How will Future Defence Forces Operate in a World Drained of Fossil Fuels?

Defence Engineering and Science Group

Graduate Discussion Group 5/01

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Fossil Fuels Report

The views presented in this report are the opinions of Graduate Discussion Group 5/01. They are not the opinions of the MoD, Dstl or NATO nor should they be taken as.

ABSTRACT

This report investigates military dependency on fossil fuels and their derivatives and highlights the problems that will occur once such fuels have become depleted. It attempts to identify the capability gaps that may occur, and proposes methods of addressing them.

EXECUTIVE SUMMARY

This report attempts to address the problem of fossil fuel depletion and highlight the effects it will have on the MoD's ability to protect UK interests.

It is indisputable that fossil fuels will run out, but the time scale of depletion will vary according to many factors in addition to the absolute quantity of fuel available. The time of greatest interest is the point at which fossil fuels become more expensive than alternative energy sources. Many political and economic changes will occur at this time, and the UK must position itself to emerge as a world leader in the post-fossil era. Although it is difficult to predict the future, GDG 5/01 believes that there will be "high-tech" and "low-tech" countries. The UK should create plans that put it firmly in the high-tech bracket.

Alternative energy sources will need to be developed and implemented. This will require efficient planning to allow new technologies to be introduced and mature before they become vital requirements. The UK has a number of excellent renewable energy sources and mature technology to utilise some of these forms such as wind energy. The country must insure that the only obstacles to their implementation are technical issues, not political considerations.

With effective planning, the country should have all the primary energy it requires, but a major problem will be its transportation and use of this energy. This will especially be the case for military users, who have high mobility requirements. However, this report shows that current land, sea and air defence systems can either be converted to use new energy supplies or be replaced using alternative technologies to meet capability gaps in different ways.

The MoD apparently does not have an over arching policy concerning the depletion of fossil fuels; the report recommends adopting a more proactive role in this area to avoid the department being left out of government planning. This could be implemented by setting up a focal point team, to liase with other departments and co-ordinate work within the MoD.

The depletion of fossil fuels represents an opportunity for this country to become a leader in renewable energy technology, its infrastructure and its implementation. This can only be achieved through effective dynamic planning and clear strategies encompassing all parties involved. The MoD has a key and positive role to play in this process.

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ABBREVIATIONS

AAR	Air-Air Refuelling
ACV	Armoured Combat Vehicle
APC	Armoured Personnel Carrier
APV	Armoured Patrol Vehicle
ASW	Anti-Submarine Warfare
ASuW	Anti-Surface Warfare
ATMP	All Terrain Mobility Platform
AWACS	Airborne Warning and Control System
BBC	British Broadcasting Corporation
BP	British Petroleum
bpd	Barrels per day
boed	Barrels Oil Equivalent per Day (= 6000 cubic feet gas)
CALCM	Conventionally-armed Air-Launched Long-range Cruise Missiles
CCGT	Combined Cycle Gas Turbines
CHP	Combined Heat and Power
CNG	Compressed Natural Gas
CVF	Future Aircraft Carrier
CVRT	Combat Vehicle Reconnaissance Tracked
CVS	Current Aircraft Carrier
DEC	Director of Equipment Capability
DESG	Defence Engineering and Sciences Group
DPA	Defence Procurement Agency
Dstl	Defence Science and Technology Laboratories.
DTI	Department of Trade and Industry
EAF	Electric Arc Furnace
EIA	Energy Information Administration
ELINT	Electronic Intelligence
EMP	Electromagnetic Pulse
EU	European Union
FAME	Fatty Acid Methyl Ethers
FCLV	Future Command Liaison Vehicle
FIST	Future Integrated Solider Technology
FOAS	Future Offensive Air System
FRES	Future Rapid Effects System
FSC	Future Surface Combatant
FSU	Former Soviet Union
GBL	Ground Based Laser
GDG	Graduate Discussion Group
GDP	Gross Domestic Product
GTL	Gas-To-Liquid
HAPP	High-Altitude Powered Platform
HEV	Hybrid Electric Vehicles
HVA	High Value Assets
HVM	High Velocity Missile
IC	Internal Combustion
IFV	Infantry Fighting Vehicle
IPT	Integrated Project Team
JSF	Joint Strike Fighter
LIMPET	Land Installed Marine Powered Energy Transformer
LNG	Liquid Natural Gas
LPG	Liquid Petroleum Gas
MBT	Main Battle Tank
MIRA	Motor Industry Research Agencies
MNC	Multi-National Corporation
MoD	Ministry of Defence
MSP	Member of the Scottish Parliament
MM	Million
NATO	North Atlantic Treaty Organisation
OPEC	Organisation of the Petroleum Exporting Countries
PE	Polyethylene
PET	Terephthalate
PFI	Private Finance Initiative
PGM	Precision Guided Munitions
PHA	Polyhydroxyalkanote
PIU	Performance and Innovation Group
PLA	Polylactide
PPP	Public/Private Partnership
PV	Photovoltaic
R&D	Research and Development
RME	Rape Methyl Ester
RN	Royal Navy
RV	Research Vessel
SBL	Space Based Laser
SDR	Strategic Defence Review
SIT	Spontaneous Ignition Temperature
SMW	Solid Municipal Wastes
SNC	Strategic Nuclear Command
SNP	Scottish National Party
TET	Turbine Entry Temperature
TLMP	Through Life Management Plan
TRACER	Tactical Reconnaissance Armoured Combat Equipment Requirement
UAE	United Arab Emirates
UBHC	UnBurned HydroCarbons
UCAV	Unmanned Combat Air Vehicles
URD	User Requirements Document
USAF	United States Air Force
UV	Ultra Violet
WMD	Weapons of Mass Destruction
WWII	Second World War

OVERALL OBJECTIVES

- To highlight the current dependency on and impending demise of fossil fuels.
- To address the future battle space, develop possible requirements and investigate emerging technologies that could fill these.
- To suggest a policy to initiate and implement development of future non-fossil fuel technologies.
- To gain experience in co-ordinating work, presenting and writing a report.

1 INTRODUCTION

On joining the Defence Engineering and Science Group (DESG) graduate training scheme within the Ministry of Defence, graduates are split into a number of small groups of about 10-12 people. These groups are known as GDGs or Graduate Discussion Groups.

Each of these discussion groups is set a research project to complete over the following months. The graduates are responsible for all aspects of research and organisation including division of work, budget management and producing and presenting a final report. Each group is assigned a mentor whose purpose is to oversee the way the group works and to provide support to them, but not to tell the group how to write or what to put in their report.

This report has been produced by GDG 5/01. The group came together for the first time in late October 2001 and was set the following project: -

'How will defence forces function in a world drained of fossil fuels?'

The group went about this project by brain storming all the possible areas that could be covered by the project. It was soon realised just how large an area the project could cover. This was found to be a mixed blessing for the group as we did not have the time or resources to allow the group to go into all the possible subject areas in as much detail as we would have liked.

Initially it was decided to try to come up with a time scale for the depletion of fossil fuels and a number of possible scenarios for the world in which the future defence force would have to operate. After this, the next logical step was to investigate the possible technologies available, how they would function and what their effects on future operations would be.

Once all the information was collected it was collated into a draft report to be reviewed by the whole group. This then lead to many hours of discussion on whether certain parts of the report were relevant and if so, how best to present them. The process of rewriting the report was being undertaken by a small section of the group. In parallel, the majority of the group designed the final presentation, the purpose of which is to present the group's findings and recommendations.

The recurring theme within this report will be that of unanswered questions. Themes are addressed that contain so many diverse variables that suitable single answers would be impossible and foolish to generate. Therefore, suggestions are made, based on what is currently known. However, this report is intended to provoke interest and debate into the areas as opposed to an exhaustive investigation.

The reader is probably aware that energy is more than merely fuel for cars and electricity for houses. It defines an entire infrastructure, from the primary source, through the distribution network to the end user. This structure is addressed in the report by investigating the current primary sources of energy and the alternatives to these. It includes a look at the current distribution networks, the current in-service platforms and how technology could be developed to maintain their capability or develop new systems to provide future capabilities and fulfil future requirements.

2 CURRENT PRIMARY ENERGY SOURCES

2.1 AIM

To identify the current sources of primary energy, their world-wide location, cost and future potential.

2.2 SUMMARY

- Oil provides 40% of world-wide primary energy. Being controlled by a minority of countries it has a strong influence on world economics and politics.
- Four barrels of oil are consumed for every barrel discovered. The UK government expects cheap oil to last until 2020-5, thereafter, technology will need to be developed to obtain “less pipeable” reserves.
- Gas has gone from being a wasted by product of oil mining to a major source of primary energy.
- Reserves of gas are of less concern than the problems posed by the technological and financial risks of extraction, which could potentially prevent reserves from being utilised.
- Coal is still a well-distributed source of primary energy, despite its decline in the UK.
- Coal’s future depends upon technology to reduce the pollution it produces, primarily CO_2 emissions.
- Nuclear fission provides a relatively CO_2 free source of energy, although its costs are higher than fossil fuels per unit of energy and there are public fears over its safety.
- Future uranium reserves could see fission for another 250 years, although new generators would have to be developed through international collaboration to replace the ageing ones that currently exist.

2.3 INTRODUCTION

A primary source of energy is one that is used at the start of an energy chain. It can represent fuel in a power station, or fuel to operate a vehicle, but it represents the initial release of energy from a source. In the UK and the world four main primary energy sectors exist, with an emerging fifth. These sectors are oil, gas, coal and nuclear fission, with renewable sources emerging as the fifth source. Figure 1 shows the UK split in the year 2000.

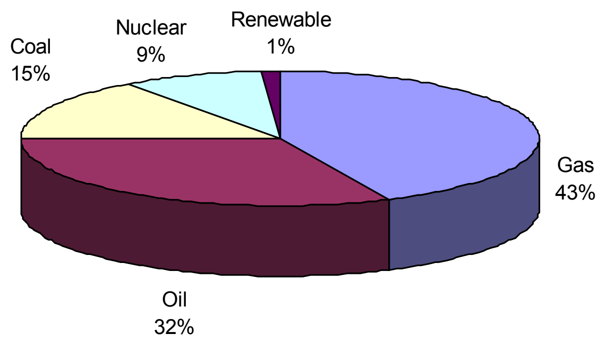

Figure 1. UK energy sources in 2000.

It will be seen that apparent supply diversity is restricted by political, economic and physical constraints. In addition, that the UK dependence for primary energy is heavily placed on the fossil fuel market. In all cases of energy provision the total costs, the innovation of technology required, security of supply, environmental, economical and social impacts must be taken into consideration, on a global scale across a large time frame.

2.4 OIL

2.4.1 WORLD OIL LOCATION

Oil is the most commonly used of the fossil fuels and accounts for 40% of the World's total primary energy demand. Energy demand and economic conditions are therefore governed to a large degree by the availability of oil. The estimated recoverable oil in the earth is 2,330 billion barrels and of this 1,000 billion barrels is in proven crude oil reserves. The largest known deposits can be found in the Gulf region under Saudi Arabia, Iraq, the United Arab Emirates, Kuwait and Iran. All are members of the Organisation of the Petroleum Exporting Countries (OPEC). Russia and China also have large proven reserves but are pumping at rates that will cease to be sustainable far sooner than the Middle East countries. Table 1 shows the OPEC and non-OPEC countries with the largest reserves (Reference 2).

OPEC		Non-OPEC	
Country	No. of barrels (billion)	Country	No. of barrels (billion)
Saudi Arabia	260	Russia	49
Iraq	110	Mexico	27
UAE	95	China	24
Kuwait	95	United States	23
Iran	92	Kazakhstan	14
Venezuela	66	Norway	10

Table 1. The six highest oil reserves OPEC and non-OPEC countries.

OPEC is a permanent, intergovernmental organisation, created at the Baghdad Conference of 10-14 September 1960, by Iran, Iraq, Kuwait, Saudi Arabia and Venezuela. These founding members were then joined by Qatar (1961); Indonesia (1962); the Socialist Peoples Libyan Arab Jamahiriya (1962); the United Arab Emirates (1967); Algeria (1969) and Nigeria (1971).

The major oil producers (in barrels per day) are Saudi Arabia (8 million (MM)), United States (6.5 MM), Russia (5.9 MM), Iran (3.5 MM) and China (3.5 MM). The 11 members of OPEC produce about 40% of the world's crude oil. As OPEC member countries hold more than 75% of the world's proven oil reserves, the production from these countries is set to rise well above this figure in the future. Non-OPEC countries consume large amounts of the oil they produce, so about 60% of the oil traded internationally comes from OPEC countries. These countries have a tendency to pump at full capacity whilst members subscribe to a quota system.

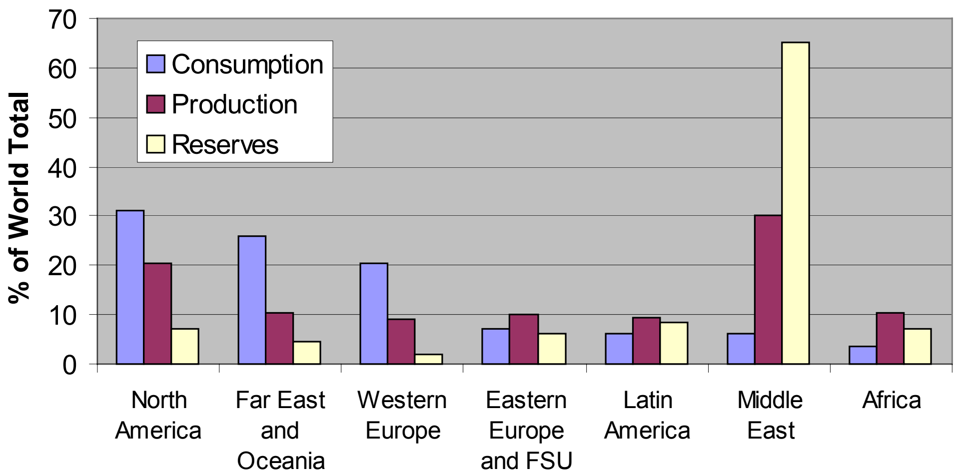

Figure 2. The Global Oil Consumption, Production and Reserves as at end 2000.

These figures compare with the UK production of 4.3 mboe per day, a figure that is currently falling (Reference 1).

2.4.2 FUTURE WORLD OIL SUPPLY

A study in 1999 of oil and gas distribution and depletion (Peak Oil by Colin Campbell) indicated that 90% of the world's oil has been discovered. This is based on an estimate that the recoverable oil in the Earth was 2330 billion barrels. Of this figure 50% has been produced and the World consumes approximately four barrels for every one discovered. The current depletion rate has been calculated at 2.2% per year. This percentage can only increase as oil moves from being in abundant supply to being rare to find. It would give an overall figure of 100 years of consumption left, representative of all countries producing and consuming equal amounts. From Figure 2 this is clearly not the case so for countries such as North America, Western Europe, the Far East and Oceania, 100 years is an unrealistically long time frame. It is also unrealistic for the Middle East but unrealistically short rather than long.

A source found from the BBC news describes how consumption at present is approximately 70 MM bpd (barrels per day) and oil producers expect this to rise to 100 MM bpd by 2020. OPEC says that its reserves are sufficient to last another 80 years at the current rate of production. What is more likely is that there will always be oil around but it will simply become harder and harder to extract thus increasing the costs to a level that will not sustain production.

The supply of cheap oil will be available up to 2020, after this period oil supply will rely more heavily on extracting from unconventional sources. This will cause the price to rise. The future of affordable oil after 2025 depends upon the cost of the technology to extract these oil sources. (Reference 1).

This is simply looking at the availability of oil in the Earth. The future of oil, certainly for the UK forces, can bring into account many other factors. For instance politics can play an important role. In 1973 the OPEC members, led by Saudi Arabia, cut oil supply to punish the West for supporting Israel in the Arab-Israeli war. This move caused a price increase from $3 per barrel to $12, which caused economic crisis in the developed world.

2.5 NATURAL GAS

2.5.1 WORLD GAS LOCATION

It used to be assumed that oil would be abundant forever. People did not look to alternative energy sources and as a result the utilisation of gas in the past has not been optimal. Due to economic constraints most gas in the past was flared. Increasing concerns about diminishing energy reserves and environmental hazards has forced industry to utilise a higher percentage of this gas. Many countries are increasing their use of gas primarily for domestic consumption in order to decrease the amount of oil imported or to increase the amount of oil that can be exported. Gas is becoming a primary focus for exploration in many areas. From Figure 3 it is clear that most countries consume what they produce, with the exception of Western Europe which consumes more than it produces and Eastern Europe and the Former Soviet Union and Africa who produce more than they consume.

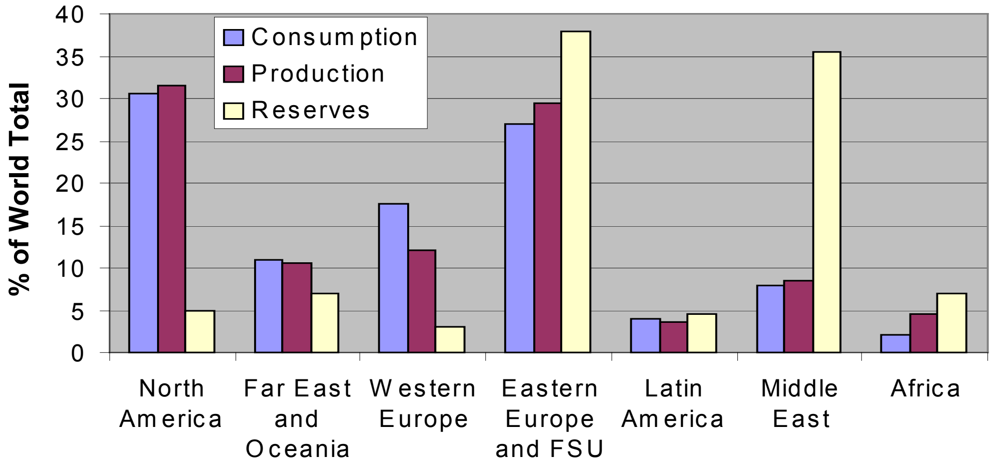

Figure 3. The Global Natural Gas Consumption, Production and Reserves as at end 2000.

2.5.2 FUTURE WORLD GAS SUPPLY

Quite simply we do not use natural gas to its full potential. For us to get optimal use from this fuel we must stop flaring it, improve the technology for extracting it and develop ways to use it efficiently. If this happens natural gas could easily last longer than oil; sources have quoted between 20-40 years.

In addition, "Two thirds of the world's global gas reserves are already within economic distance of the European gas market" (Reference 2). Thus, the sources are more favourably placed to the European market, and importantly the UK. Reserves of gas are not the main concern, of course they will eventually deplete, but the government identifies that the primary risk is that of accessing the gas. (Reference 1) This supply risk, according to the recent PIU report, The Energy Review, is related to:

- *Unreliable supply source.*
- *Lack of investment in infrastructure*
- *Facility failure*
- *Market power*
- *Delayed European liberalisation (Reference 1*)

It is a familiar problem that faces the gas supply industry. Supply infrastructure costs time and money. The money must be offset through higher prices. Thus the risk must be assessed at whether investment is worthwhile, or better spent on more long-term sources of alternative energy. This applies to all fossil fuel sources, but is most poignant to gas, due to its high concentration in few countries. This is a particular problem for the Former Soviet Union (FSU), which must find huge investment to realise its natural gas resources.

2.6 COAL

2.6.1 WORLD COAL LOCATION

The world's coal is distributed more evenly than oil and gas on a geographical basis. It is apparent from Figure 4 that all world regions consume what they produce except for Europe, which again consumes considerably more than it produces.

