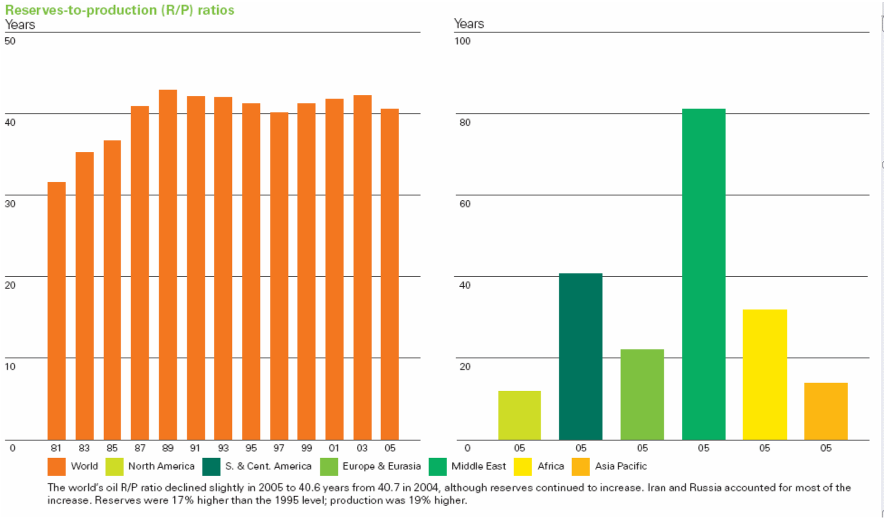

FIG.5 – KNOWN OIL RESERVES AND REGIONS – COURTESY BP

Whilst the oil companies could continue to exploit oil reserves for many years to come, international legislation, government initiatives on energy conservation and treaty obligations have caused them to seek and develop liquid fuels from alternative sources. Policies differ from company to company in responding to these challenges, but the consensus of opinion[11,12,13,14] is that liquid fossil fuel will predominate with the addition of varying percentages of bio-fuel and synthetic components as extenders. For example, Shell expects that globally over the next 20 years, bio-fuel use will grow to >7 % of their road transport fuel volume, with additionally up to 4% synthetic fuel in road diesel.

Marine Gas Oil (and F-76) forms a decreasing market sector as ship operators move to using cheaper grades of residual fuel and is only produced at certain refineries. Also in the Far East and Australasia, due to the lack of a market for heating oil, the only commercial fuel available for marine use is from the same product stream as automotive diesel. There is no commercial threat to the supply of NATO F-76 or MGO in Europe in the immediate future, but it is important that a dialogue with industry is maintained and close attention is paid to market trends in order to react to any changes in the supply situation.

Similarly, there is limited capability to supply naval aviation fuel, F-44, within the EU. Although it is not prohibitively expensive to purchase, the limited source of supply is an issue. This situation might change if the US Navy adopts the Single Naval Fuel at Sea, based on F-44 (JP-5), but this would require support from the petrochemical industry. As with road transport fuels, it is expected that aviation fuel will contain a proportion of synthetic fuel in the near future.

Price & Price Stability

The future price of fuel is the most difficult to predict with any accuracy. The Department of Trade and industry (DTi) relies on illustrative scenarios to predict prices, rather than detailed predictions. The updated fossil fuel price scenarios published in the Quarterly Energy Review of Sept. 2006[15] predict a fall in the crude oil price from 55 $ / Barrel (bbl) to 45 $ / bbl by 2020. However, the DTi also predicts that prices are likely to remain high and volatile for the immediate future (at the time of writing the Brent Crude Oil Price stands at 62 $ / bbl). The problem is that oil is a tradable commodity, tradable in dollars and is therefore subject to market forces and fluctuating exchange rates. An unstable situation in the Middle East, concerns over continuity of supply from Russia, limited refining capacity and the steep rise in demand from China and India have all contributed to high fuel prices in recent years.