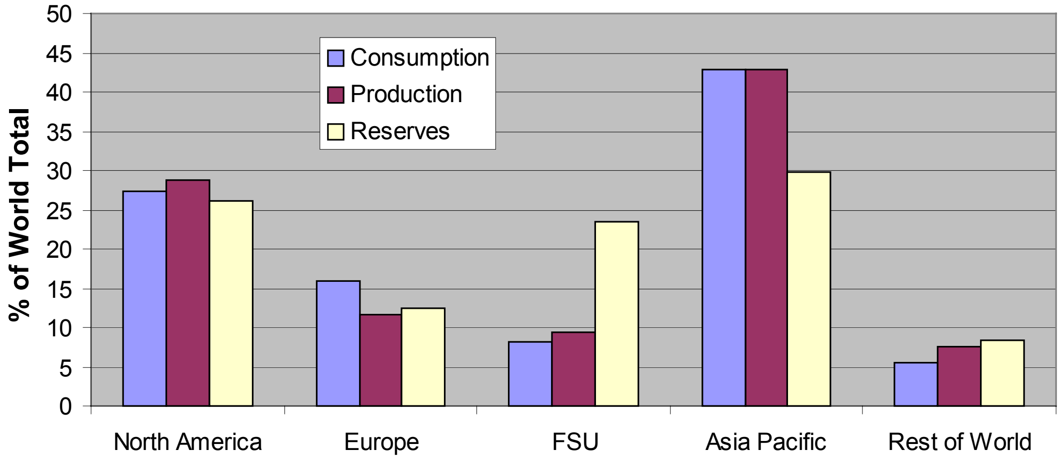

Figure 4. The Global Coal Consumption, Production and Reserves as at end 2000

2.6.2 FUTURE WORLD COAL SUPPLY

Coal is the most abundant of the three fossil fuels and although it is distributed more evenly, Russia, the US, Asia Pacific and Europe have much larger reserves than the Middle East and the rest of the world. The problem with the future of coal is the difficulty of mining it.

Coal is also very harmful to the environment as it produces a large amount of CO_2 when it is burned, so much in fact that if all the coal reserves were to be used then there would be a global warming crisis. Technologies to develop carbon capture and sequestration could reduce CO_2 emissions and keep coal as a valid electricity generation energy source. Figures found from varying sources have suggested that there are between 200 and 600 years of coal reserve left in the world.

2.7 NUCLEAR FISSION

2.7.1 WORLD NUCLEAR FISSION LOCATION

The majority of industrialised nations, including all the G7 nations, operate a nuclear fission programme. Sited fifty years ago as the cheap, clean alternative to fossil fuel use, nuclear fission represents a mature source of electricity production. Its past has been blurred with environmental catastrophes across the globe, however, advocates argue that well managed sites do not suffer such disasters, and that the near zero carbon dioxide emissions benefit balances out the risk mitigation effort required.

The source of the energy is uranium. Which has predicted world-wide reserves of 250 years at current consumption (Reference 1). In addition to being available from a number of world-wide locations, it can be easily stockpiled to avoid the risk of supply shortages.

2.7.2 WORLD NUCLEAR FISSION FUTURE

The continued use of nuclear fission depends upon the development of new modular reactors; these may require international collaboration to cover the investment costs. The UK situation is the current nuclear capability will require decommissioning within the next 10 years (Reference 1). This can either be replaced by other energy sources, or a renewed effort into nuclear power.

Certain aspects would have to be addressed if the UK were to continue to rely on nuclear power:

- Environmental issues: ensure that the radioactive waste can be properly dealt with and that accidental radioactive emissions do not occur. This is very important as public opinion is strong on this matter, and public opinion has the ability to sway political policy.
- Cost: nuclear presently does not represent the cheapest form of energy supply. The huge initial cost of research, development and installation can make the entire life span of the site uneconomical. Such investment is substantial, and future nuclear investments would transfer these costs to the taxpayer or the customer. (Reference 1)
- Carbon: nuclear power generation would provide the UK with a source of energy that would reduce its carbon emissions.

2.8 CONCLUSION

Quite simply the oil in the Western world will run out long before that in the Middle East. Ease of access and quality mean that Middle Eastern oil in particular is the most profitable and cheapest to produce in the world. Should the stable politics decline in the future then the armed forces of Europe and the US will have to find alternative energies long before the Middle Eastern countries.

However, the Western World does fare better against the Middle East on both natural gas and coal. The only two regions of the world that are increasing their natural gas reserves through increased production are Africa and the Middle East. This is also true for coal although South America can also be added to the list for this fossil fuel. A theory on this is that the more developed countries have had the technology to produce these resources and a wider need to use them for power. Africa and the Middle East are now becoming more developed so with improvements in technology and increases in need they will be able to find and produce more of these fuels to increase their reserves. However, they are a long way behind regions such as Asia Pacific and Europe. Most likely Africa and the Middle East will never become dominant in coal or gas production, since these two fuels are clearly less abundant in those areas than oil.

After considering research from many sources the assumption that will be made for this GDG project is that we will be completely drained of fossil fuels in 80 years time. It is likely that oil and gas will be totally consumed in approximately 40 years. With increased use, coal will then last a further 40 years. Estimating the time scale is a difficult task, and only time will prove estimates right or wrong. The reality is that fossil fuels are a finite resource and they will eventually be exhausted.

The depletion of the fossil fuels for the UK will be the result of many different factors. Although there still may be more fossil fuels in the earth, technology will not allow us to mine for them. Environmental reasons will not allow the total use of all the coal reserves. The UK may drain its land of fossil fuels, which will bring about political struggles and possibly conflicts to obtain other fuels. What is likely to happen is that there will be a crossing point when the increasing economic costs of obtaining fossil fuels will meet the decreasing economic costs of alternative fuels. At this point the fossil fuels will no longer be mined and drilled but simply left in the earth and the new power sources will take over.

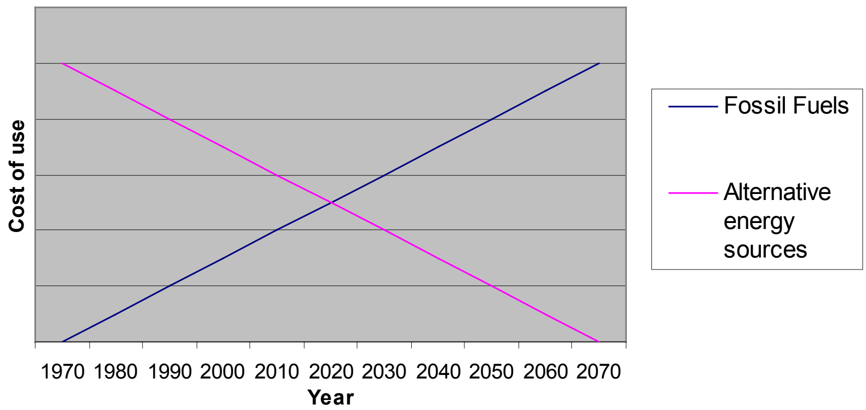

Figure 5. A sketch graph illustrating the fact that the cost of obtaining fossil fuels will eventually outweigh the cost of using alternative energies.

3 ALTERNATIVE SOURCES OF PRIMARY ENERGY

3.1 AIM

To show the various alternative sources of energy, their level of technological maturity and future cost implications, thus viability.

3.2 SUMMARY

- Wind power is technologically mature and can provide grid or decentralised capability.
- Wind power is predicted to be the cheapest source of energy in 2020, the main hindrances are investment and the logistics of set-up.
- Tidal and wave energy offer large potential sources of energy. However, energy capture technology is still immature with no commercial market.
- Photovoltaic solar power is applicable to hot climates. In the UK it could provide a cheap decentralised alternative.
- Energy crops are reliant on the development of combustion technologies, but could provide useful input into the primary energy source market.
- Nuclear fusion could provide a clean, cheap source of future energy. However, it is heavily dependent on a major technology breakthrough and therefore carries a lot of risk.
- A number of substitute fuels have been identified, including the criteria against which a suitable new fuel should be judged.

3.3 INTRODUCTION

Alternative sources of energy are those not included in the group of fossil fuels and nuclear fission. At present they account for 1% of the UK's primary fuel source. Some alternative energy sources offer long-term cost savings, environmental benefits, or a combination of the two. Some alternative sources are technologically mature whereas others need a lot of development. Those sources considered here have the largest potential to produce energy.

3.4 WIND ENERGY

3.4.1 TECHNOLOGY DESCRIPTION AND MATURITY

Numerous public opinion surveys have consistently shown that the public prefers wind and other renewable energy forms to conventional sources. The benefits of wind energy are quite obvious. It is a free and renewable source. No matter how much is used today, there will be plenty left tomorrow. Wind is a clean, non-polluting source of electricity. To get a perspective, in 1990 California's wind power plants offset the emission of more than 1.1 billion kg of carbon dioxide and 6.8 million kg of other pollutants.

Wind turbines, like propeller blades, turn and power an electric generator, which supplies an electric current. The turbines are usually grouped together in a 'wind farm' to generate bulk electrical power. There are two types of wind generation: on shore and off shore.

Wind turbines are available in a range of sizes, and therefore power ratings. The largest machine has blades that span more then the length of a rugby pitch and stands 20 stories high. This size produces enough energy to power 1400 homes. A small home-sized wind machine has rotors between 8 and 25 feet (2.5 – 8 m) in diameter and stands 30+ feet (10+ m) tall. This size can supply the needs of an all-electric home.

Problems with wind energy include noise pollution of the rotor blades, the aesthetic impact of turbines, the intermittent nature of the energy source and their location. Good wind sites are usually in remote areas away from population centres where electricity demand exists.

3.4.2 COST AND FUTURE POTENTIAL

Although the cost of wind power is continuously decreasing, the technology requires a higher initial investment than fossil fuel generators. Roughly 80% of the cost is the machinery, the remainder being additional network provision from the grid to the remote locations used for wind farms. If wind-generating systems are compared with fossil fuel systems on a life cycle cost basis (incorporating fuel and operating expenses), they are much more competitive as there are no fuel costs and minimal operating expenses.

Wind energy avoids the costs associated with conventional sources such as the trade deficit from importing foreign oil, the health and environmental costs of pollution and the cost of depleted resources. Utility scale wind projects are competitive with the direct operating costs of many conventional forms of electricity generation. The PIU predicts that on shore wind generation will become the cheapest form of electricity generation in 20 years time, in the range of 1.5-2.5 p/kWh (Reference 1).

Although wind energy is a mature and demonstrated technology, there are problems with its implementation, even when there is willing funding available. The case study at Annex A shows this.

3.5 WAVE AND TIDAL ENERGY

3.5.1 TECHNOLOGY DESCRIPTION AND MATURITY

The total power of waves breaking on the world's coastlines is estimated at 2-3 million MW. In favourable locations, wave energy density can average 65 MW per mile of coastline.

The UK is one of the world's leaders in developing wave power but recent setbacks including lack of funding have slowed research. Wavegen has set up a test system on the island of Isley. The energy is transformed by using a LIMPET 500 (Land Installed Marine Powered Energy Transformer). It will feed 50 kW of electricity into the island's grid. Limpet was born out of a 10-year research project on the island where the team had built a demonstration plant capable of generating 75kW of electricity.

Wavegen say that there could be sufficient recoverable wave power around the UK to generate enough power to exceed domestic electricity demand. Some research from renewable energy supporters suggests that less than 0.1% of the renewable energy within the world's oceans could supply more than five times the global energy demand, if it could be economically harnessed. Large-scale plants have faced opposition for similar wind farm arguments as the noise and aesthetics will be unfavourable in near shore locations.

Tidal energy traditionally involves erecting a dam across the opening to a tidal basin. The barrage at Cardiff Bay is an example of this system. A sluice gate in the dam is opened to allow the tide to flow into the basin. The sluice is closed, and as the sea level drops, traditional hydropower technologies can be used to generate electricity from the elevated water in the basin. Some researchers are looking at extracting energy directly from the flow.

Figure 6. Cardiff Bay Barrage.

3.5.2 COST AND FUTURE POTENTIAL

Whereas wind turbine generation is a developed technology, wave and tidal energies are not. Commercial markets do not exist within this field. Cost estimates of between 4 and 8 p/kWh are cited for the first commercial scale devices.

3.6 PHOTOVOLTAIC ENERGY

3.6.1 TECHNOLOGY DESCRIPTION AND MATURITY

More commonly known as solar power, this is a familiar technology and is seen on a number of electronic devices. It can be used on a large scale in solar farms to produce grid electricity. Alternatively it can be used to produce decentralised sources of local electricity.

Solar power is heavily dependent on the sun; therefore, a country without a sunny climate would not fare well in choosing solar power. Solar power, although developed throughout the space race, still has some technology advances to be made. These revolve around improving efficiency (proportion of available sunlight converted to electricity), by improving the photochemicals in the cell and reducing their susceptibility to degradation by UV rays.

3.6.2 COST AND FUTURE POTENTIAL

A sunny climate is essential. The cost of PV electricity is predicted at 10-16p/kWh by 2020 (Reference 1). Therefore, PV generation is not the most favoured option in the UK. In addition, present new cell technology (featuring gallium arsenide), is significantly more expensive to produce (Reference 3).

3.7 NUCLEAR FUSION

3.7.1 TECHNOLOGY DESCRIPTION AND MATURITY

The nuclear fusion process reflects the reaction that occurs on the surface of the sun. Hydrogen nuclei collide, to form helium and release energy. This energy can then be harnessed to produce electricity. The process is clean with cheap fuel and no CO_2 emissions.

The temperatures involved make confinement of the reaction extremely difficult. There is excited research into this technology. The European studies are based in Culham, UK. However, the technology is at an early stage and if actually possible a demonstration reactor could take 25 years, even at an accelerated development rate (Reference 1).

3.7.2 COST AND FUTURE POTENTIAL

Nuclear fusion has huge potential to be a primary source of electricity. However, it relies on a large technology leap, which may not even be possible. This presents a dilemma in that the development requires more money, but more money will not arrive until people are sure of their investment. It is a high-risk option that goes against current funding initiatives. The private sector demands profit thus favours incremental technology jumps. The government also favours this low risk approach.

3.8 ENERGY CROPS

3.8.1 TECHNOLOGY DESCRIPTION AND MATURITY

The principle is that crops are grown, then either combusted to generate electricity, or used to manufacture a combustible fuel. Examples have been seen in the press: buses that run on rapeseed oil, or cars that run on alcohol from sugar cane.

The key aspects to the technology are that of efficient farming and combustion. Combustion technology is currently at the demonstration phase with more development required.

3.8.2 COST AND FUTURE POTENTIAL

Estimates of energy cost lie in the range of 2.5-4 p/kWh, (Reference 1) but depend highly on advancements in combustion technology. Energy crops will compete with food crops for farming land in the UK, but as with food today, imports may prove economically sound.

3.9 POTENTIAL SUBSTITUTE FUELS

3.9.1 TECHNOLOGY

The development of new processes to supplement conventional fuels raises the additional question of processes for *new* fuels. Those materials, which may be described as a *substitute fuel*, will be reviewed. These substitute fuels appear as potential replacements for conventional (hydrocarbon) fuels but have different properties and sources. They include:

- Liquefied Hydrocarbon Gases
- Liquid Hydrogen
- Hydrocarbon Oxygenates (Alcohols and Vegetable Oils)
- Synthetic Gas
- Hydrogen – Nitrogen Compounds (such as Hydrazine)
- High Performance Fuels (such as exotic metals and solid rocket propellant)

3.9.2 CONSIDERATIONS

Viable substitute fuels must be meet the criterion listed below:

3.9.2.1 AVAILABILITY

The potential fuel should be available on a large scale or be 'renewable'. It would be advantageous if the fuel or raw material for the fuel was evenly distributed on a global scale.

3.9.2.2 HANDLING QUALITIES

It would be desirable that the fuel source (either pre- or post- manufacture) does not require any special handling techniques. Ideally, it should be no more hazardous or dangerous to handle than current fuels.

3.9.2.3 MASS SPECIFIC ENERGY CONTENT (SPECIFIC ENERGY)

This quantity is useful when comparing specific fuels. Mass specific energy content (specific energy, for brevity) can be defined as the amount of energy present per unit *mass*. In physical terms a fuel with a *high* specific energy will allow a vehicle to travel further per unit mass of fuel, all other factors being constant.

3.9.2.4 VOLUME SPECIFIC ENERGY CONTENT (ENERGY DENSITY)

This quantity is useful when comparing specific fuels. The volume specific energy content (energy density, for brevity) can be defined as the amount of energy present per unit *volume*. In physical terms a fuel with *high* energy density will require less storage volume than a *low* energy density fuel.

Low energy density fuels are not desirable, as excessive internal volume would be required to hold a given amount of energy. Furthermore, the physical size of the vehicle in question would be large.

3.9.2.5 COMBUSTION PERFORMANCE

Combustion performance is a major design driver when considering propulsion. The substitute fuel under consideration should burn easily and be readily incorporated into existing combustor designs.

From this point of view it can be seen that gaseous fuels hold many advantages over more viscous liquid fuels. Gases will readily mix to form a combustible mixture, whereas a liquid fuel must first be atomised before mixing in droplet form.

3.9.2.6 PRICE

The present cost of setting up an infrastructure to supply a potential substitute fuel is large, as is the cost of collecting and manufacturing raw materials into a usable product.

Presently the price differential between existing conventional fossil fuels will remain unfavourable until quantity production is established. Probably, conventional fuels will continue to become more expensive.

3.10 COST ANALYSIS

3.10.1 PREDICTION PROBLEMS

Predicting future trends and costs is extremely difficult and the following are estimates based on research and best engineering judgement in cases (Reference 1).

Technology	2000 Cost/p/kWh	2020 Cost/p/kWh	Basis for Assessment	Confidence in Estimate	Cost Trends to 2050
End use efficiency sources					
Fuel cells	In development	Unclear	Engineering assessment	NA	Sustained decrease
Large Combined Heat and Power (CHP)	Less than 2	Less than 2	Engineering assessment	High	Limited decrease
Micro CHP	In development	2.5 to 3.5	Engineering assessment	Moderate	Sustained decrease
Transport efficiency sources					
PV	70	10-16	Learning rate and market growth rate	High	Sustained decrease
Onshore wind	2,5-3	1.5 to 30	Learning rate and	High	Limited

			market growth rate		decrease
Offshore wind	5-6	2 to 3	Engineering assessment and onshore learning rate	Moderate	Decrease
Energy crops	8	2.5 to 4	Engineering assessment and learning rate	Moderate	Decrease
Wave	In development	3 to 6	Engineering assessment	Low	Uncertain
Fossil generation with CO_2 collection	In development	3 to 4.5	Engineering assessment	Moderate	Uncertain
Nuclear	6	3 to 4	Engineering assessment	Moderate	Decrease
Combined Cycle Gas Turbines (CCGT)	2.2	2 to 2.3	Engineering assessment and learning rate	High	Limited decrease

Table 2. Current and Future Costs of Primary Energy Sources

Table 2 summarises current and future sources of primary energy supply. It shows that alternative and renewable energy production will become financially comparable to their fossil fuel counterparts over the next 50 years. This table should not be taken as definitive; it highlights that a lot of “judgement” is involved and that the future will require flexibility and adaptability. Despite exact details being unclear, the end result is certain. Fossil fuels *will* deplete. This offers an opportunity for the UK to become a major player in this emerging industry.

3.11 CONCLUSION

The previous chapter concluded that fossil fuel depletion will eventually mean concession to alternatives on economic grounds. However, it is not just a case of waiting for the economic point at which renewables become cheaper than fossil fuels. In the energy market, this could span several years. The reasoning is twofold: firstly the energy market has very high inertia and to implement change takes years. Therefore early decisions must be made to cope with the transitory period. Secondly, this represents a growth market in industry that the UK, with its talent for engineering design, could easily exploit with early investment.

The UK has a wide number of natural assets that are suited to renewable energy - good wind locations and a lot of coastline. The main hindrance to application is logistics and bureaucracy (as is the case of mature technology such as wind power). Wave and tidal energy must show technological maturity through the demonstration phase before commercially accepted. Nuclear fusion, although very promising, must mitigate the huge technological risk involved in order to attract the appropriate funding. This alternative is probably viable after the next twenty years.

Through effective planning and organisation, the development of alternatives will replace the need for fossil fuels as a primary fuel source. The impact on the military, and indeed the country, is that they will still receive the energy they require but the form in which they receive it may change. In addition, this chapter has considered primary energy. Storing and utilising energy are additional huge considerations.

Cost estimates show a possible marginal increase, which may be another publicly felt effect of fossil fuel depletion. However, this comparison is conjecture considering issues such as improved home and vehicle efficiency, which result in less energy consumed at a slightly higher rate.

4 ENERGY DISTRIBUTION

4.1 AIM

To highlight the considerations of supplying energy to the end user.

4.2 SUMMARY

- Most forms of energy require some kind of distribution network to make them usable.
- Fixed networks are a weak point in a defence force, since they are vulnerable to attack and slow to deploy.
- Secondary energy sources are convenient ways of transporting energy generated by other means.
- Fuel cells offer an efficient solution to energy transport for some mobile applications.

4.3 INTRODUCTION

The reason that oil and its derivatives are so widely used as vehicular fuels is because they can conveniently be transported. The amount of energy they contain per unit mass and per unit volume is great enough to make them viable for use on a wide range of platforms. These systems use the fuel as a primary energy source, directly using the energy released by burning it.

There will be no lack of energy in the future, but it may be derived from primary sources that are not as portable as oil. This may be the case if renewable energies such as wind or hydroelectric power are used to a large extent. Efficient distribution networks or secondary power sources will then be required to supply the energy to the end users.

4.4 DISTRIBUTION NETWORKS

Fixed networks provide an easy way of supplying energy to where it is needed. Electricity can be transmitted along wires, gaseous or liquid fuels along pipelines. Such transports may be easy to construct, but have many drawbacks for a defence force:

- Attacks may easily target fixed networks.
- There can be many single points of failure.
- Operations are limited to a geographic area.
- Fixed networks cannot quickly be deployed to new locations.

For these reasons, it would be unwise to become dependent on an energy source that requires use of a fixed network, unless that network is ubiquitous in all potential areas of operation.

Some primary energy sources can be supplied over mobile networks. An example is petrol. Although normally supplied to the end user through fixed refuelling points, petrol has a sufficient energy density that it can viably be transported using tankers rather than pipelines. Such a network has higher running costs than a fixed system, but allows a network to be implemented for a much lower initial cost. Also, since the tankers do not travel fixed routes, most of the problems outlined above are solved.

4.5 SECONDARY ENERGY SOURCES

Rather than supplying energy directly in the form of electricity or a chemical fuel, it may be desirable to use a secondary energy source. This is done when the primary source produces energy in a form which is either difficult to transport, difficult to store, or simply not usable.

In many cases, the preferred solution will be to convert the energy to electricity. By this means we are able to use coal, oil, gas, wind and hydroelectric power in our homes, via the National Grid. However, while electricity is easily converted to other forms of energy, for immediate use in many applications, it energy cannot easily be stored in electrical form. It also suffers from the problems of fixed network distribution described in Section 4.4.

To overcome these problems, electrical energy is often converted to chemical form. Although there is research into electrical and magnetic energy storage, chemical media such as batteries currently give higher energy densities. The usefulness of batteries hinges around their weight and size for given energy capacities, although cost and operating temperature are also factors.

4.5.1 FUEL CELLS

4.5.1.1 INTRODUCTION

A more recent alternative to conventional batteries is the fuel cell. Electricity can be stored by using it to decompose water into hydrogen and oxygen, which the cell then uses as fuel.

The fuel cell is a viable method of storing energy in a readily useable and transportable medium. It has an almost inexhaustible supply of fuel material, extremely high efficiency, virtually zero pollution, and the ability to integrate with current energy vectors through the use of reformed fossil fuels. There is also the potential to couple all the input processing energy to renewable sources – in what is being referred to as the Closed Loop Hydrogen Cycle or Hydrogen Economy.

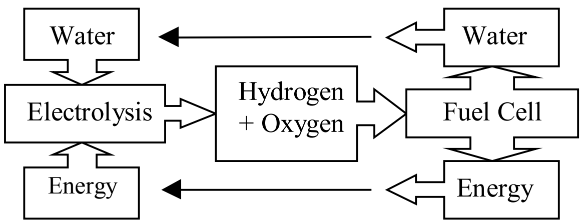

Figure 7. The Hydrogen Cycle

As Figure 7 illustrates, both the inputs and outputs are desirable, yet the fuel cell is still able to provide a storage medium with a high efficiency.

"The challenge now is to move from the carbon-dominated energy system of the 20th century to a hydrogen economy during the course of the 21st century. A hydrogen economy would be based on the most abundant element in the universe, which is broadly available in sea water and which can be turned into a useful fuel using solar energy and other renewable forms of energy." (Reference 4).

4.5.1.2 OPERATION OF A BASIC FUEL CELL

In principle, a fuel cell operates like a battery. Unlike a battery, a fuel cell does not run down, but produces electricity and heat as long as fuel is supplied. A fuel cell consists of two electrodes sandwiched around an electrolyte. Oxygen passes over one electrode and hydrogen over the other, generating electricity, water and heat.

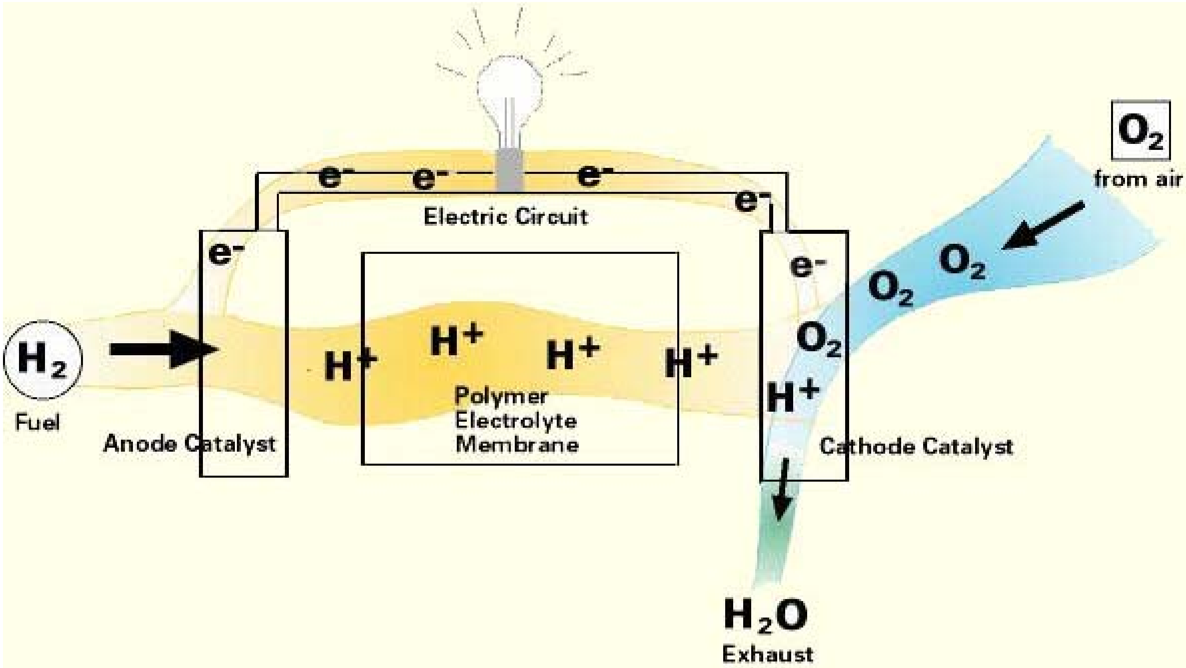

Figure 8. Fuel cell operation.

Hydrogen fuel is fed into the anode of the fuel cell. Oxygen (or air) enters the fuel cell through the cathode. Encouraged by a catalyst, the hydrogen atom is ionised, its proton and electron, taking different paths to the cathode. The proton passes through the electrolyte. The electrons create a separate current that can be utilised, before they return to the cathode to be reunited with the hydrogen and oxygen in a molecule of water.

A fuel cell system that includes a "fuel reformer" can utilise the hydrogen from any hydrocarbon fuel - from natural gas to methanol or even gasoline. Since fuel cells do not rely on combustion, emissions from this type of a system would still be much smaller than emissions from the cleanest fuel combustion processes (Reference 5).

This demonstrates the great versatility with which fuel cells can integrate with the current carbon based energy vector, allowing the transitional phase to be less risky, both technically and from a cost perspective.

5 NON-FUEL DEPENDENCY ON FOSSILS

5.1 AIM

To highlight the ways defence forces are dependent on fossil products, beyond their application as propulsion fuels.

5.2 SUMMARY

- Many materials are produced directly or indirectly from fossil hydrocarbons.
- Plastics, lubricants, etc. use fossil fuels as a raw material.
- Other common materials use fossil fuels to generate high temperatures for production.
- Alternative materials and techniques will be available in the future, but are likely be more expensive.

5.3 INTRODUCTION

At present nearly every material used by defence forces around the globe requires the use of fossil fuels in some way. When fossil fuel reserves are exhausted, there will be dramatic effects on the equipment defence forces have available to them. Not only will the fossil fuel depletion have an effect on the materials available, it will also effect the way materials are produced. However, with technology improving at an accelerated rate, this may not cause as large a problem in the near future as it would pose in the present day. Still, the size and complexity of the problem not only affects defence forces, but also the wider society.

The production of materials using fossil fuels can be split into two different categories:

- **Direct use materials** - made or refined directly from fossil fuels, e.g. plastics.
- **Indirect use materials** - requiring the use of fossil fuels in production, e.g. burning fossil fuels to give the high temperatures for the production of metals.

5.4 DIRECT USE MATERIALS

A few examples of the materials that are produced directly from fossil fuels are:

- Petroleum Products e.g. petrol, diesel, aviation fuels.
- Plastics
- Lubricants e.g. oils

The dependence of defence forces on petroleum products, derived from crude oil and used extensively as fuels, are covered in depth in the Existing Hardware section of the report.

Plastics are used in a very wide range of equipment. One reason why they are currently used so extensively is that they are cheap and easy to manufacture compared to the possible alternatives. They are also lighter in weight than most materials that could be used to replace them, such as metals. Another advantage of plastics is that they can be produced to become more durable than a lot of alternative materials. All these factors have contributed to making plastics some of the most ubiquitous materials in the modern battle space.

The requirement for lubricants is as great as that for petroleum products. Without lubrication all defence equipment with moving parts would seize up and cease to function. Defence forces are almost totally dependent on motor vehicles, ships or aircraft for transportation of men and supplies to where they are needed. Without lubricants the use of these pieces of transportation and equipment would be impossible. As a result personnel and supplies would have to move around the battle space exposed and unprotected, moving any equipment they require by hand or alternative means.

5.5 INDIRECT USE MATERIALS

These are materials that indirectly require the use of fossil fuels in their production. Three examples of materials that indirectly use fossil fuels are:

- **Metals** e.g. steel, aluminium.
- **Semiconductors** e.g. silicon, germanium.
- **Polymers** e.g. carbon fibre.

Metals such as steel, aluminium and titanium are commonly used by defence forces in the construction of machines and equipment that are used either in the modern battle space, or to support operations for the battle space. These materials are used by all of the tri-services. The requirement to be able to produce these metals in a world depleted of fossil fuels is great because at present and in the immediate future there are, and will be, no direct replacements available.

Semiconductor materials such as silicon and to a lesser extent germanium are some of the most important materials on the planet at present. They are vital to the electronics that are so pervasive in modern society, defence included. The reliance of defence forces on semiconductor technology can be seen with the increasing trend towards network-centric warfare and high-tech projects such as FIST, the Future Integrated Soldier Technology.

Composite materials are used in many areas of the modern battle space by modern defence forces. They are used in place of conventional materials due to the special properties that can be designed into them. For example, composite materials can be produced to withstand high temperatures but still be lightweight and have high tensile strength. Such materials have uses within the area of missile or rocket nose cones and tail fins. Composite materials in general are used in many other specialised areas.

All these materials have one thing in common: the use of fossil fuel in their production. This is normally to generate high temperatures. In future these high temperatures, often in the order of 1400-1700°C, must be generated without the burning of fossil fuels. This temperature range is achievable using current techniques such as electric arc furnaces (EAF). The only problem is the larger issue of finding a suitable source of electricity. This will also be the case for a variety of other materials, such as aluminium, which is produced by a very energy-intensive electrolysis process.

While ‘indirect use’ materials will still be present in the future, the production locations may change according to the availability of energy. There is also likely to be a much greater use of recycling.

5.6 ALTERNATIVE MATERIALS

After considering the problems affecting materials that are currently used in the constructing of modern defence equipment, the next logical question is that of alternative materials which require no fossil resources. These materials could be natural or man-made or a combination of both. There are at present a number of materials being researched that could provide a solution.

Current avenues of research include:

- Genetic engineering to overcome production problems of natural materials such as spiders’ silk.
- Novel plastics produced from “green” or renewable base materials.

- Organic polymers to replace semiconductors in electronic and optical systems.

Although these materials can be engineered to be technically better than the materials they replace, there are disadvantages. Due to high development costs and more complicated production processes, alternative materials will normally be more expensive than their conventional predecessors.

6 DEFENCE FORCES WORLD-WIDE

6.1 AIM

To show the scale of world-wide defence forces and that they are heavily dependent on fossil fuels.

6.2 SUMMARY

- Defence is in-built in human society, therefore the provision for defence will continue into the future.
- Defence budgets are a significant percentage of world spending; the forces they support contain vast quantities of equipment, supplies and network resources.
- The whole defence system will be deeply affected by depleting fossil fuels, on a world-wide scale.

Conflict existed in the world long before man's primeval instincts to divide and conquer were historically recorded. Defence 'strategy' has therefore evolved as an important factor ultimate to man's survival and the role of the 'Defence Force' has continuously advanced in direct proportion to its requirements.

6.3 INTRODUCTION

The effectiveness of a nation's 'defence force' depends on many factors. Prime examples include economic funding, resources, equipment, technology, management, manpower, but above all, a successful strategy in reaction to enemy threat. In AD 600 the Great Wall of China was built to protect people from anti-social invasion. Today's Chinese defence force now harbours mobile armoured and nuclear defence capabilities, a potential manpower strength of some 200 million (Reference 7) and a science & technology interest financially coupled with an annual defence budget recently published at 166 Billion yen (Reference 8). As mankind strives for better defence alternatives, three key points are notable:

1. A record of pioneering science and technology breakthroughs, often driven by defence applications.
2. Intelligent soldiering – 'smart weapons' technology has evolved to the state that potential conflicts can be analysed before they occur. Reaction to enemy threat can now be implemented from longer distances.
3. The development of combined forces, capable of reacting to a single threat as a 'coalition' community of many.

Whatever shape, size, or form defence forces may take, it is clear that the global powers of today are severely dependent on the governing factors of the future. As the world's supply of fossil fuels start to deplete, the ultimate concern is the availability of the petroleum products needed to drive defence forces to and from the battle space.

6.4 LOGISTICS AND BASIC RESOURCES

Global defence force deployment relies on basic resources. These are: ammunition/munitions, water, food, petrol/oil & lubricants, operational ancillaries (equipment, clothing etc.), and morale. With the exception of the latter, these are delivered by necessary supply. In the case of fossil fuels, pipelines are used. It is said that 'an army marches on it's stomach' but the transport and logistics needed to deliver a defence force to it's theatre of operation is similar to a well oiled machine. Remove the resources vital to operation and the machine ceases to function. 21st Century combat relies on the best resources available to man, e.g. command and control, intelligence and high-tech electronics/telecommunications equipment. Defence hardware procurement is no longer platform dependent but capability driven. Reduce resources and you severely limit defence force capability. If the oil runs dry, the machine simply stops turning.

6.5 DEFENCE FORCES WORLD-WIDE

The combined résumé of the world's defence forces is colossal. American intelligence suggests the top 53 of the worlds most populated and developed nations have a combined (potential) military manpower strength of around 1,072 million - of which aircraft, ships and land vehicles are common and readily available. Whilst Figure 9 shows the quantity of crude oil reserves available to the top 6 OPEC and non-OPEC nations, military hardware also exists with countries who have less oil in reserve (Reference 9,10,11). Failure to provide fuel for this hardware warrants them worthless. The next technology race is therefore underway to develop an appropriate fuel/system substitute. If present capabilities are taken as a base line, this must fulfil the future needs of defence forces world-wide.

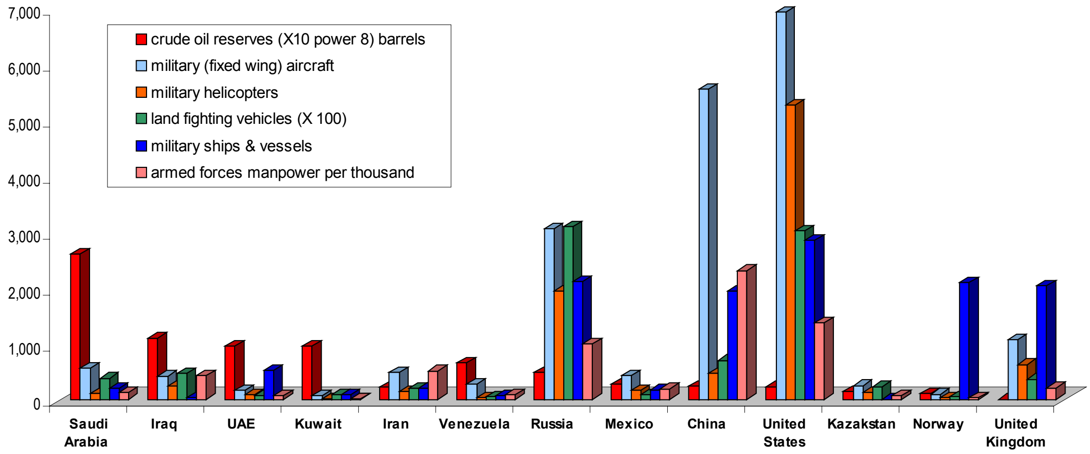

Figure 9. Defence forces of the top six OPEC and non-OPEC countries.

6.6 CONCLUSION

Defence forces on a world-wide scale are heavily dependent on fossil fuels. Their depletion will surely have an effect on operation capability. Efforts will need to be made to maintain capability through equipment replacement or updating. In addition, the requirement should be investigated to see if new alternative capabilities could be developed.

7 EXISTING HARDWARE

7.1 LAND SYSTEMS

7.1.1 AIM

The focus of this section of the report will be to look at land systems hardware currently in-service in the UK armed forces. It will attempt to show how it could be adapted to cope in a world devoid of fossil fuels.

7.1.2 SUMMARY

- The UK forces use a variety of land vehicles dependent on fossil fuels. These fulfil a wide range of requirements.
- In a 30 to 40 year time frame, it is predicted standard road vehicles could maintain current capability levels through development of adapted or alternative power plants.
- High specification military land vehicles rely on the high energy density of petrol and diesel. Replacing these units may call for more radical advances in power plant technology.
- Fossil fuels are not just used for power; they provide other resources such as lubricants, which must also be replaced.
- Land systems have the advantage of having a shorter lead-time to service entry than sea or air platforms. Thus less technology speculation is necessary, although a “wait and see” attitude is definitely not recommended.
- Hybrid vehicles and alternatives have been considered in some sectors, for example Tactical Reconnaissance Armoured Combat Equipment Requirement (TRACER).
- Industry is investigating possible uses or electric drive motors.
- An early start is advised, so that developed generations of technology are available when required in service.
- An early start also encourages technology development and investment within the UK, which is good for the long-term sustainability of a healthy economy.

7.1.3 INTRODUCTION

This section includes examples of equipment and its role, specifications of fuel consumption and dependencies on oils and plastics. It highlights possible alternatives for fossil fuels and speculates on how such changes can be implemented.

Looking specifically at the types of vehicles currently in-service in the UK armed forces, this section will attempt to rationalise how these vehicles, or more appropriately, the capability gap that they fill, could be developed to allow for an ever-decreasing amount of fossil fuels in the world.

7.1.4 EQUIPMENT EXAMPLES

Here we can see examples of equipment used by UK land forces and their basic specifications.