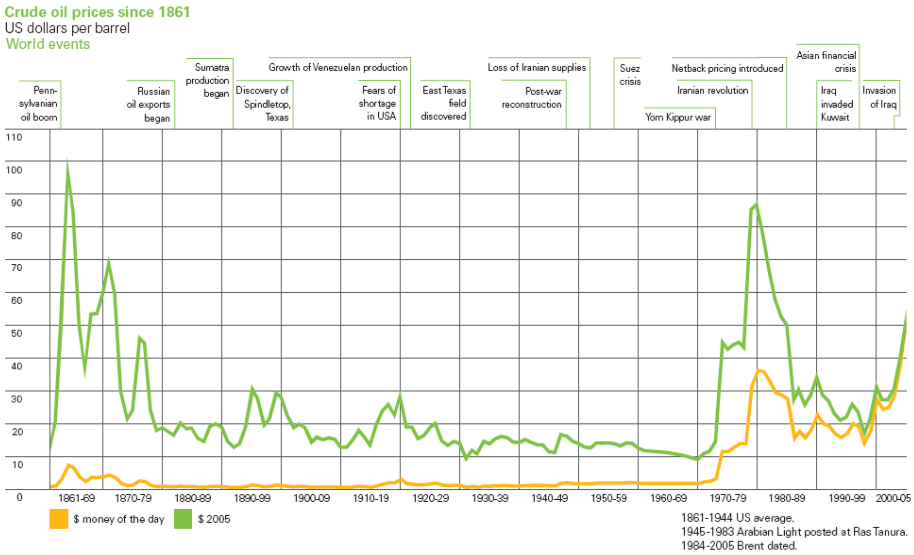

FIG.6 – CRUDE OIL PRICES SINCE 1861 FROM THE BP STATISTICAL REVIEW OF WORLD ENERGY 2006 [11]

To illustrate price variability and the premium charged by the refineries, (FIG.7) shows the variations in the Rotterdam gasoline, gas oil and heavy fuel oil product prices from 1988 to 2005. There is also a premium charged for F-76 over commercial MGO due to the additional cleanliness requirements and the need to segregate this fuel from the domestic fuel and MGO streams. Note also the increasing gap between the price of heavy fuel oil and the gas oil products between 2003 and 2005.

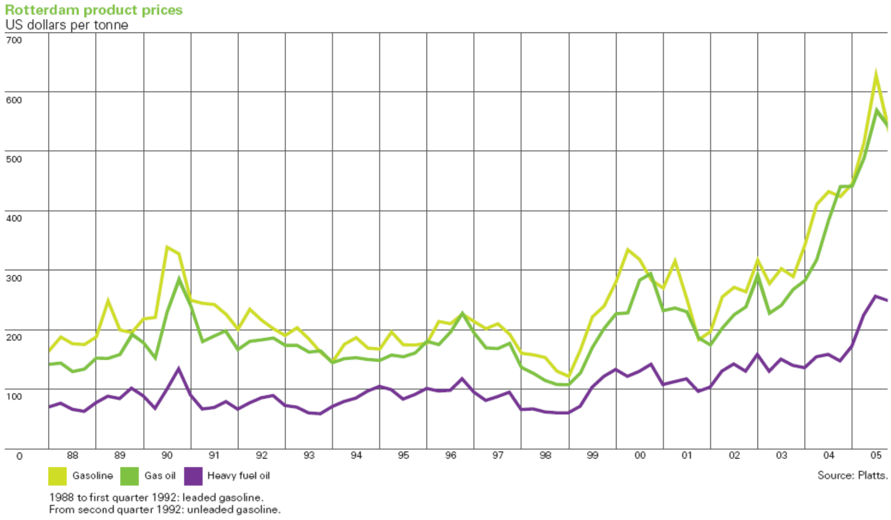

FIG.7 – ROTTERDAM OIL PRODUCT PRICES[11]

Price instability, the premiums charged on the higher quality fuels and the dependence on market forces reinforces the need to take measures to optimise Fleet fuel usage. It is also necessary to ensure that standards are pitched at a level that strikes a balance between the minimum quality required for the propulsion machinery and avoids 'gold plating'.