Figure 10. Challenger 2 MBT

Crew: 4
Combat weight: 62.5 tonnes
Power pack: Perkins Engines Company CV-12 TCA Condor V-12 developing 1,200hp coupled to David Brown Engineering TN54 transmission
Power-to-weight ratio: 19.2hp/t
Max road speed: 56 km/h
Average cross-country speed: 40 km/h
Useable fuel capacity: 1,592

Figure 11. Alvis Scorpion/Scimitar CVRT

Crew: 3
Weight: approx. 7.8 tonnes
Power pack: Perkins diesel developing 200bhp coupled to TN15 semi-automatic transmission.
Power-to-weight ratio: 22.92hp/t
Maximum speed: approx. 72.5 km/h
Fuel capacity: 391 litres
Operating range road: approx. 756 km

Figure 12. Alvis Stormer (CVRT/HVM)

Crew: 3 + 8*
Combat weight: 12.7 tonnes*
Power pack: Perkins T6.3544, 6 cylinder diesel developing 250 bhp, coupled to David Brown T300 transmission
Power-weight-ratio: 19.68bht/t*
Max speed 80km/h
Fuel capacity: 405 litres
Range: 650km, Depending on weapon system fitted

Crew: 3 + 7
Combat weight: 28 tonnes
Power pack: Perkins CV-8 TCA V-8 diesel developing 550bhp, with a Perkins X-300-4B fully automatic transmission.
Power-to-weight ratio: 19.6 bhp/t
Max road speed: 75 km/h
Fuel capacity: 770 litres
Range: 660 km

Figure 13. Alvis Warrior (IFV)

Crew: 2 + 8
Weight: 11.6 tonnes
Power pack: Diesel - Bedford 600 6-cylinder diesel developing 164bhp at 2,8000 rmp.
Power-to-weight ratio: 14.14 bhp/t
Max speed: 64 km/h
Fuel capacity: 155 litres
Range: 400km

Figure 14. Alvis Saxon (APC)

Crew: 1 + 5.
Weight: Max 2.65 tones.
Power pack: VW ADE 1900 1.896 litre, 4 cylinder turbo diesel developing 78 bhp.
Power-to-weight ratio: 29.43 hp/t
Max speed: 64 km/h.
Range: 531 Km.
Fuel capacity: 63.6 litres.

Figure 15. Supacat (ATMP)

Figure 16. Landrover APV

Crew: 2 + 6
Max weight: 3.9 tonnes
Power pack: Rover 4-stroke V-*
3,528 cc petrol developing 114 bhp
at 4,000rpm (or turbocharged diesel)
Power-to-weight ratio: 29.23 hp/t
Max Road Speed: 120km/h
Fuel capacity: 68 litres
Range: 240 km

Figure 17. Alvis Scarab (FCLV) - Optional Prototype

Crew: 3 - 5
Weight: 10.4 tonnes
Power pack: Mercedes-Benz 6
cylinder diesel developing
230bhp coupled to an Allision
automatic transmission
Power-to-weight ratio: 22.1hp/t
Max speed: 110km/h
Fuel capacity: 160 litres
Range: 600km

7.1.5 CURRENT FUELS

As we have seen, there are many different types of land vehicles operating in the UK armed forces, ranging from huge tank transporters to comparatively small vehicles such as Land Rovers. The MoD also uses a large quantity of production line vehicles for standard road usage.

Land vehicles are not just dependent on fossil resources for fuel; they also require large amounts of petrochemicals for lubrication and cleaning. These applications are not just the preserve of the power pack and transmission systems, they are also used in tactical and weapon systems, and must be properly integrated. For example, oils used to clean the barrel of a tank's gun must not adversely interfere with or affect the oils used to lubricate it. Such interference could cause an inability to fire reliably. A variety of synthetic oils and lubricants are now produced which could negate this problem.

7.1.6 ALTERNATIVE PROPULSION SYSTEMS

Despite the large quantity of these production line vehicles, the focus of this report will be on the non-standard or specialised pieces of equipment. The reason for this is that motor manufactures have already started producing vehicles which use alternative fuels such as Liquid Petroleum Gas (LPG), and Hybrid Electric Vehicles (HEV's). Technology advancements over recent years have even allowed them to start designing and developing vehicles that use fuel cell technology. It would seem highly likely that in 30 to 40 years, replacements for standard production line road vehicles will already be in place.

The military of course have a much higher specification and demand for off-road vehicles, many of which will need to travel over a variety of terrain throughout their useful life. As such, there is a much greater need for these vehicles to have a very high performance and reliability. Presently nearly all off-road vehicles use petrol or diesel as their sole source of fuel.

These fossil fuels offer a variety of performance criteria, which stem from the amount of energy given out through burning. Alternatives to petrol and diesel may have similar energy outputs, however there are several potential downsides to these alternatives. E.g. they may weigh more, thus adversely affecting performance.

7.1.6.1 FUTURE SUBSTITUTE FUELS

Table 3 below, is taken from the Motor Industry Research Agencies (MIRA) web-site, and shows the environmental and cost aspects of alternative fuels. However, it should be noted that this table does not refer to performance criteria, such as energy given out per unit mass.

Fuel	Net % change in greenhouse gas emissions	Change in air pollution impacts	Other environmental and safety impacts	Cost disadvantage
Natural Gas/Methane	-21 to +5	Significant net benefit but little NOx advantage	Potent greenhouse gas. Resource conservation if sourced from landfill. Compression required.	Slight
Hydrogen	-70 to –10	Major net benefit	Resource conservation if sourced from water. Major infrastructure changes. Compression or cooling required.	Major
Methanol	+30 to +70 (if from coal) -15 to +5 (if from natural gas)	Modest net benefit but formaldehyde problem	Toxic, soluble in water.	Significant
Ethanol	-75 to –40 (if from wood) -20 to +30 (if from corn, sugar etc)	Modest net benefit but aldehyde problem.	Resource conservation. Land constraints and landscapes.	Major
Rape Methyl Ester (RME)	Not known	Modest net benefit but benzene and PAH problem.	Resource conservation. Land constraints and landscapes.	Significant

Table 3. Environmental and cost aspects of alternative fuels.

Largely these alternative fuels offer minimal changes in overall design of the internal combustion engine, giving obvious advantages. Downsides to these are easily shown, such as cost and resulting pollutants.

Other possible solutions to the problem of future fuel could include the use of fuel cell technology. Electricity is produced in a fuel cell via an electromechanical reaction of hydrogen and oxygen. There are significant resource and tactical advantages to this technology. If vehicles can run from a near silent power source, then there is a military advantage. That said current view is that fuel cell technology is far too immature to be used for any current military application, but should be noted for use by future vehicles.

7.1.6.2 ELECTRICAL PROPULSION SYSTEMS

Hybrid electric vehicles (HEVs) are the other main option left for vehicle manufactures. Although, current HEVs use fossil fuels to power the internal combustion (IC) part of the engine, these can easily be adapted for use with alternative fuels. Future generations of hybrid vehicles will most likely be designed to run on alternatives alone.

There are two types of hybrid vehicle: series and parallel. The series arrangement hybrid has the IC engine separate from the drive train, and essentially is only used to regenerate the charge in the battery pack. This gives a highly efficient vehicle but in consequence performance and power suffer. The parallel arrangement allows both the IC engine and electric motor to operate simultaneously, the IC engine can be clutched out and the vehicle can run off electric power alone. In addition, power can be drawn from the IC engine, giving performance levels comparable to that of conventional IC engines. This also allows the batteries to recharge when the clutch is engaged, as this turns the motor's rotor, effectively turning it into a generator. Parallel hybrids are preferable where bursts of speed are necessary and are also better equipped to deal with hill climbing.

Other advantages of HEVs over conventional vehicles are greater fuel efficiency, a reduced dependency on fossil fuels and utilisation of the effects of regenerative braking, minimising energy loss.

7.1.7 PLATFORM PROCUREMENT

Typically, land vehicles are not in service as long as other platforms such as ships and in some cases aircraft. The relative cost to procure such equipment is also lower, despite the fact that there may be many more land vehicles in service than any other class of platform. With relatively short life spans and high disposability/replace-ability, land equipment IPTs, in general, do not have to be as forward thinking as say a "Future Frigate IPT". However, this does not mean that they should allow themselves to become ignorant or closed minded about alternatives.

On the contrary to this, there is good evidence to support that more people are thinking towards a future with a lesser dependency on fossil fuels. For example, a report in Jane's Armour and Artillery, dated 12 Feb 2002, states that in late 1996 both the UK and USA signed onto a joint venture to develop a reconnaissance/scout vehicle. The UK's aim of this venture was to develop a Tactical Reconnaissance Armoured Combat Equipment Requirement (TRACER), a replacement for the Alvis Scimitar and Sabre reconnaissance vehicles.

Two international consortiums were formed, to develop prototype technology demonstrators. One such consortium, (lead by BAe Systems, and including United Defence and Raytheon Systems Company of the US, and Alvis Vehicles of the UK), were envisaging the use of a hybrid electric drive system, as the power pack for their vehicle. However, in late 2001, the UK MoD stated that funding for this project will cease after mid 2002 and that it was studying other ways to meet the requirement. It was generally accepted that the technology gained from this project would probably be used in other programmes.

One such program is the Future Rapid Effects System (FRES). Lt Col Wilson of the UK MoD's Director of Equipment Capability (DEC), was reported in Jane's Defence Weekly to have said that an examination of the TRACER project will be undertaken to see if it could be applied affordably to FRES. Hybrid electric drives are among the technologies being considered. (Reference 12).

Reference 13 talks about the UK's Director General's (Research and Technology) invitation for six companies, including Alvis Vehicles; BAe Systems and QinetiQ Ltd, to tender for a three year contract to explore possible applications for electric drive technology. The application of this technology would be for wheeled and tracked, light and heavy, and armoured and unarmoured vehicles.

7.1.8 THE WAY AHEAD

Necessity being the mother of all invention dictates that technology will advance, as and when it is needed. However, sufficient planning must be done to cope with the inertia in the energy market, and for design and manufacture. One of the main drivers of technology advancement in the modern day is cost. Alternatives to fossil fuels are available but as Table 3 shows cost plays a big part in the assessment of these alternatives.

To a single user these costs, although measurable, are somewhat insignificant compared to the cost of designing and maintaining equipment for an entire country’s armed forces. It is known that the logistical cost of maintaining and running equipment by far outweighs the cost of the initial procurement. This said, it implies that the cost of designing new types of power supply will be small when compared to the cost of fuel and maintenance.

Despite the fact that the UK armed forces need to start embracing technology that allows their equipment to become less dependent on fossil fuels, they need a place to start. It would appear through our research into this area that work has already begun into the use of HEVs for military applications. This is clearly only the first step towards becoming a nation independent of fossil fuels. Development of these next generation HEVs will be required to make them run entirely independently of fossil fuel resources.

7.1.9 CONCLUSIONS

The UK could hope to replace its existing land capability with either replacement fuels or new power plants technology. In addition, the requirement for land vehicles needs to be constantly addressed so that technology is not developed to replace old requirements. Novel approaches to fill requirements could be sought that better utilise the strong elements of emerging technology.

A continuous approach to developing fuel technology also needs to be embraced so that the "immature" technology, as it stands, can become one of the mainstays of the UK's vehicle power providers. It must also be ensured that the UK armed forces remain in the "high technology" environment, as described in the "Scenarios" section of this report. Hybrid powered vehicles will most likely become effective only after 2 or even 3 generations of the technology. This would put us in the region of the 30-40 year time frame within which fossil fuels are expected to become depleted.

7.2 AIR SYSTEMS

7.2.1 AIM

This section of the report looks at the roles military aircraft will perform in the future, what alternatives (if any) could be available and possible solutions to providing new sources of aeronautical power.

7.2.2 SUMMARY

- There are four broad requirements for air capability: air defence, strike/attack, logistics/support, and reconnaissance.
- Each requirement could be addressed by new systems that use alternative technological capabilities.
- Air capability could be maintained through the development of replacement fuels.
- It could also be maintained through the development of replacement power plants and specifically designed aircraft.

7.2.3 INTRODUCTION

At the moment the Aviation world is almost entirely dependent on fossil fuels. As fossil fuels begin to deplete the industry will need to look at the alternatives if flying is to continue. Air systems are the most technologically advanced of the three categories of platforms, and are built to the most stringent engineering tolerances. Therefore aircraft could offer the most challenging area of technology development if current capability is to be maintained.

The nature of the roles and the requirements of air forces in the future are likely to be radically different from today. The impact from the depletion of fossil fuels may, or may not have an impact on the way air forces operate. Another important consideration is that of whether an aerial platform will still be the most suitable method of accomplishing an operational requirement (i.e. is there a better/cheaper alternative?), and if not, what is the best solution?

7.2.4 OPERATIONAL REQUIREMENTS

7.2.4.1 OVERVIEW

There are possibly four main requirements that can be envisioned to be required of future air forces. These are:

- Air Defence
- Strike/Attack
- Logistics/Support
- Reconnaissance

At present, all of these (at least in part) are undertaken by aircraft. The list should not be judged exhaustive, and as we will see, many of these roles could be fulfilled by other means. It should also be noted that alternative fuels may result in increases in costs, affecting the equation in any decision.

The next section looks at the current solutions to operational requirements and potential future and alternative solutions.

7.2.4.2 AIR DEFENCE

Can be defined as the defence of the airspace and ground of a country/location. Currently this requirement is fulfilled in the UK by the RAF in the form of the Tornado F3 (to be replaced by Eurofighter Typhoon).

For many years alternatives to these manned aircraft have included missiles (both long and short range), whilst these would have the same fuel problems as an aircraft, they offer no danger to a pilot and are only used once (thus having a much lower fuel cost compared with an aircraft). The advance of Star Wars systems that negate the use of fossil fuels is another alternative, and could be used as a method of repelling conventional, as well as nuclear, attacks.

7.2.4.3 LOGISTICS

Logistics in this case is the process of transporting people and equipment. Currently the majority of logistical transport is provided by:

- RAF Long Range Aircraft (e.g. C-17A, VC-10, C-130J, Civil)
- Tactical Aircraft (e.g. Helicopters, C-130,)

Alternatives to Air Transport include land and sea, but an interesting alternative is to avoid transportation of resources in the first place. For example, already Defence policy is moving towards avoiding the deployment of ground troops. However, the major issue remains that if a deployment was necessary, there is still the problem of how it is achieved.

7.2.4.4 GROUND ATTACK/STRIKE

Ground attack/strike by aircraft is the deployment of force close to the battlefield and beyond. It can be broken down into:

- Offensive Support (e.g. Harrier GR9, Jaguar GR1)
- Ground Attack/Interdiction (Tornado GR4)

Again, as with Air Defence, this could be achieved by a number of alternative solutions. The use of missiles (already used to some extent e.g. Cruise) or perhaps a Star Wars style attack system would eliminate the need for manned aircraft. These possibilities are already being given thought in the form of the 'Future Offensive weapon System' (FOAS) mentioned later in this report.

7.2.4.5 RECONNAISSANCE

This encompasses various methods of intelligence gathering. Roles currently fulfilled by aircraft include:

- Photographic (e.g. Canberra PR9, Jaguar GR1A, Tornado GR1A)
- Maritime (e.g. Nimrod MR2)
- AWACS (e.g. AEW1 Sentry)
- ELINT (e.g. Nimrod R1)

These roles could be, and already are being, taken over by satellite systems (e.g. the USAF SR-71 Blackbird being taken out of service in the 1990's). However, the versatility of aircraft to locate a specific target may warrant the retention of such a capability. Indeed, battlefield surveillance from solar powered, pilotless aircraft is already being used (see Section 7.2.7.1.2). This provides a solution to the fuelling problem, does not risk personnel and is inexpensive in comparison to conventional aircraft reconnaissance.

7.2.5 CURRENT PROPULSION TECHNOLOGY

The following are methods of propulsion used by current technology airborne platforms:

- Reciprocating combustion engine
- Gas turbine
- Ramjet
- Rocket

Of the above reciprocating combustion engines are no longer generally used for military applications.

The most common form of aircraft propulsion is the gas turbine, generally in the turbofan form. Current engines run on kerosene type fuel (or derivatives of), more robust engines have been seen to use diesel or plant (vegetable) oils. The gas turbine is the most common means of aircraft propulsion seen today; this is largely attributed to the fact that it is highly efficient (when using kerosene). Gas turbine technology can be allied to many applications, from cruise missile propulsion to transatlantic passenger aircraft.

Ramjet and rocket propulsion are generally used in high-speed (missile type), most use kerosene and solid propellant. Ramjet and rocket propulsion devices are most widely used in (supersonic) missile propulsion; this is mainly due to its relative simplicity on a dispensable missile system.

7.2.6 ALTERNATIVE FUELS

7.2.6.1 CRYOGENIC GASES

Of the potential fuel substitutes, only the cryogenics appear promising. Liquid methane could become more available and less expensive than petroleum throughout much of the world, depending on developments within the *complete* energy scene. As a clean burning fuel with minimal carbon content, a high combustor life would be expected, together with reduced emissions of carbon dioxide.

In comparison to methane, more energy is required to liquefy hydrogen, and the cryogenic handling problems are much more acute, but a remarkably high specific energy results. Flame radiation is minimal, leading to high combustor lives, as is pollution. Furthermore, for those nations deprived of fossil energy feed stocks, the combination of resources of water and nuclear, hydroelectric, solar or geothermal power renders liquid hydrogen attractive as a universal aviation fuel.

7.2.6.2 HYDROCARBON OXYGENATES

Alcohols (in particular methanol and ethanol) have been used in a number of trial aviation propulsion systems. Although proven to be clean burning in piston engines, the presence of oxygen and the problem with water separation preclude it from being a viable gas turbine fuel. Low specific energy and energy density add to this conclusion.

7.2.6.3 HYDROGEN-NITROGEN COMPOUNDS

Not significantly tested in gas turbine engines, low specific energy and energy density make this an unlikely gas turbine fuel candidate. Hydrazine will continue to be used as a rocket reactant.

7.2.6.4 HIGH PERFORMANCE FUELS

High performance fuels (such as the exotic metals boron and beryllium) are likely to be used as additives in ‘slurry’ type fuels, to supplement the energy carrying ability of the parent fuel. These additives are likely to feature more in the future, as it is likely that substitute fuels will lack the potency of current aviation kerosene. Rocket fuels, both liquid and solid, will continue to be used. They are a mature technology and have little reliance on fossil fuel.

7.2.6.5 SUMMARY

Table 4 shows a summary of the findings with respect to potential substitute fuels.

Substitute Fuel	Source	Comment	Effect on Platform Design	Gas Turbine	Ramjet	Rocket
Avtur	HCS, Coal, Shale, Tar	Conventional fuel	None	Yes	Yes	Yes
Hydrogen	HCS, Coal, Water	Very high MJ/kg, clean burning but very low MJ/L and cryogenic	New aircraft needed, combustor redesign required	Possible	Yes	Yes
Methane	NG, HCS, SMW	High MJ/kg, clean burning but low MJ/L and cryogenic	New aircraft needed, combustor redesign required	Possible	Possible	Possible
Hydrocarbon Oxygenates	NG, HCS, Biomatter	Clean burning, but low MJ/kg and MJ/L	Modification to rocket combustors	Unlikely	Possible	Possible
Hydrogen - Nitrogen Compounds	HCS, N_2, H_2, HNO_3	Clean burning, but low MJ/kg and MJ/L. High hazard index. Main application as rocket reactant	Modification to rocket combustors	Unlikely	Possible	Possible
High Performance Fuels	Various	Very high MJ/kg, very high MJ/L, can be toxic (fuel and combustion products)	High temperature alloys required in propulsion design	Possible	Yes	Yes

NG = Natural Gas

SMW = Solid Municipal Waste

HCS = Hydrocarbons (Liquid)

Table 4. Applicability of Substitute Fuels to Various Propulsion Devices (Reference 27, 28)

7.2.7 ALTERNATIVE PROPULSION SYSTEMS

The previous discussion has been centred on the high-temperature exothermic processes of combustion, either with flame or catalytically (cf. hypergolic reactions). The following propulsion systems make use of other energy systems.

7.2.7.1 ELECTRICAL PROPULSION

Developments in high power to weight ratio electric motors have increased the likelihood of producing a workable electrical powered flight system. However, the problem of powering such motors still exists, a number of methods are presented below.

7.2.7.1.1 Batteries

At present high power, long endurance batteries are heavy. Future advances in silver-zinc and lithium hydroxide batteries are expected to yield high power to weight ratio batteries.

7.2.7.1.2 Solar Cells

Concepts have been developed (by Lockheed-Martin) to design a high-altitude surveillance platform. The solar powered (unmanned) craft is to have the entire upper surface of its flying-wing configuration covered in photovoltaic cells. The High-Altitude Powered Platform (HAPP) is designed to fly for many months at altitudes in excess of 21 km (70,000 ft). The HAPP would carry cameras and other surveillance devices to observe vast areas of land; such a system would be far more versatile than satellite surveillance. The proposed configuration can be seen at Figure 18.

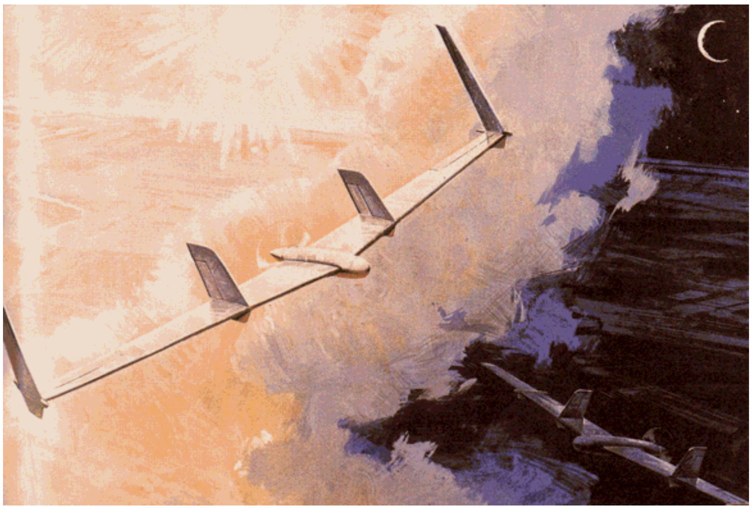

Figure 18. High – Altitude Powered Platform (*HAPP*) Configuration (Shown during Light and Darkness)

HAPP will use solar cells to power electric motors; excess energy will be used to charge batteries for use in darkness. The configuration show above would also allow periods of unpowered flight; it is likely that periods of powered flight would be interspersed with unpowered flight.

7.2.7.1.3 Fuel Cells

Fuel cell technology has been widely employed in space (satellite) technology, and is applicable to electrically powered flight. Fuel cells offer a higher power to weight ratio than batteries. Fuel cells could also make use of hydrocarbon oxygenate fuel that would otherwise be unsuitable for gas turbine applications.

7.2.7.2 NUCLEAR PROPULSION

From the upper end of the energy spectrum there are the heavy elements capable of nuclear fission. It is likely that enriched oxides of Uranium (U_{235}) and Plutonium (Pu_{239}) would be used, employing water as a moderator.

A schematic of the device (as applied to a ramjet) can be seen Figure 19. Heat addition to the working fluid (air) takes place as it moves over the reactor (some form of heat exchanger would be required to ensure that the working fluid absorbs a large amount of energy). As such, it can be seen that the reactor, in effect, would replace the conventional combustion chamber as the sole means of heat addition.

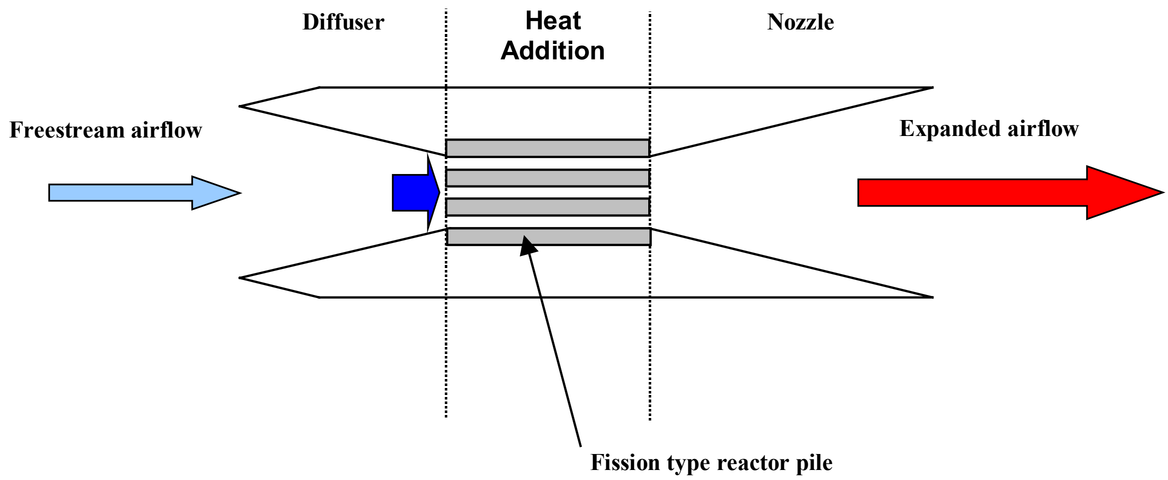

Figure 19. Schematic of Nuclear Fission Powered Ramjet Device

The fuel consumption of such a device would be negligible, allowing the device to be run over a long (compared to existing combustor based devices) period of time, possibly allowing global flight.

To date a small reactor has been run critically (a major design challenge in small reactor), and tested in flight. All radioactive components would be shielded in a containment vessel capable of withstanding high-speed impact (in the case of the flight tested device up to Mach 1).

7.2.7.3 LASER PROPULSION

It has been seen previously that alternative means of providing heat addition to the working fluid are possible. The technique to be described here shows great potential as it has one major advantage over all other forms of propulsion (either fossil-fuel based, or otherwise): the device does not carry any propellant, of any form, with it. Thus, aircraft internal volume/load carrying capability devoted to the carriage of propellant can be devoted to the carriage of payload.

Heat would be supplied to the working fluid (air) via an aperture, as seen in Figure 20.

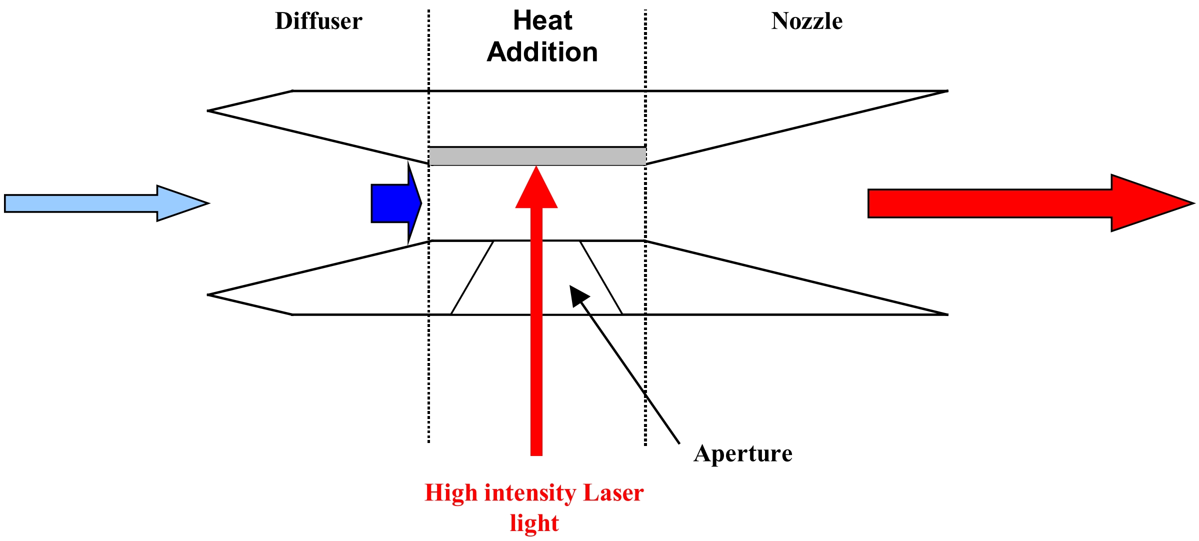

Figure 20. Schematic of Laser Powered Ramjet Device

The high intensity laser light would have to be provided, with great accuracy, from airborne platforms or satellites in low Earth orbit. The satellite option seems more viable; orbital solar 'power stations' using vast solar arrays could provide many megawatts of power, fuel cells or batteries providing this power over periods of darkness.

7.2.8 PLATFORM PROCUREMENT

It is envisioned that at the time of fossil fuel depletion there will be a number of aircraft, which are currently in procurement, in service with the RAF. The question rises as to what will happen to this equipment and the capability it represents. Essentially there are two possible options:

- The platform is scrapped and replaced with another aircraft or alternative solution
- The platform is upgraded using:
  A. New fuel types **or**
  B. New Engine & Fuel types

7.2.8.1 AIR DEFENCE/STRIKE (E.G. TYPHOON, JSF)

The nature in the design of all modern defence/strike aircraft is that of the power plants being integrated with that of the airframe. This means that it is not easy to redesign the engine and greatly reduces the scope of modification/replacement of the engines. If we consider 'A' above, then the cost of modifying the aircraft (new fuel lines/tanks, minor engine modifications etc.) should not be prohibitive. However, looking at 'B' we can see that replacing the power plant in such designs would be very costly, difficult and perhaps impossible. As such, we can conclude that in the case of aircraft currently being procured, it would be much more desirable to find a suitable replacement fuel that could run with existing engines.

7.2.8.2 FUTURE OFFENSIVE AIR SYSTEM (FOAS)

This is a platform currently under procurement. It is envisioned that it will have an in-service date of 2015. The platform will provide the UK armed forces with strike and attack capability. There are three main areas currently being investigated:

- Manned aircraft platforms
- Unmanned Combat Air Vehicles (UCAV)
- Conventionally-armed Air-launched Long-range Cruise Missiles (CALCM)
- Force-mix (combinations of the above, as dictated by a particular mission)

The current thrust of the procurement strategy is directed toward procuring air breathing, kerosene-propelled systems, and in particular using gas-turbine technology. (This includes the CALCM option, which, given the long-range requirement, is likely to use gas-turbine propulsion).

Whichever option is taken the system will have no capability to use the substitute fuels mentioned previously without a serious degradation in performance. The RAF will therefore be fossil fuel dependent for many years beyond the introduction of FOAS.

7.2.8.3 LOGISTICAL TRANSPORT/RECONNAISSANCE (E.G. A400M TRANSPORT AIRCRAFT)

Unlike combat aircraft, these are designed with engines connected to the wing/fuselage by pylons/pods. This means that replacing an aircraft's power plants is far easier than that of a combat aircraft, with little in the way of redesign except that of the pylon-engine connection.

This means that either option A or B would be viable, and as such would give greater potential for aircraft to be upgraded.

7.2.9 CONCLUSIONS

The area of air flight represents one of the toughest challenges of the fossil fuel depletion scenario. Careful analysis of requirements and development of capability will be required. Two basic system approaches exist, that of replacing the fuel, or developing new power plant technologies. It has also been highlighted that airborne platforms are highly dependent on fossil fuels, for both fuel and lubrication. Whichever route is chosen, or a combination, it should be remembered that the lead-time to launch a new technology is large. Especially when it is expected to perform, or outperform, an existing technology in a high state of maturity.

Of the presented options, the use of cryogenic gases (mainly methane and hydrogen) seems to hold the most promise. These substitute fuels use known (gas turbine) technology and are manufactured from largely available resources.

It has also been shown that the future procurement platforms, namely Eurofighter, JSF and FOAS; are all dependant on fossil fuel based kerosene fuels. As such, RAF air systems will be dependent on fossil fuels for many years to come.

7.3 SEA SYSTEMS

7.3.1 AIM

To show current UK sea capability, how this could be adapted for use after fossil fuel depletion and the process of adaptation.

7.3.2 SUMMARY

- Current platforms rely heavily on diesel as a source of energy.
- Recent procurement programmes can offer many lessons on how to decide on future power plants.
- Policy decisions are difficult due to the number of variables involved and the long life expectancy of a sea-going vessel.
- 2020 has previously been mentioned as the UK government date for exhaustion of easily obtainable oil reserves. It has been suggested that the RN expects to utilise diesel up to 2030-40.
- Synthetic fuels are being developed that take less useable fossil fuels and convert them to clean and useful fuels. This could be a possible interim measure.
- There are several alternative fuel types under investigation: synthetic gas, biomass, compressed gas, alcohols and hydrogen.

7.3.3 INTRODUCTION

The UK sea forces encompass a wide variety of vessels, the vast majority of which are reliant on fossil fuels. Clearly an alternative will need to be sought. Sea systems will probably have a much less radical approach to air systems, as the engineering constraints are not as tight. Power plant variety is already demonstrated by installed gas turbine, diesel, steam and nuclear systems; as opposed to predominantly gas turbine for aircraft. Ships are often retrofitted with new engines, so engineering experience of such procedures is present.

7.3.4 CURRENT STATUS

As it stands at the beginning of the 21st century, the Royal Navy's status is that its surface fleet and the operations it undertakes are totally reliant on fossil fuels, while only the submarine fleet uses nuclear power (with diesel backup systems). The mainstay fuel at the present time is Dieso, NATO code F-76 diesel distillate. This is used for both the prime motion generators and the auxiliary generators of the surface fleet, most of which uses the same types of propulsion system. This section outlines those systems, using information from Reference 15.

7.3.4.1 TYPE 22 & TYPE 23

Figure 21. Type 22 and Type 23 Frigates

The Type 22 frigate uses two propulsion systems, consisting of two kinds of engine. They have Rolls Royce *Tyne* and *Olympus* gas turbines. The *Tynes* are used for cruising speeds of around 18 knots, giving a range of 4,000 nautical miles without refuel. The *Olympus* engines are used for short sprints, at up to 30 knots. Four 1 MW Paxman diesel generators provide electrical power for all the ship's needs.

The Type 23 propulsion system consists of GEC electric motors and two sets of Rolls Royce *Spey* gas turbine engines. The combination of diesel-electric and gas turbine propulsion is unique to the Type 23. It allows extremely quiet operation when in hunting mode.

7.3.4.2 TYPE 42 DESTROYERS.

Figure 22. Type 42 Destroyer.

The Type 42 is powered by a similar propulsion system to the Type 22 & 23. It has both the *Tyne* and *Olympus* Rolls Royce gas turbines, providing similar performance ratings.

7.3.4.3 CURRENT AIRCRAFT CARRIER (CVS)

Figure 23. Current Aircraft Carrier.

The aircraft carriers are powered by 4 Rolls Royce *Olympus* gas turbines. These are the same turbines that are used for sprinting in the frigates and destroyers; hence the fuel consumption is vastly higher. Coupled with this, there are 8 Paxman *Velenta* diesel generators (seen below) providing enough electrical power to light a small town.

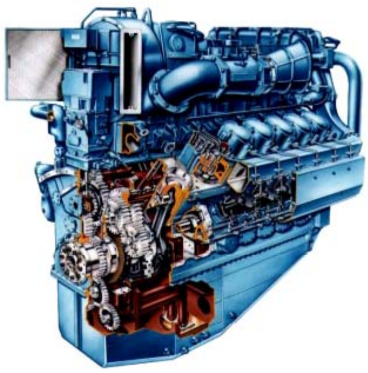

Figure 24. Paxman Velenta diesel generators.

It is widely recognised in the naval community that fossil fuels or moreover oil-derived fuels will remain to be the mainstay energy source for RN platforms. There have been many predictions on when fossil fuel production will peak and hence at some point become so uneconomical that alternatives will have to be found. The era of prediction is to a large degree conjecture. What is not conjecture, is that when a resource that is non-renewable is being used consumed faster than it can be extracted the point of exhaustion will move ever closer.

It is on this note that it is necessary for the RN to consider future policy toward their reliance on fossil fuel derived energy.

7.3.5 PLATFORM PROCUREMENT

To see how the Royal Navy and Ministry of Defence are planning to address this issue, it was necessary to establish what moves have been put in place for the next generation of vessels that will replace the ones previously discussed.

What are the plans for the propulsion systems? What fuel will they use?

7.3.5.1 FUTURE SURFACE COMBATANT – THE TYPE 23 REPLACEMENT PROGRAMME

Figure 25. RV Triton.

The Research Vessel (RV) Triton seen above was launched on 6 May 2000. It is designed to investigate the suitability of a trimaran hull to fulfil the Navy's requirement for the Future Surface Combatant (FSC). The FSC frigate is due to enter service in 2013 and will replace the ageing Type 23. But what considerations have been given to the propulsion systems and the fuel that they will use?

7.3.5.2 TYPE 45 – THE TYPE 42 REPLACEMENT PROGRAMME

Figure 26. Type 45 - artists' impressions.

The Type 45 class is the replacement programme for the Type 42 Destroyers. It will provide the most powerful air defence destroyer ever operated by the Royal Navy. The Type 45 programme is due to enter the in-service phase later this decade. It would therefore be prudent to look at the proposed propulsion system and relative energy reliance of the Type 45 procurement project.

7.3.5.3 FUTURE AIRCRAFT CARRIER (CVF)

Figure 27. CVF - artists' impressions.

A capability gap that was highlighted in the Strategic Defence Review brought about the requirement for a new larger class of aircraft carrier. Two of the new CVF class will be required to replace the three existing Invincible class ships.

The new vessels will be roughly twice the size of the current Invincible class. It is assuming that they will require a suitable propulsion system to match this increased displacement. The first replacement vessel is due to enter service in 2012.

7.3.5.4 PROPULSION OF PROCUREMENT PROJECTS

The current status of thinking regarding propulsion systems for the Type 45 is that it will be powered by diesel generators and driven by WR 21 electrical induction motors. The FSC is likely to employ similar systems for the main drive with unknown backup options. The CVF as it stands is likely to make use of these or similar systems for its propulsion, although no decision has been finalised.

This means that as the current policy stands, all of the replacement ship projects will be highly dependent upon fossil fuels for their main source of energy, just as their predecessors were. However, survivability will have been increased.

Is this the correct policy for the next generation RN vessels? The following relevant components of the equation would have to be investigated:

- Time or era of fuel depletion
- Cost
- Available / suitable fuel technologies
- Supply lines
- Political environment

7.3.6 CURRENT NAVAL FUELS

A recent US geological survey of the remaining conventional oil resources gave an optimistic date of 2040 and a pessimistic date of 2010 for 50% exhaustion (Reference 14). The Energy Information Administration (EIA) used these values and, assuming that the world demand for crude supplies is likely to continue to increase at a rate of approximately 2% annually, predicts that conventional oil production will peak in 2020 and then begin a long-term decline due to depletion of reserves. Following this, the price of crude and its derivatives will accordingly rise. This date of 2020 is also backed by the UK government through the PIU report, The Energy Review.

It would seem to be the general consensus of the research material consulted and also that of the authors that the Marine Diesel Distillate F-76, will remain the basis for the majority of RN energy supply, for the foreseeable future, to 2030-40 (Reference 14).

It must be noted though that the life span of some of the previously mentioned replacement programmes will overlap the downward trend of production of crude. This suggests that it would be prudent for these projects to consider the gradual investment and introduction of alternative supplies of energy for these platforms.

7.3.7 FUTURE NAVAL FUELS

7.3.7.1 SYNTHETIC FUELS

Hydrogen and Carbon Monoxide can be combined in a particular way to form a fuel. The process is known as “gas to liquid” (GTL) chemical synthesis which comprises three steps. It begins with natural gas and oxygen partially oxidising the methane to carbon monoxide and hydrogen (Synthesis Gas). The second stage is to react the synthesis gas with a catalyst to produce a broad range of higher molecular weight hydrocarbons, similar to crude oil. These compounds can then be fractionised and converted into the high value end products.

“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 etc.” (Reference 14).