Future Fuels [16,17]

Marine Gas Turbines will operate on a liquid hydrocarbon based fuel at least until the late 21st Century. The source of this liquid fuel will continue to be petroleum based (albeit increasingly supplemented with synthetic / semi-synthetic blend stocks), for several decades. However, availability and price stability is market driven and dependent on the political situation in the Middle East, which will have the largest concentration of crude oil stocks into the foreseeable future. At some point in the future (opinions vary on exactly when, but probably from about 2020) world petroleum stocks will diminish and it will be necessary to replace the resource with economic, viable alternatives. Countries with large reserves of gas, coal and oil shales are actively pursuing the development of their natural resources by providing the oil companies with incentives and granting licences. There is also the recent EU decision to set targets for the reduction of carbon emissions by 2020, which will have a significant impact on the development of alternative energy sources. The main alternative fuels are discussed below.

Synthetic Fuels

These fuels are made from hydrogen and carbon monoxide in a 'gas to liquid' (GTL) Fischer-Tropsch chemical synthesis process. This process provides a flexible method of producing high quality fuels (virtually designer fuels) from a wide range of sources including gas, coal, shale tar sands and biomass (to produce "second – generation bio-fuels" identical in properties to other synthetic fuels rather than conventional bio-fuels). Producing fuel from a wide range of sources is often referred to as 'XTL' i.e. 'anything to liquid' or 'energy to liquid'. All the major oil companies are investing heavily in these processes and expect to have production plants coming on stream within the next year or two. The US Government and military are stimulating interest in producing synthetic fuels from indigenous resources to help alleviate security of supply concerns. The process concept is illustrated in (FIG.8).

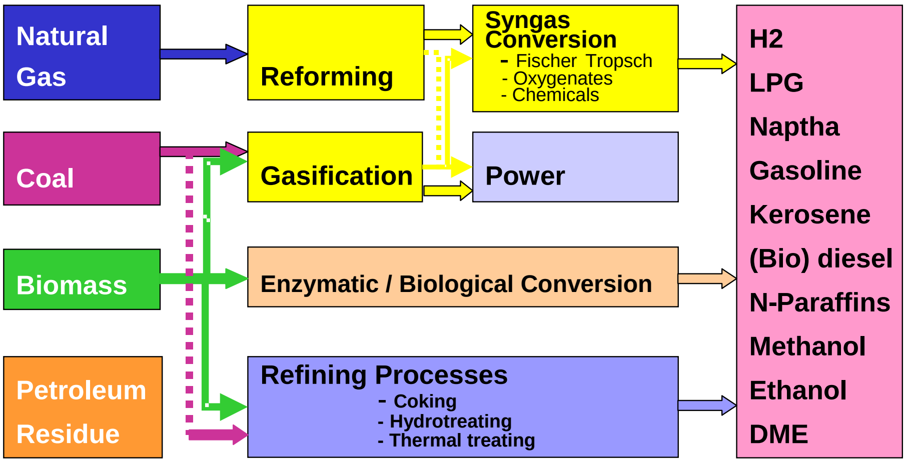

FIG.8 – XTL CONCEPT

Synthetics contain no sulphur because sulphur in the feed material poisons the process catalysts. Safety and toxicology would be the same or very similar to todays diesel / jet fuels. Emissions (smoke & particulate) by gas turbines would be significantly reduced by use of these low aromatic fuels. Zero sulphur content would also make these types of fuels well suited for fuel cell systems.

The commercial transport market, especially aviation, will drive the development of readily available semi-synthetic and synthetic liquid fuels. SASOL in South Africa is already marketing semi-synthetic aviation fuel and wants to introduce a fully synthetic product. In order to introduce these fuels there is a need for control by specification, which is already under consideration for aviation fuel. This would also be necessary for marine fuel because F-76 is at present a batch conformance specification, which assumes that it is crude oil derived. It must not be assumed that a synthetic fuel produced to Def Stan 91-4 would meet the engine requirements or even burn satisfactorily. There would be a need to control the production processes and fuel composition in generating an appropriate specification. Evaluation of blends to assess the impact of synthetic components on the following operational parameters would be required:

- Compatibility with elastomeric materials;
- Lubricity;

- Electrical properties (dielectric constant, conductivity);
- Additive miscibility and compatibility;
- Compatibility and miscibility with other fuels;
- Combustion properties including starting and re-light performance and emissions.

Bio-fuels

Since the first oil crisis in 1973, biomass has been considered and in some cases promoted as an alternative to fossil fuel as a source of energy. Particular attention has been given to the potential for using biomass as the basis for production of alternative motor vehicle fuel (diesel or gasoline) because of the transport sector's almost exclusive dependence on oil.

Current, or "first –generation" bio-fuels are typically produced from oil extracted from the seeds of plants such as Rape, Sunflower or Soya. This oil is subjected to a process called esterification to produce Fatty Acid Methyl Esters (FAME) (commonly known as bio-diesel). Ethanol, produced from sugar beet or cane, is used as an alternative to or an extender for gasoline may also be termed a "first generation" bio-fuel. "Second generation" bio-fuels (briefly referred to in the previous section) utilise more of the biomass from the plant. These are expected to become more commonplace in the next 10 to 15 years.

In theory, bio-fuels offer a suitable alternative since, when based on EU grown crops, they offer security of supply. They are seen as being CO_2 neutral, as the CO_2 released during combustion is absorbed by the crop from the atmosphere. However, the overall energy consumption for growing the crop, transportation to the refinery and producing the fuel means that more than half of the CO_2 benefit is offset during the production process. Additionally, there is unlikely to be enough available land to produce sufficient quantities of bio-fuel to replace petroleum derived diesel fuel. It will increasingly be used as an extender especially as under the UK's Renewable Transport Fuels Obligation (RTFO)[8]. This will, from April 2008, place an obligation on fuel suppliers to ensure that a certain percentage of their aggregate sales are made up of bio-fuels. The effect of this will be to require 5% of all UK fuel sold on UK forecourts to come from a renewable source by 2010 in order to meet climate change objectives as well as contributing to other Government objectives, including security of energy supply. Powers to set up an RTFO were provided by the 2004 Energy Act subject to secondary legislation. The RTFO Regulations are expected to be approved by Parliament in late 2007. Further legislation to increase the percentage of bio-fuels in transport fuels to 20% is also likely.

The advantages and disadvantages of the increasing use of bio-fuel for the RN are shown in (TABLE 1). There are significant concerns over the use of bio-fuels, including the fact that different source material produces fuel with different characteristics, which render them undesirable at present.

TABLE 1 – *Advantages and Disadvantages of Bio-Fuels for Marine Use*

Advantages:	**Disadvantages:**
Lower sulphur emissions	Reduced Energy density
Increased lubricity	Only viable if cost of petroleum derived fuel is high
Increased cetane	Increased water separation problems
	Increased microbiological contamination
	Increased fuel system maintenance
	Potential combustion problems in GTs
	Poor Storage Stability with certain blends, especially in contact with metals commonly found in fuel systems
	Poor thermal stability during combustion

There is no legislative or economic pressure to include FAME in MGO at present, but some marine fuels are derived from the same product stream as automotive diesel and therefore the RN can expect to see some bio-fuel received in spot bunkers in the near future. An understanding of the effects of bio-fuel on filtration equipment and prime movers and a strategy for handling such fuel is therefore essential.

Other Candidate Fuels of the Future

Natural Gas

Because of the gaseous nature of this type of fuel it is stored as either a Compressed Natural Gas (CNG) or Liquid Natural Gas (LNG). CNG is stored in bottle like tanks at pressures of up to 3600 psi. Delivery to the engine is usually as a low-pressure vapour. LNG is typically stored in an efficiently insulated pressure vessel at extremely low temperature, minus 160°C. Both fuels are available with limited distribution systems. Proven reserves of gas is somewhere in the region of 60-100 years at current rates of consumption, with a third of that being in the former Soviet Union.