Synthetic fuels have begun to make their first appearance in the jet fuel world just recently. Obviously the technology is in its youth and the speed at which it develops will depend upon market forces such as the comparative price of crude, etc. All the major oil companies have begun to invest seriously in this new fuel concept, and are likely to have major plants on-stream from around 2006-7. The initial production volumes will be low but are expected to become an increasingly large percentage of total transportation fuel beyond 2010.

The attraction of synthetic fuel technology is that the fuels can be tailored to suit the specific needs of the situation. They would contain no sulphur, allowing them to be used in fuel cells, their chemical properties would be similar to current transportation fuels, handling could occur through existing distribution systems, safety & toxicology would be similar to diesel or jet fuels and there would be low particulate emissions from gas turbines. Synthetic fuels could prove to be an attractive medium to long term option for the replacement or supplement of F-76 for marine platforms.

7.3.7.2 BIOMASS FUELS

Previous oil crises have produced support for the use of biomass as an alternative of energy. Due to the almost absolute dependence of the motor industry on fossil fuels, much interest has been paid to this option.

Some of the predominant options are as follows: -

- Plant Oils (Soyabean, Sunflower, etc.) can be converted into a diesel substitute or supplement.
- Sugar Beets, cereals and other crops can be fermented to produce alcohol (bio-ethanol) which can be combined with gasoline or burnt in its pure form.

- Organic waste material can be converted into energy which can be used as auto fuel, waste oil (cooking oil) into biodiesel, animal manure and organic household waste into bio-gas and plant waste into bio-ethanol.

At the current time biomass technology has some significant drawbacks. It is inherently expensive, land area intensive and has no distribution infrastructure.

Many biomass products are miscible with water, or will absorb a significant amount of water, e.g. Fatty Acid Methyl Ethers (FAME), and most are readily biodegradable. This would cause significant problems in vessels with compressed fuel tanks. Bio-fuels made from FAME would lead to formation of deposits on surfaces causing large operating and maintenance problems.

7.3.7.3 COMPRESSED NATURAL GAS / LIQUIFIED NATURAL GAS

Natural gas is a mixture of hydrocarbons, with the majority being methane. These are by-products of the crude oil production industry. Due to the physical nature of the fuel it is usually stored as either a compressed gas (CNG) or as a liquid (LNG). CNG is stored in bottle like tanks at pressures of up to 3600 psi. Delivery to the engine is normally as a low pressure vapour. LNG is usually stored in an efficiently insulated pressure vessel at extremely low temperature, -100^{o}C.

Limited distribution systems are already in place, and the proven reserves are estimated at around 60-100 years. Natural gas is colourless, odourless, and non-corrosive and burns with a luminous flame. It will not detonate and spillage disperses quickly in an open environment.

Marine applicability is hampered by the handling conditions and the low energy density. It is however, conceivable that the tanker industry could use the boil off to provide the required steady propulsion fuel.

7.3.7.4 ALCOHOLS (METHANOL AND ETHANOL)

Both forms of alcohol could be used for propulsion and can be derived from many sources, some environmentally friendly some not.

Alcohols do however suffer from many drawbacks, especially when considered from a marine military aspect. There are quite toxic, will burn with a colourless flame and both forms are totally miscible with water. The most serious factor is that alcohols have a low volumetric energy density, meaning either less range or much larger fuel tanks. These factors make this form of energy storage unlikely to be adopted by military platforms.

7.3.7.5 HYDROGEN

Using hydrogen as a fuel material has the potential to become a very important fuel decision for mankind. It has the scope to offer a fully integrated energy market with almost inexhaustible supplies and with virtually zero emissions.

By connecting the electrolytic decomposition of water (H_20) with electricity produced from a non-polluting fully renewable source, a closed loop energy storage process can be formed. Whether the hydrogen is then used as a combustible gas or reacted with oxygen as in many fuel cell applications, the likely waste product is going to be water.

The current availability of hydrogen is severely limited, due to the lack of the necessary infrastructure for storage or distribution across the globe. For the military to consider adopting hydrogen as a prime moving fuel for marine platforms, an infrastructure would need developing. This is most likely to happen through the commercial exploitation of this technology by the land transport market. The marine world is likely to lag behind due to less environmental pressures.

One of the main issues with hydrogen as a fuel is the storage medium. Hydrogen is lighter than air and its small molecular size and reactivity means that it leaks out of many types of containment vessels.

There are various avenues of research: -

- **Compressed Gas** - Using advanced over-wrapped composite cylinders.
- **Cryogenic Liquid** - Boil off issues, good energy density, refuel problem.
- **Hydrides** - Currently being installed on Canadian and German submarines.
- **Absorbent Materials** - Research into carbon nano-stacks.
- **Local Electrolysis** - Requires local electricity generation.
- **Reformation of Hydrocarbons** - Diesel for prime mover / Fuel cell after reformation.

As a propulsion fuel hydrogen is clean burning and as a compressed gas has a high gravimetric energy density but a poor volumetric density compared with F-76 diesel fuel. This means that the RN would have to consider providing more storage space for the same range. Hydrogen can however be burnt in many reciprocating engines with only small modifications. This could mean an easier acceptance process than other technologies. Hydrogen is also the ideal fuel for fuel cell technologies.

Fuel Cell technologies are by their own merit very diverse and already well into the development cycle. They are considered in more detail in Section 4.5.1. There are many different development projects underway both in the military and within industry. Various MoD personnel are actively involved with assessing the technologies and their possible applications to the RN. The Marine Propulsion IPT has a watching brief on several of these projects.

It is highly conceivable that a fuel cell could form part of the back up or auxiliary supply on the CVF carriers when they enter service, and possibly be integrated onto the other platforms mentioned, although this is just conjecture at present.

For hydrogen to be used on warships there are a number of issues that need to be addressed:

- Safety
- Storage
- Loading – refuel at sea
- Cost
- Handling

"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 ship becomes practical." (Reference 14).

7.3.8 THE WAY AHEAD

7.3.8.1 CURRENT FUELS 1-5 YEARS

It is most likely that there will be little change in the RN policy on energy provision aboard the fleet during the above mentioned time frame. It is likely however, that there will increasing environmental constraints upon the fuels of this era.

- Lower Sulphur Content
- Lower Aromatics Content
- Better Thermal and Storage Stability
- Poorer Lubricity, due to lower sulphur content
- Reduction in greenhouse exhaust gasses.

These are likely to be the main source of concern for the RN in the near future.

7.3.8.2 FUTURE FUELS 5-20 YEARS

Fossil fuels are still likely to be the predominant source of energy aboard RN vessels. They will probably have virtually zero sulphur content, which will present corresponding problems.

There is the possibility of an advance toward synthetic and designer fuels. It is recommended that the technology watching brief that is currently in place be continued to maintain the technology awareness.

Bio-fuels could well be included on many non-marine modes of transport, which could pose contamination risks to RN supply.

Possible Occurrences within this time frame (Reference 14).

- Hydrogen storage problems solved, some limited distribution systems set up.
- Single RN fuel onboard carrier (0-10 years)
- Single RN fuel (10-20 years from now)
- Fuel cells for auxiliary power on RN ships
- Crude oil production peaks!

7.3.8.3 FUTURE FUELS BEYOND 20 YEARS

Fossil fuels could quite likely still be in use, but in a much cleaner form than they are today. Synthetic fuels may well be in widespread use, using the GTL process described earlier. The technology may be adaptable to the RN.

Fuels cells could be powering many land based transport vehicles. As such the hydrogen economy will be developing fast for land uses. Therefore it is conceivable that hydrogen may be beginning to be accepted for marine use.

7.3.8.4 WHAT SHOULD HAPPEN NOW?

As the previously mentioned procurement programmes have life cycles that are likely to run into an era of uncertainty regarding fossil fuels or energy derived from such. It would seem highly prudent to at least plan for the possible integration of the most suitable new technologies, to ensure capabilities are not diminished.

7.3.9 CONCLUSIONS

As with most areas of fossil fuel depletion it is extremely difficult to create a full plan now. It is a case of understanding the possibilities and ensuring that sufficient development and infrastructure is in place to cope when events finally occur.

Fuel cells could be developed to run auxiliary power systems, initially by reforming the hydro-carbon fuels. This would provide a technology demonstrator and reduce the technology leap to a series of steps.

The technology and engineering facility should remain in this country to develop and build sea-going capabilities. These facilities would be vital to any plan that looked to cope with the depletion of fossil fuels.

8 FUTURE BATTLE SPACE

8.1 AIM

To suggest some possible future world political and economical climates and with these develop the likely types of threat that might emerge.

8.2 SUMMARY

- Three possible scenarios for the future were recorded. For analysis purposes a future where "low and high tech" countries exist, i.e. those who have developed fossil fuel alternatives and those who have not.
- The threat of asymmetric attacks will increase and demand determined thought into how they can be defended against.
- Peacekeeping operations will continue to be of prime importance, especially if the world is to become more confrontational.
- As a result of the world's potential scenario, future threats, implications and countermeasures should be considered, including but bot limited to: conventional attacks, weapons of mass destruction, cyber warfare, electromagnetic pulse, star wars.

8.3 INTRODUCTION

Predicting the future is incredibly difficult. The variation in fuel reserves is a hotly contested topic, and the estimates are not always based on engineering judgement. Therefore, to develop the scenario of fuel depletion is equally, if not more difficult, as the variables increase dramatically and include more from the fields of politics and economics. These fields are by no means predictable, and add drastically the possible number of outcomes that might occur. The team has attempted to develop some ideas, the key ones are noted in this section.

8.4 SCENARIOS

In the future when the world has depleted its accessible fossil fuel supply the battle space could be assumed to look considerably different to its present shape. To predict the future battle space it is important to understand the three likely scenarios that may exist when fuel reserves begin to run low. The only certain factor in these predicted scenarios is that some countries will be in possession of large amounts of fossil fuel reserves and others will have little.

1. It could be that a diplomatic solution is met between the countries holding the majority of fossil fuel reserves and the rest of the World. Thus it could be surmised that all countries would have an even share to sustain their current infrastructure to the point when the reserves have totally run out. The world would then be more united to find alternative fuel sources.

2. Those countries that control the majority of fossil fuel reserves may be pressured for control of their reserves. Should it be that countries have not developed alternative energy supplies and no diplomatic agreements are in place, then it will be a simple case of whoever controls the fuel, controls the world! This would lead to conventional conflicts – it can be argued that this is already happening, as shown by the Gulf War.

3. Those countries that import the majority of their fossil fuels might develop new technologies, to become less dependent on the fossil reserves. The other countries will want to acquire the 'new' technology so that

they can continue their 'normal' way of life once their reserves deplete. They may also want to inhibit the new technologies, to maintain oil-based dominance. If such conflicts are not resolved through diplomatic avenues, unconventional warfare (such as asymmetric warfare, espionage and sabotage) may be used to maintain control of oil as the world's only supply of fuel, or to capitalise on the advantages of new technologies. This could bring about a world divided into 'high-tech' and 'low-tech' countries.

While the first scenario might be an optimum case, it seems unlikely in the current political environment. The second scenario, stealing fuel supplies, is unsustainable in the long term and presents a high risk for nations using such strategies. It is also unlikely to involve markedly different strategies to today's. The following sections of the report will therefore concentrate on the third scenario and the types of military roles, threats and technologies that may be present.

8.4.1 ASYMMETRIC WARFARE, SABOTAGE AND ESPIONAGE

It can be assumed that if the future world falls into groups of high and low technology countries then the three aspects of warfare that will become more widespread are espionage, sabotage and asymmetric warfare.

Espionage and sabotage have long been carried out, both by small groups and by the specialist sections of more established forces. However, their relative importance is likely to become greater in the future.

Asymmetric threats encompass any tactics that enable a "weak" adversary to successfully attack a stronger, more sophisticated opponent. These include novel methods of attacks, often against targets that have not previously been considered vulnerable. They may be employed both by nations and other independent groups, operating for political, commercial or religious reasons.

These three assumed types of future warfare are likely to become increasingly attractive since they are cost effective. They can allow small forces to produce large impacts with minimum use of resources. To counter them, effective communication and intelligence will be key. In particular, there must be more emphasis on human intelligence.

The threats of espionage and sabotage will lead our armed services to increase defence of research sites and the energy supply and distribution networks. As well as a physical presence on the ground and surroundings, there will be more protection against electronic and information technology based attacks: the so-called cyber warfare.

8.4.2 PEACEKEEPING

With the likelihood of conflicts arising as identified above, defence forces will have an increasing role as peacekeepers. The peacekeeping role can be broken down into four missions:

1. **Peace Enforcement.** Countries with effective militaries are going to have to prevent nations or factions exploiting any small military advantages they posses over their neighbours. This peace enforcement role means that forces will have to be quick to deploy to areas as well as being a strong enough deterrent to stop countries resorting to violence.

2. **Service Evacuations.** In cases of unrest the continuing need for forces to perform evacuations of nationals from countries is likely to need rapid reaction forces. These can quickly enter countries, locate the population that requires evacuation and leave without becoming bogged down in struggles. As many countries are likely to become disillusioned with their governments over the handling of fuel problems, there is a fair chance that an operation of this nature will be required. However, Service Evacuation will remain a requirement regardless of fuel issues, due to the many other sources of civil unrest.

3. **Civil Duties.** Other rapid deployments may be required to help emergency forces either at home or abroad in times of difficulty. For example it is possible that some nations which start to prosper may find that the number of migrants arriving starts to cause trouble. In this case forces would be needed to help police restore order and help border patrols. There are many other possible civil duties, ranging from helping in large-scale emergencies to helping customs patrols.

4. **Peace Keeping.** In addition to these missions the traditional role of peacekeepers is likely to remain, helping to keep the peace after factions have negotiated agreements. This role will most likely remain the same as today but will have to take account of new technology. This may mean slightly different skills are required but the mission of helping the return to normality will remain the same.

Although these roles are common to today it is the opinion of GDG 5/01 that they are likely to remain primary missions for peacekeeping forces. It should be noted that, though the Peacekeeping mission is similar, in the future the opposition is liable to change. For example, at present large Multi-National Corporations (MNCs) have large resources at their disposal; often larger than the Gross Domestic Product (GDP) of smaller countries. It would be possible for these MNCs to raise private armies to resolve problems. This could result in peacekeeping forces having to act in situations where the potential threat is as capable or possible even more capable than themselves. Already BP and Shell employ private armies to protect their interests (Reference 17).

8.5 FUTURE THREATS, IMPLICATIONS AND COUNTERMEASURES

8.5.1 CONVENTIONAL ATTACKS

Conventional attacks will remain an option to military forces. Although new weapon systems will be introduced, many conventional weapons in service or in design today will still be operational as fossil fuels become scarce. The threats from these sources will be largely similar to those faced today and must still be countered.

8.5.2 COUNTERACTING WEAPONS OF MASS DESTRUCTION (WMD).

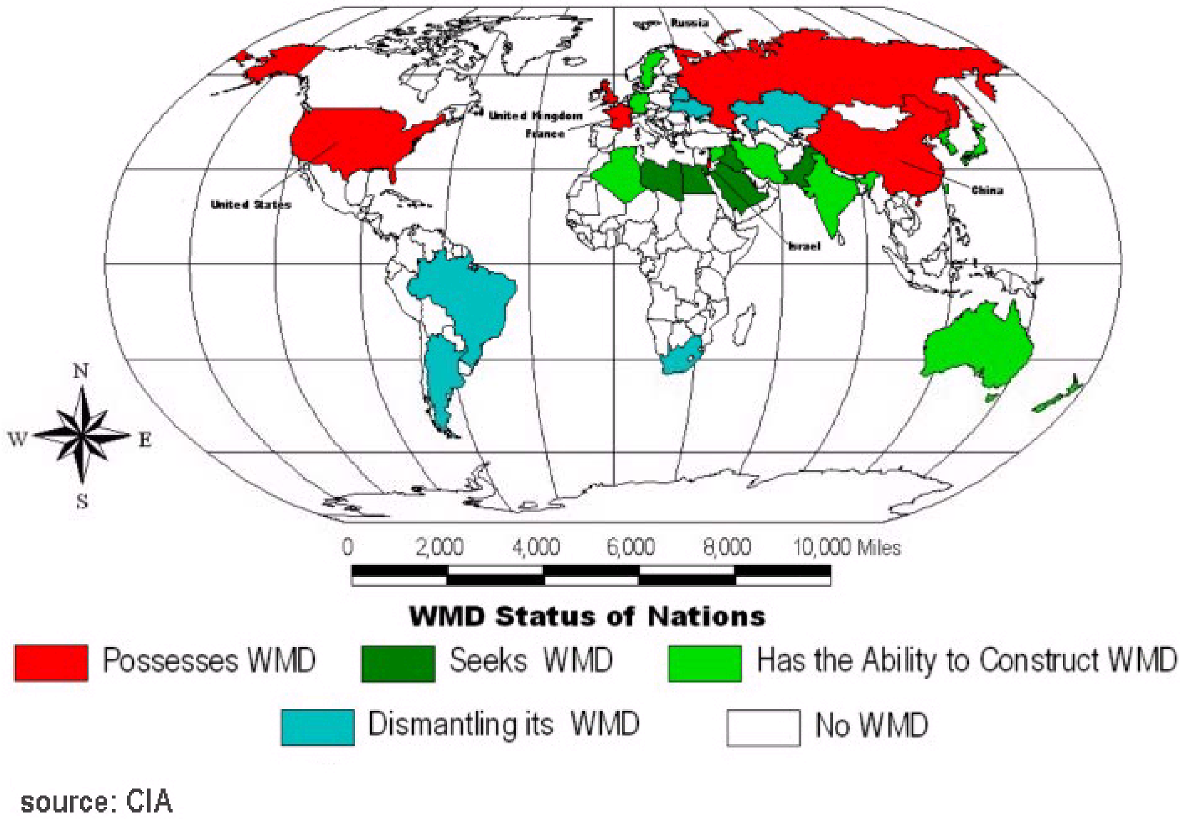

Figure 28. Nations' WMD Status

The number of countries with weapons of WMD is increasing. Figure 28 shows a recent picture of the world in relation to the possession of WMD. It is believed that the number of countries with nuclear weapons is increasing. Currently India and Pakistan are playing a nuclear poker game (Reference 18) while developing a reliable WMD. It has recently been reported that India's Strategic Nuclear Command (SNC) will be in place by June 2002, four years after declaring itself nuclear-capable (Reference 19). It can not be denied that the number of nations with WMD is increasing along with the countries capable of constructing them. This means that the possibility of WMD being used or involved in an accident is also rising. If countries are deprived of the use of conventional forces, WMD is one way in which they may decide to replace unusable equipment. The threat is therefore real and careful consideration is needed on how to counteract it.

Even an unreliable WMD is a danger. During the cold war Russia was short of nuclear warheads, so used radioactive dust in some of their missiles. This would not cause wide scale damage but would cause problems for the nation it was fired upon (Reference 20). This example shows that it is possible to produce low-tech WMD which while not being effective as high-tech alternatives would still cause wide scale problems to whoever they were used upon. As nations build defences against conventional attacks, attackers are more likely to investigate alternatives. For example, in Sri Lanka in 1990 the Liberation Tigers of Tamil Eelam attacked a government military base that they were too weak to overrun, by breaking open drums of chlorine upwind of the base (Reference 21). If conventional forces are removed, this type of occurrence is likely to become more frequent. As the military create defences against WMD, the civilian population whom it is the military's main role is to defend must not be forgotten. Recent events in America have shown that the military was protected from biological attack while the civilian population was not.

In conclusion: with fossil fuel depletion many countries may resort to WMD as a deterrent against the use of force. This means that safe and secure methods of storing WMD are required and better diplomatic relations are needed to ensure that they are never used.

8.5.3 CYBER WARFARE

"What was manual is now automated; what was analogue is now digital; and what once stood alone is now connected to everything else. Increasingly we have no choice but to trust them. If they fail we are sunk."

Dr Martin Libicki
Senior Policy Analyst, RAND

Information warfare uses the power of information to aid in a conflict, and invariably the side with the most information is the stronger. The information advantage can be won in two ways. The opponent's information infrastructure can be sabotaged, thus preventing them from gaining or conveying information of technology to aid in a conflict. Alternatively a higher level of information retrieval and technology can be maintained. The Gulf War was a good example of information warfare. Superior technology was used to gain knowledge of targets and eliminate them. Cyber Warfare involves attacks on computer systems and the organisations that use them. It involves unlawful entry into computer systems for the purpose of gaining access to classified information or for the purpose of disrupting its operation.

The key systems vulnerable from a Cyber Attack are:

- Telecommunications/Communications
- Banking and Finance
- Energy, e.g. the National Grid
- Water
- Transport
- Emergency and Government Services

It can be seen that taking out any one of these systems would cause great disruption. Take them all out and the country would be crippled. Using conventional warfare, how would you direct a strike exactly to the right place so as to take out all these systems at once? This is virtually impossible. To penetrate a country's defences and know the exact target that will take down, for example a country's communication networks, is extremely difficult. There is however, an alternative. One that is virtually anonymous, can be rehearsed for years and executed in seconds, and can be mounted from thousands of miles away without anyone knowing. Sounds like a perfect weapon – Cyber Warfare.

Why then have we not heard anything of a Cyber Warfare attack? The Pentagon maintains the threat is real, however details pertaining to it are far too sensitive to release. Also why use complex weapons if the old ones are still effective, and there are the simpler new techniques of asymmetric warfare?

We are not looking at the current situation today. We are considering the world forty years in the future when it has been drained of fossil fuels. Standard defences will be much stronger. For example new technologies will be in place in airport security. Old threats will have become obsolete. This is when we will see Cyber Warfare coming to play.

It is not possible to say who will have what in the future, however we can look at the state of play at the moment. China is the world leader in Cyber Warfare, and as a response Taiwan is investing heavily. The US is also reported to have a massive arsenal of cyber weapons that once deployed will corrupt and destroy a computer system. Therefore, Cyber Warfare can be seen as a growing threat, and in our future high tech scenario will become even larger.

So how will the MoD cope? All the sources of information used for this section mainly mention America's efforts, and very little was found on how the UK stood regarding this topic. However, our conclusion is that they will need to take the threat seriously. In the future we may even see a Royal Cyber Force.

8.5.4 ELECTROMAGNETIC PULSE

Many people regard the explosion of a nuclear detonation and the destruction caused to be the only result from a nuclear attack. However, the resultant electromagnetic pulse (EMP) produced could cause far more damage. It produces a large magnetic field that in turn induces destructive electric fields in virtually all electronic and electrical systems. There are also methods of producing EMPs without nuclear explosions.

Although military systems are normally hardened against such attack, the disruption to civilian systems could be enormous. A small nuclear warhead exploding several miles above London could devastate most of the capitol's communications, financial markets and computing infrastructure.

Systems can be hardened against EMP by methods such as screening and replacing metal links with fibre-optics. These precautions can be very expensive. The only other option is to prevent an EMP being produced in the first place. This relies on good intelligence and the control of equipment capable of generating EMPs.

8.5.5 STAR WARS

The proliferation of space weapons is a threat that is very real as more nations develop space programs. Star Wars weapons are normally regarded as those that are either space-based, or can be deployed against space targets.

Various technologies have been considered for Star Wars projects. They include missiles, kinetic and directed energy weapons, especially lasers.

Space-based weapons have the advantage of being hard to attack, while covering a virtually unlimited area. Satellites have the capability of launching attacks with minimal risk to the home territory. For instance, ballistic missiles can be destroyed just after they have been fired, while they are still over enemy territory. Energy weapons such as lasers can produce instant effects, with no possibility of interception. Such weapons give instant force projection world-wide, with no reliance on fossil fuels.

Although orbiting weapons may not use fossil fuels for launch or operation, they have various drawbacks. They are expensive to implement and maintain, and have a limited capability. In particular, they are hard to defend, especially against other space weapons.

8.6 CONCLUSIONS

The depletion of fossil fuels will cause political and economic change on a world-wide scale. It is extremely difficult to predict the exact format of this future world, but it is possible to generate potential threats to national security. An exact plan cannot be developed for defence against these threats but the process recognises that events will happen, and that future national powers should be ever aware of potential conflicts. With this in mind the infrastructure should exist to adapt to some of the more likely scenarios. It is the belief of this team that the UK should achieve this by maintaining a position in the group of "high tech" countries.

9 CURRENT AND FUTURE FUEL POLICY

9.1 AIM

To identify the MoD and government's current and future stance on fossil fuel depletion. To locate deficiencies in these strategies and suggest improvements.

9.2 SUMMARY

- Lack of fossil fuels poses a threat to national security.
- Political and socio-economic factors may bring forward the effective date of fossil fuel depletion.
- Lack of alternative technology is not the main problem. Effective implementation and management is of greater concern.
- The MoD has traditionally led new technology development. Its diverse experience makes it potentially a key player in the implementation of new technology.
- The DTI Energy group is the government lead on future energy issues.
- A new unit has been created to deal with policy relating to future energy concerns, called Sustainable Energy Policy Unit (SEPU). Containing nearly all the government departments, except the MoD.
- The MoD is currently out of the government policy loop, and should look to redress this balance.
- Work is being done across the MoD to address energy issues, however, an over arching policy can not be located.

9.3 INTRODUCTION

In a previous section it has been identified that fossil fuel reserves will be reduced to a level at which they are no longer a viable economic source of energy. This scenario represents a problem that the MoD should address. This section will investigate the reasons for doing so. It will look at the current work addressing the depletion of fossil fuels and at what action the MoD should take within the realm of current project organisation and planning.

9.4 THE POLICY PROBLEM

As identified fossil fuels will deplete to a level at which they are not economically viable to extract and utilise. In addition, there is inherent risk in relying on dwindling oil reserves for defence of the nation and for domestic use. Although this paper has not developed the scenario leading up to fossil fuel depletion, it is assumed that oil will remain of paramount importance and the centre of conflict between nations. In fact, tensions will escalate in a world with dwindling reserves. A key tactic of WWII was to try to starve the opposition of fuel, thus reducing their fighting potential. The importance of fuel on domestic life was demonstrated by the summer 2000 fuel blockades in the UK, in which the country nearly ground to a halt and panic set in over a temporary shortage.

The problem exists in the world of apparently dwindling reserves and a desperate political climate. The first scenario is dispelled by optimists and would see no alternative but to take action. However, apparent dwindling reserves can still cause anxiety in a nation and uncertainty in the economy. More importantly, the world political climate is changing, with a large proportion of the oil reserves being held by "unstable countries". Iraq has just demonstrated its contempt for military might through economic means, by halting its supply of oil for the month of April. Reliance on fossil fuels therefore can be considered a military risk. In addition, relying on fossil fuels puts the stability of the economy into the hands of oil bearing countries.

As identified earlier in this report, the solution to this problem will be through identifying alternative sources of energy and means of production and utilisation, while maintaining defensive military power and sustaining a healthy economy. This has been recognised by the UK Department of Trade and Industry (DTI). The argument is not which technology to use or where, it is how to manage the implementation. All new fuel technologies will require a vast amount of investment of time, money and resources. It is important to consider that the lead-time on these technologies will be in the order of tens of years, with a high degree of uncertainty. Therefore this is a situation in which the economic forces must be predicted many years in advance so that they can be combated as they arise. It should be addressed as a large multifunctional project and therefore be addressed as such through the agreed best practises of project management at the moment.

9.5 WHY IS IT THE RESPONSIBILITY OF THE MOD?

Firstly, the MoD has a responsibility to address this problem as it can be seen as a capability gap between our current defence forces and future needs. There is a requirement for the defence forces to operate in adverse conditions and with the resources available. In future the supply of fossil fuels can not be guaranteed, therefore the requirement exists that defence forces should maintain capability through alternative means.

Historically military research has progressed technology. Conflicts have forced nations to develop their technology in an attempt to gain an advantage over the opposite side. This trend has not changed and it is still the thought of being militarily compromised that drives us to develop new technologies to counter the threat. Therefore, as it is continuing the trend, it would be expected that the military field would have a leading role in the development of alternative energies. This would send out a clear public signal that the country was reacting to the problem, although a fine balance still exists between public awareness and scare mongering people into action, which could be very detrimental to the economy.

The MoD is a flagship department of the government. Across its diverse cross-section it contains some of the best minds and has an inherent planning and implementation ability, as a consequence as of the nature of its duty. Additionally the MoD, particularly the DPA, has in recent years developed its project management techniques so that it can fulfil requirements quickly and at a good price. Therefore, the MoD should address the issue of fossil fuel depletion, since it is the best equipped organisation to try and solve the problem.

9.6 WHAT IS CURRENTLY BEING DONE?

It seems to be the case that the MoD has no overall policy regarding the extinction of fossil fuels. Areas of research exist into alternative weapons and platforms. In addition, the MoD has performed well in making its use of energy more environmentally friendly. However, there does not appear to be a broad ranging policy on how the problem should be addressed. If one does exist, then it is partly failing in one of its objectives, which is to raise awareness of the problem, as GDG 5/01 has failed to find such a policy.

However, the government as a whole has identified that this is an issue and has started significant work in dealing with the problem. As an overview of the government´s stance here is an extract from Reference 22:

"*The Government's key energy policy objectives are to ensure secure, diverse and sustainable supplies of energy at competitive prices, and to ensure efficiency in energy use.*"

The government is realising its objectives through the Department of Trade and Industry's (DTI) Energy Group. It has realised that "rigorous environmental targets" must be met, while maintaining competitive energy prices. This is being achieved through innovation into new areas of energy production, with the DTI Energy Group funding such projects.

At present the DTI Energy Group spends around £40 million per year (Reference 22), and this is set to increase. This money is spread between R&D efforts on cleaner coal, oil and gas, and the nuclear industry. The Energy Group is ensuring good future policy through close relations with stakeholders, including academia and industry. However, the military are not included in this list. The Energy Group realises that although the effort is being made to develop new technologies, the stakeholders and practical applications have yet to be decided. They have recently implemented an initiative to create a route mapping exercise to actually implement the technologies. This action is in line with the discussion in GDG 05/01 meeting 2, in which it was agreed that although technology was good, implementation would take a dedicated attack using project management best practices.

The Energy Group is working to make the implementation of alternative energy as easy as possible, by advising on planning or other considerations. However, this policy view was not shared by the MoD, who blocked plans for a massive wind farm in Scotland. The Energy Group is acting to maintain a secure, reliable and diverse energy supply, for the good of the nation and to sustain the economy. In addition, it highlights that significant money can be generated in British industry through developing technology for alternative energy production.

The Energy Group have identified a problem, assigned objectives and devised a clear strategy to achieve them. They are constantly reviewing practises and keeping the public, industry and other stakeholders informed through their web site and published reports. They have initiated R&D spending and have a structured departmental management of the different technologies. They are aware of the foreign capabilities in the different areas, and how collaborative projects can be beneficial to the UK and others. On face value they have a well-implemented strategy for alternative energies, which accepts the need to be dynamic and ready to change.

9.7 WHAT IS THE MOD DOING AND WHAT SHOULD IT DO?

Firstly, it is reassuring to note that the majority of the aspects of the DTI´s strategy were outlined in meetings by this GDG. The worrying aspect is that a similar strategy can not be located for the MoD. In addition, it does not seem to be mentioned in the DTI report as a stakeholder or a contributor, or as having any involvement. This goes against the objectives of Smart Acquisition given in Reference 23, some of which are:

"to acquire military capability progressively, at lower risk"

and

"to secure military advantage and industrial competitiveness"

Surely to be involved with what will be essential military technology at the instigation, will reduce risk and costs in the future.

This can be broken into two different ideas: what needs to be done and how it should be done. Firstly, an overall strategy must be produced, as this will guide all the work that will follow. Hence, it should be very carefully thought about, containing input from areas of the MoD, government and key industry. A small group should decide upon the scope of work that is likely to be done within the MoD. The specific risks must be identified and also the capability gaps that will ensue. The MoD could choose to research its own solutions, but this would not be in line with the current best practise. Its best option would to become a collaborative partner or stakeholder in the DTI´s current set-up. Thus putting itself into the loop for renewable energy.

The armed forces and MoD are customers. Therefore, it could set out its requirements in terms of a User Requirement Document (URD), this "*identifies the capability that over time, may be satisfied by one or several systems"* (Reference 23). This then leads to the question of how the MoD structures itself to meet this problem. Although it needs to be associated with the government's wider policy, it does not have the scope to simply throw money at a project; it needs to have clear aims and objectives. Unfortunately, with the unpredictable time-scale it would be hard to address specific requirements until they became closer. The MoD could enter a series of conversion programmes for current platforms, although this might not offer the best solutions. It would also not provide good relations with the relevant industries at an early stage.

Another solution could be for a "Future Platforms" IPT to be initiated. This would investigate the risk of fossil fuel depletion across the armed forces and MoD installations. Using this investigation, likely capability requirements could be identified. This is not to assume that the same platforms will exist – the IPT should look to issue requirements, not technical solutions. The IPT would form links with the relevant industries, stakeholders and other government departments, and instigate a Through Life Management Plan (TLMP) for the project. The total scope for such a project would be massive, and for quite a while nothing could happen. The major issue to address is having something in place and being at the base level with industry, so that when things do start to happen the MoD has the ground work done. The issue is such a potentially large one that an organising body or IPT would be the desired solution, as they would need to co-ordinate work and effort in many different departments and areas.

Smart acquisition practices advise us that incremental acquisition of equipment is the preferred route to gaining full capability. In particular reasons for this are (Reference 23):

"A reduction of the risk inherent in introducing large improvements in capability through a single major technological step."

and

"Systems can be developed and put into service which can progressively incorporate evolving technology as it becomes available."

These statements make sense, however they apply to a currently running project. They do not apply to simply buying as and when the problem arises; this would be taking them out of context. The advantages and theories of incremental acquisition apply when the project has been running, industry and the stakeholders have been involved, i.e. one should be initially in the loop somewhere to maximise benefits. Therefore, again, if smart acquisition policies are to be adhered to, then early involvement must be sought, thus risk reduction can occur through not relying on large technological steps.

The DTI Energy Group has recognised (Reference 22), as has Smart Acquisition, that collaborative international projects are increasingly likely in the future. It is recognised that they can increase risk in cost (risk is shared), time and performance (Reference 23). However, if done successfully they can reduce the amount of work duplicated in achieving a common requirement between allies. However, as with forging links with industry, international collaboration must be developed at an early stage to gain the full benefits.

The development of any new programme brings with it risk and investment. A new method to deal with this is the Public/Private Partnership. The PPP concept encompasses the PFI – Private Finance Initiative, which involves transferring more of the risk and responsibility to the supplier. The supplier then offers the capability as a service to the MoD. This "Partnering" entails the creation of "*new, much more co-operative long term relationships between MoD and Industry"* (Reference 23). Although PPP offers a route by which the MoD can buy new capability as a service, there is still a need for it to develop the relationship in advance of the requirement. The introduction of this technology could suit the requirements of a PFI project, which are (Reference 23):

- A requirement for significant capital investment now or in the future.
- A substantial element in the requirement can be configured as a service.
- Scope for innovation in the delivery of the service.
- MoD risks which could be better managed in the private sector.
- Scope for long term contracts.

9.8 CONCLUSIONS

The future situation is highly dependent on issues more complex than the physical amount of fossil fuels remaining in the world. Political socio-economic effects could easily bring forward the "cross over" date identified in section 2.8, where alternatives become favourable compared to fossil fuels. Therefore, early provision and planning is advised, with the ability to be dynamic.

The MoD has a responsibility to address the depletion of fossil fuels and the effect on its capability. It should develop a focal body to address the problem, potentially an IPT. In line with current management best practise it should forge early relationships with industry, stakeholders and other government departments. It should decide its role amongst the existing infrastructure of research, to maximise development at best value for money. In addition, it should be considering how best to finance such efforts and if PFI is the way forward.

10 OVERALL CONCLUSIONS

This report has attempted to address the problem of fossil fuel depletion and its effects on the MoD's ability to protect UK interests. The following points summarise its conclusions:

- Fossil fuels will run out. This will happen over a time scale that is dependent on many factors and is very difficult to judge accurately. The point of interest is the time when fossil fuels become more expensive than alternatives. It should be noted that political socio-economic effects could vary greatly the timing of this event, compared to estimates relying purely on fuel quantities.
- Alternative energy systems will need to be developed and implemented. This will need very effective planning, considering the task's lead-time and the inertia of the energy industry.
- The UK has a number of excellent renewable energy sources. Mature technology is available to utilise some of these forms, such as wind energy. The hindrance to implementation is often based more on political arguments and confused policies than technical problems.
- With effective planning, the country should have all the primary energy it requires. However, the transportation and utilisation of this energy will be an additional problem that must be addressed. There should be a combined effort, with the end users recognising the likely primary sources to be used.
- Current land, sea and air systems could either be converted to use new energy supplies, or be replaced by using alternative technologies to meet capability gaps in different ways.
- New technologies will have to be developed early, to give the generations released into service the required performance. Reductions in performance would probably be unacceptable.
- Although it is difficult to predict the future, GDG 5/01 believes that there will be "high-tech" and "low-tech" countries. The UK should create plans that put it firmly in the high-tech bracket.
- The MoD apparently does not have an over arching policy concerning the depletion of fossil fuels. It is therefore out of the loop concerning the current government policy. It could adopt a more proactive role in this area.

The depletion of fossil fuels represents an opportunity for this country to become a leader in renewable energy technology, its infrastructure and its implementation. This can only be achieved through effective dynamic planning and clear strategies encompassing all parties involved. The MoD has a key and positive role to play in this process.

In order to achieve this goal, GDG 5/01 offers the following recommendations:

- Form a team to act as a focal point for fossil fuel depletion and alternative energy research within the MoD. This should involve all areas of expertise, and aim to give a clear vision and objectives to the good work already being done.
- The focal group should be publicly visible. The general public should see the work done by the MoD on this subject; where possible it should be visible and transparent, to inspire others.
- The focal point team should liase with the other government departments. The MoD should be a key contributor to future policy on fossil fuel depletion.
- Graduate scientists and engineers should be paid vastly more money, for being great.

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12 ANNEXES

A SCOTTISH ENERGY: A CASE STUDY

A.1 INTRODUCTION

This case study shows an example alternative energy implementation, that of harnessing the sources available in Scotland. It aims to highlight that despite technical difficulties involved with implementing new technology, it is other issues which are slowing the progress down.

A.2 TECHNICAL DETAILS

Recent reports have shown that Scotland has enough potential wind and wave energy to look after it's own needs and help supply the rest of the UK. Scotland has the best wind energy potential in Europe - recent studies suggest a hefty 23% of the total. Adding wave and tidal stream energy takes the potential generating capacity to 60 GW at reasonable cost. This total is equivalent to 75% of Britain's existing capacity.

There is unfortunately a gap between potentially available energy and what can reasonably be harnessed. Even so, independent consultants have found that there is enough potential onshore wind power to meet Scotland's peak-winter demand twice over. That total is without building wind farms on designated scenic areas. This is an important consideration as Scotland attracts a large revenue through tourism. In addition, the opinions of the people are key to keeping a positive spin on alternative energy sources.

A second report suggests there is enough room on the national grid to meet the Scottish Executive's target of 18% electricity from renewable sources by the end of the decade. A quote from Mr Finnie, Scottish Environment Minister – "Both reports demonstrate that Scotland, both in environmental terms and in economic terms, stands to gain hugely from this potential energy resource". A report form the BBC, 10th December 2001, highlights Scotland's potential:

"Green Member of the Scottish Parliament (MSP) Robin Haper's attempts to get the Scottish Executive to seize the potential of energy sources such as wind and wave power have failed to win support".

This despite the fact the Scotland would become a word leader in renewable energy as it has the best natural resources in the EU.

A.3 OTHER ISSUES

Despite the huge potential in Scotland and the fact that private industry *wants* to invest, there are still many obstacles slowing progress down.