Cost is difficult to assess because of the different tax regimes in place but generally LNG / CNG is less expensive than diesel on an equivalent energy basis.

However, the handling problems and low energy density make it unlikely that LNG / CNG will ever become a RN propulsion fuel. Commercial tankers that ship gas (LNG) can utilise the gas boil off for propulsion but for RN use, a synthetic liquid fuel using gas as the raw material would seem a more practical route.

Alcohols

Methanol and ethanol are two alcohols that could be used for propulsion. They are cleaner burning than diesel fuel and can be readily produced at low cost and from renewable sources (biomass). Most methanol however is produced from natural gas in an industrial process that causes significant carbon emissions. Although alcohols are readily available there is no worldwide infrastructure that could be accessed by RN vessels.

Alcohols have a number of problems for use on board ship, they are toxic (particularly methanol). They burn with a colourless flame (methanol flash point 12°C, ethanol flash point 17°C) and are totally miscible with water. However, the most serious problem is the low volumetric energy density (less than half of that for F-76) that would mandate either considerably less range or much larger fuel tanks.

Hydrogen

Much has been made of a future ‘hydrogen economy’ when fossil fuels eventually run out. The use of hydrogen as a main propulsion fuel by RN vessels is likely to lag behind any extensive use of hydrogen for land transport and there are a number of issues that need to be addressed, among of them safety, storage and handling, loading / RAS, cost and infrastructure. None of these issues appears insurmountable when considering a new ship type but several significant breakthroughs in technology need to be achieved before the hydrogen-powered ship becomes practical.[18]

In theory, hydrogen could be used to fuel prime movers and secondary power systems on ships. Hydrogen could power gas turbines in a similar fashion to land-based gas turbines running on natural gas for static power generation, but this would involve a significant programme of development work. However, current wisdom is that hydrogen would be used in fuel cells directly to produce electrical power. Fuel cells could be employed as prime movers but the power levels required (tens of MW) means that a great deal of development needs to occur before the technology is suitable for use at this scale in a marine environment. A number of studies are ongoing or have been conducted recently to produce hydrogen by reforming a logistic fuel in fuel cell systems for use in military ships. Using current technology, cost and weight disadvantages currently outweigh the small projected efficiency improvements, although future fuel cell systems (perhaps based on hybrid gas turbine – solid oxide fuel cells) are likely to offer system efficiencies well in excess of 60% (c.f. WR21 high speed alternator efficiency of circa 40%).[19]

Air independent propulsion (AIP) is one area where hydrogen may have advantages in military applications. The non-nuclear submarine has to carry all of its energy (fuel and oxidant) within the bounds of the vessel when operating underwater. This is currently achieved using vary large banks of batteries whereas the use of fuel cells and stored hydrogen and oxygen may offer a viable alternative. The nature of underwater warfare may be changing and the increased use of autonomous unmanned underwater vehicles (UUV) may lead to fuel cells as a power source with hydrogen as the fuel. UUV may have a number of systems onboard that require electrical power. Stored hydrogen and oxidant feeding a fuel cell offers an attractive way to provide the electricity required, but the systems are volume intensive.

Response to Change

Legislative Issues

National and international legislation will result in the continuing necessity to review and amend naval standards in order to comply with Secretary of State's policy for meeting or exceeding legislative requirements. Recent legislative changes have mainly concerned emissions control (e.g. MARPOL Annex VI and EU Directive on Sulphur in Marine Fuel 2005/33/EC) and further legislation to address climate change and energy conservation is expected soon. If legislation forces the introduction of bio-fuels and in particular, FAME in diesel or gas oil, there are consequences for storage and transport of fuels, fuel filtration system integrity and engine performance. FAME is banned from F-76, but the MoD has little influence over the international MGO specification[3] therefore a strategy for dealing with its possible introduction will need to be considered.

Quality Issues

Global fuel quality is variable and a number of contaminants may affect the integrity of the on-board equipment and systems. It is unrealistic to set standards at too high a level whilst aiming for good availability and best value for money, therefore some compromise is necessary to ensure flexibility in meeting OC. The Naval Service Authority seeks to maintain two levels of protection to assure the required fuel quality at the point of use:

- Product standards and quality control of supply. This may be described as Quality Assurance;

- On-board fuel system integrity, procedural control, operator training and good fuel husbandry. This constitutes Quality Reassurance.[20]

The chemical composition of the fuel is changing, as it becomes more refined to remove sulphur and more useable product is 'squeezed' from each barrel of crude. The use of additives to compensate for the loss of some properties removed in the refining process will need to be considered in future issues of the Defence Standards. The approval of additives, acceptable to allies and partner navies to ensure continued exchange of fuels, is an important issue.

Research and Development

To manage future changes in legislation and the transition to alternative fuels will require the MoD to review current technologies. Continued Research and Development is essential to meet these changes and whilst the marine environment has its own unique challenges, its direction will be largely influenced and driven by the available fuels and government policy. Energy is the real issue; it's big business, global, economic and politically motivated, with the key drivers being geography, cost and climate change. The Military cannot lead, but it needs to respond accordingly.

On-going R&D is therefore targeted at producing answers to the questions on the additives and contaminants present in fuels and the limitations of the on-board fuel treatment and filtration systems. What additives in what proportion are acceptable? What levels of contaminants are tolerable? How robust and tolerant is the on-board fuel filtration equipment? What modifications to equipment would improve performance? What changes in ships staff training and education are necessary? What changes are necessary to ships fuel husbandry and procedural control?

Conclusions

The Naval Service Authority requirements, based on a large body of evidence, are for a fuel that delivers OC and allows interoperability with allied nations. It is based around the datum NATO standard fuels F-76 (Def Stan 91-4) and F-44 (Def Stan 91-86), with recommendations for alternatives when these fuels are not available.

Future Fuel (5 to 20 years)

The future vision is built on the continued use of liquid fuels for both marine and aviation applications, although the use of synthetic fuels will become more widespread and may be tailored for use in the marine environment. Crude oil production is likely to peak during this period and fossil fuels will still predominate, with the finished products having very low sulphur content.

There will be the start of a major advance towards synthetic fuels progressing from the use of semi-synthetic to fully synthetic liquid fuels. There will be increasing use of bio-fuels for non-marine modes of transport, with some limited use in commercial marine gas oils. The use of lubricity and possibly other types of additives will be necessary to replace properties currently present in petroleum derived fuels and standards will need to be revised to allow their use.

Fuel cells may be considered for auxiliary power on RN ships, emergency power for nuclear submarines and for powering Unmanned Underwater Vehicles (UUV).

Future Fuel beyond 20 years

Middle distillate type liquid fuels will still be in use, although they are likely to be much cleaner than current products. Synthetic fuels will be in widespread use. Commercial aircraft will require large volumes of liquid hydrocarbon fuel, which will drive the development of synthetic gas to liquid processes and it is expected that their development will be exploited for marine use.

Fuel cells will power land based transport, gaining in popularity and becoming dominant. The hydrogen economy, subject to technological breakthroughs in hydrogen production, transportation and storage (and possibly subject to developments in carbon dioxide sequestration) will be developing for land use. There may be potential for using hydrogen in marine applications, possibly in a solid oxide fuel cell or gas turbine hybrids, but synthetic liquid fuels will predominate for aviation and marine use.

The Way Ahead

The RN has long since ceased to be in a position to influence the fuels market. Indeed, the reverse is true and that means that the Service Authority and the DFG must react to changes in fuel availability, global conditions, legislation, price and quality.

With uncertainty over fuel prices, security of supply and a potentially long logistic chain, optimising Fleet fuel usage and improved fuel economy should be high on the priority list for support and future surface ship procurement.

The challenge for the future is to frame changes to the fuels standards to maintain a balance between quality, price and availability to meet current user requirements and anticipate future legislative and procurement constraints.

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