The first of these is the issue of planning rights, which are needed to build wind farms. For eight years a project proposed by Ecogen to build a wind farm in Kielder, Northumberland, has been on hold due to planning rights issues. The DTI put in an injunction to planning permission, after the MoD informed them it would interfere with radar and flight paths at RAF Spadeadam (Reference 24). In addition, the MoD has blocked five of the proposed 18 sites for offshore wind farm sites (Reference 25).

The rest of the issues are a combination of political wrangling and cross-party politics. To summarise the following BBC report mentioned above: the Scottish Executive were in favour of wind generation, the Enterprise Minister, Labour MSP and the environment spokeswomen for the SNP were all in favour of the proposals. *But* Murray Tosh, the Conservative Unionist transport and environment spokesman (Scottish Tories are in power) sharply curtailed their plans, saying that it was "not the party's policy to close the door on nuclear energy".

This event is a complex issue. The government is trying to develop a multi-faceted approach to alternative energy. But political differences seem to have blurred the message that many options should be utilised, and that investing in wind power would not be neglecting interest in future nuclear projects.

The second main political point revolves around the fact that Scotland already generates a surplus. It exports its excess electricity to England. Producing more excess power would be to the benefit of England. The transmission system would likely need significant upgrading to carry the extra supply. The question then is "who will pay for the development". The proportion of cost between Scotland and England is yet to be decided. England benefits from being supplied, but then so does Scotland as it gets to sell the electricity. This problem stemming from devolution is under investigation and is not yet resolved (Reference 26).

A.4 LEARNING POINTS

This case study has shown that many problems present themselves once plans are put into action. It does not take much to slow an important project to a grinding halt. Considering that at the moment the wind farms are to produce excess power, and that there is time to consider things carefully, events could be a lot more difficult in a more tumultuous world climate.

This reinforces the government's idea to co-ordinate alternative energy strategy from a central body that has links across all the inter-departmental and country boarders within the UK. Effective implementation will happen faster and more efficiently if all involved have the same strategy and pull in the same direction. In addition, the government calls for plans to be dynamic and reactive. Taking this example, their plans will have to be more than just that.

B PROPULSION DESCRIPTION

B.1 ENGINE OPERATION CYCLES

A simplified schematic of gas turbine operation can be seen at Figure 29.

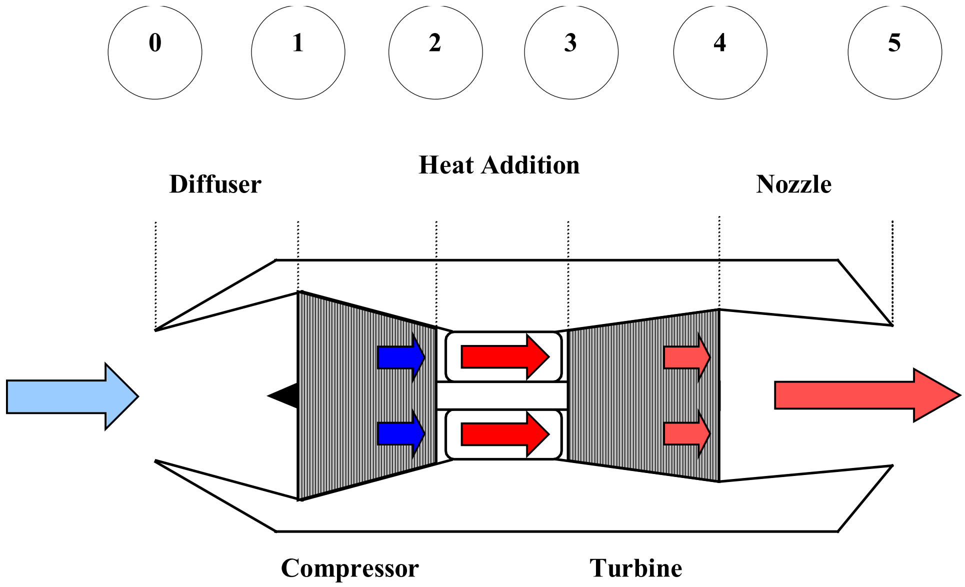

Figure 29. Schematic of Gas Turbine Operation

The general principal of a gas turbine cycle (in a subsonic freestream) is as follows:

0 – 1: Compression of air from high subsonic freestream velocity at 0 to low subsonic velocity at 1, via a divergent duct.
1 – 2: Further compression from a turbine driven.
2 – 3: Heat addition at constant pressure
3 – 4: Expansion of combustion products through a turbine
4 – 5: Acceleration of combustion products from low subsonic velocity at 4 until higher subsonic (or for special high-speed applications, supersonic) velocity at 5.

The schematic of ramjet operation can be seen at Figure 30.

The general principal of the ramjet cycle is as follows:

0 – 1: Compression of air from supersonic freestream velocity at 0 to subsonic velocity at 1, via a convergent duct.
1 – 2: Heat addition at constant pressure.
2 – 3: Acceleration of combustion products from low subsonic velocity at 2 until higher subsonic (or supersonic) velocity at 3.

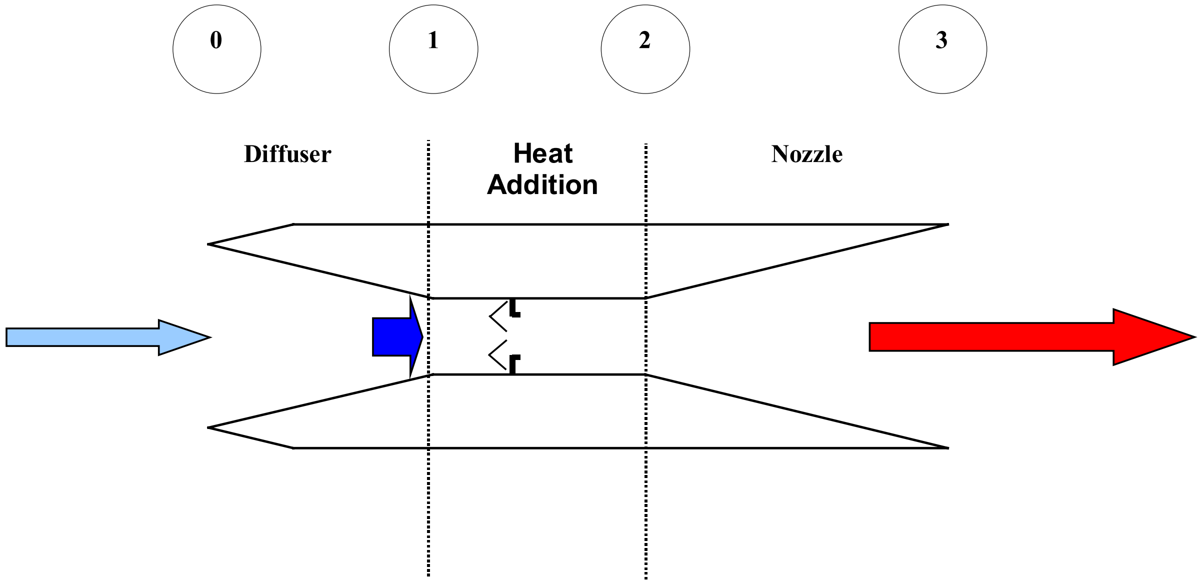

Figure 30. Schematic of Ramjet Operation

A schematic of the rocket motor operation cycle can be seen at Figure 31.

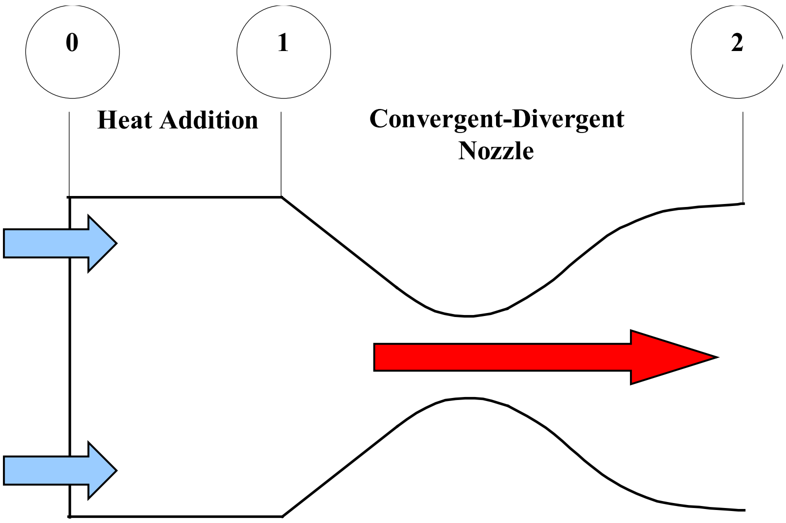

Figure 31. Schematic of Rocket Motor Operation

The general principal of the rocket cycle is as follows:

0: Propellant is added at high pressure, low velocity at 0. The propellant consists of a fuel and an oxidiser. They can be injected separately and mixed, or injected in a mixed form.

0 – 1: Combustion of mixed propellants, providing heat addition to the system.

1 – 2: Acceleration of combustion products from low subsonic velocity at 1 until high supersonic velocity at 2.

C FUEL SOURCES AND PRODUCTION

C.1 SUBSTITUTE FUEL SOURCES

		RESOURCE		
Substitute Fuel	**Formula**	**Short Term**	**Medium Term**	**Long Term**
Hydrogen	H_2	NG Crude Oil + H_2O	Coal + H_2O	H_2O
Methane	CH_4	Crude Oil Fields	Coal Degassing	Biomatter (Inc. SMW)
Methonal	CH_3OH	NG + O_2 NG + H_2O	Coal + H_2O	Biomatter (Inc. SMW)
Ethanol	C_2H_5OH	Crude Oil	Coal	Biomatter (Inc. SMW)
Hydrocarbon Oxygenates	Various	Biomatter	Biomatter	Biomatter
Ammonia	NH_3	$N_2 + H_2$	$N_2 + H_2$	$N_2 + H_2$
Nitromethane	CH_3NO_2	NG + HNO_3	NG + HNO_3	NG + HNO_3

NG = Natural Gas

SMW = Solid Municipal Waste

HNO_3 = Nitric Acid

Hydrocarbon Oxygenates = Vegetable Oils / Alcohols

Table 5. Substitute Fuel Raw Materials (Reference 27).

Table 5 shows the possible sources that substitute fuels can either be found or manufactured from. Sources have been shown, for completeness, in terms of how they can be manufactured over the short, medium and long term. For the purpose of this report the long-term source options will be of primary interest.

C.2 SUBSTITUTE FUEL PRODUCTION

C.2.1 LIQUEFIED HYDROCARBON GASES

The most attractive of these is the lightest hydrocarbon gas, methane (CH_4). Current deposits are found as a free gas in crude oil fields, or interspersed with coal seams. Methane can be derived by two principle means, namely:

- Converting CO_2 to CH_4 and H_2O by methination (using hydrogen).
- Tapping gas from Solid Municipal Wastes (SMW), and other biological matter.

Of these the latter is the preferred method, as it does not use valuable hydrogen (which can be used as fuel) in the production process.

Outlined above are the processes used to manufacture the fuel in a gaseous form. As will be shown later (Section C.3.1), it is more advantageous to use the gas in a liquefied form.

In order to condense methane to the liquid phase, cooling is necessary to the boiling point of 112 K (at 1 atmosphere); this is effected by several cycles of compression, cooling and expansion. This requires energy and must be considered as part of the energy cost of producing a given mass of fuel.

C.2.2 LIQUID HYDROGEN

Table 6 shows how hydrogen can be produced on an industrial scale. A brief explanation of the process is shown, however the detailed chemistry has been omitted for clarity.

Reactant	Process	% H_2 from H_2O	H_2 Purity (%)	η (%)
NG	Thermo/Catalytic Decomposition	0	95	75
NG to RFO + H_2O + O_2	Non-Catalytic Partial Oxidation	60 - 83	98	60
CO + H_2O + Fe	Steam-Iron Thermal Decomposition	100	99	65
H_2O	Electrolytic Decomposition	100	99.8	57 - 72
H_2O	Thermal Decomposition	100	99.8	50
H_2O	Photolytic Decomposition	100	99.8	50
H_2O	Photobiological Decomposition	100	99.8	50

NG = Natural Gas

RFO = Residual Fuel Oil

η = Process Efficiency

Table 6. Industrial Scale Hydrogen Production Techniques (Reference 27).

Processes involving methane (natural gas) are shown as a comparison to other methods of manufacturing hydrogen without fossil fuels. Water alone may be decomposed into hydrogen by providing the quantity of energy that will be released by subsequent combustion in service. This energy input could be derived by electrolytic, thermal, photolytic or photobiological means.

As with methane the processes outlined above are used to manufacture the fuel as a gas. As will be shown later (Section C.3.2), it is more advantageous to use hydrogen in a liquefied form.

Hydrogen is converted to the liquid phase by liquid nitrogen cooling to *77 K* followed by centrifugal expansion.

C.2.3 HYDROCARBON OXYGENATES

Including wood alcohols (methanol) and vegetable oils. It is possible to extract methanol by destructive distillation from wood. However, a more desirable process is to derive synthesis gas (syngas) from renewable sources such as biowaste.

Biomatter includes all natural materials associated with living organisms and consist mainly of carbohydrates. It therefore forms a logical source of methane, hydrogen and such hydrocarbon oxygenates as alcohols. A range of sources of biomatter is available, from small-scale collection of agricultural wastes to energy farming by purposeful cultivation. Biomatter is also generated continually in the form of municipal waste and manure.

C.2.4 HYDROGEN – NITROGEN COMPOUNDS

Ammonia (NH_3) can be derived by direct synthesis of hydrogen and nitrogen (Haber-Bosch catalytic method). Hydrazine (N_2H_4) is produced by oxidation of ammonia or urea with sodium hyperchlorite.

C.2.5 HIGH PERFORMANCE FUELS

'High performance' aircraft propulsion generally applies to high thrust engines for high supersonic velocity or high climb rate, or any other characteristic taking precedence over fuel economy. High performance fuels can include additives for gas turbine and ramjet devices, as well as rocket motor propellants. In future they will manifest themselves as additives to substitute fuels incapable of producing desired propulsion performance.

Gas turbine and ramjet additives have been used that are not related to fossil fuels, including elemental reactants such as boron, magnesium and carbon (graphite). These elements are relatively widespread. The cost of extracting the raw material, and processing it into a useful form may deter large – scale usage.

In terms of rocket propellants both liquid and solid types are available. Liquid rocket propellants include liquid hydrogen and hydrazine mentioned previously. Solid rocket propellants include ammonium perchlorate and aluminium.

Solid propellants are widely available since generally they do not have fossil fuel constituents in their make-up.

C.3 PROPERTIES OF SUBSTITUTE FUELS

The general and combustion properties of various aviation fuels and substitutes can be seen at Table 7.

Fuel	Fuel Group	Density at 293K (kg/L)	Net Specific Energy (MJ/kg)	Net Energy Density (MJ/L)
Avtur	Conventional	0.80	43.4	34.7
Hydrogen	Liquified Gases	0.07	120.2	8.4
Methane		0.42	50.0	21.2
Methonol	Hydrogen Oxygenates	0.80	19.9	15.9
Ethanol		0.79	27.2	21.6
Ammonia	Hydrogen - Nitrogen Compounds	0.62	18.6	11.4
Hydrazine		1.10	16.7	16.9
Nitromethane		1.12	10.9	12.3
Beryllium	High Performance Fuels	1.85	122.6	66.4
Boron		2.47	145.6	59.0
Carbon		2.27	74.3	32.8

Table 7. Comparison of Aviation Fuels and Substitutes (Reference 27)

C.3.1 LIQUEFIED HYDROCARBON GASES

As a low-density hydrocarbon fuel, methane offers a correspondingly high specific energy and low energy density.

It should be noted in passing, that methane has proved to work well in reciprocating type combustion engines. For gas turbine power plants, the gaseous nature of the fuel minimises the problems of mixing (fuel will boil rapidly from the liquid phase), combustion, temperature distribution and emissions.

The increased homogeneity of the fuel (gaseous) – air mixture is found to reduce NO_x emissions effectively, while maintaining CO and Unburnt Hydrocarbons (UBHC's) at very low-levels.

Use of the cryogenic fuel to cool bleed air (which in turn cools the turbine blades) allows higher Turbine Entry Temperatures (TET) and thus, more compact, high efficiency engines. Combustion studies have shown that combustors would require re-designing to use cryogenic fuels, but having done so, methane is a feasible substitute for use in gas turbine engines.

Methane is thermally stable and as a cryogenic liquid offers an effective heat sink capability for avionics and lubrication systems. a high level of Spontaneous Ignition Temperature (SIT), and displacement of air from fuel tanking assist in fire safety issues.

The present major problem with using methane concerns storage. As seen from Table 7, methane offers a higher specific energy than conventional Avtur (50 $MJ.kg^{-1}$ compared to 43.3 $MJ.kg^{-1}$). For an aviation application this will correspond to a 15% increase in aircraft range, or 15% less fuel mass, (all other variables constant) over a conventionally fuelled aircraft. However, comparing energy densities, around 60% more storage volume is required to accommodate the same amount of energy. In terms of aircraft design this is a major consideration, since volume and mass are always at a premium.

C.3.2 LIQUID HYDROGEN

As a low-density gas, hydrogen offers a very high specific energy (~ 120 $MJ.kg^{-1}$, compared to 43.4 $MJ.kg^{-1}$ for Avtur); exotic high performance fuels can only match this. It has however a very low energy density: 8.4 $MJ.L^{-1}$ compared to 34.7 $MJ.L^{-1}$ for Avtur.

As with other gaseous fuels, mixing is very rapid and the resulting air-fuel mixture homogeneous. Thus hydrogen lends itself well for use in gas turbine propulsion. The high flame speed and wide range of flammability imply high combustion performance and stability. The overall combustion performance for hydrogen is such that with an engine configured for hydrogen, engine specific impulse (the amount of thrust produced per unit mass of propellant) is higher than that for a conventionally fuelled engine.

Due to the nature of the air – fuel combustion system, carbon is not present. As such there are no CO, CO_2 or UBHC pollutants derived from combustion. As the flame temperature of combustion is higher than for Avtur it is likely that NO_x production may be higher. The only issue raised by combustion of hydrogen, is the increased amount of water (itself a 'Greenhouse Gas') injected into the atmosphere (double that of a conventionally fuelled engine).

The three main disadvantages of liquid hydrogen concern the tankage volume required (due to the very low energy density), the cryogenic nature of the liquid (which creates further storage problems), and safety. There is a fire hazard, partly to the flammability and flame speed, but mainly due to the very low ignition energy.

In general hydrogen only poses a danger when spilt, and then the rapid diffusion of the gas will ensure that the hazard is not present for long. Furthermore, hydrogen flames are buoyant (which implies any resulting fireball will rapidly rise out of harms way) and radiate little heat.

C.3.3 HYDROCARBON OXYGENATES

The low viscosity of alcohols such as methanol promotes mixing in gas turbine combustors, leading to effective burning. It has been shown that biomatter can be used to produce other fuels such as methane (hence, hydrogen) and alcohol type fuels, or used directly, e.g. vegetable oils.

The fundamental problem with using hydrocarbon oxygenates is the presence of oxygen in their chemical make-up. Half methanol's mass is oxygen. This situation is undesirable for two main reasons. Firstly, oxygen is freely available in the atmosphere. As such carrying oxygen in aircraft fuel tanks would unnecessarily detract from the aircraft's energy (fuel) carrying ability. Secondly, again due to the chemical make-up, over a period of time water is likely to separate from the fuel. For a high altitude aircraft this could lead to ice formation in the fuel distribution system.

C.3.4 HYDROGEN – NITROGEN COMPOUNDS

Anhydrous ammonia has been tested in gas turbine engines, but in comparison with hydrocarbon fuels, the performance of the engine and the fuel system, together with the maintenance and overall costs, where not attractive.

Hydrazine has not been tested significantly in gas turbines, although it has served as a rocket reactant.

C.3.5 HIGH PERFORMANCE FUELS

Exotic fuels such as boron and beryllium offer extremely high specific energies and energy densities (around three time the specific energy of kerosene, and around twice the energy density). However, these elements burn at higher temperatures than kerosene, so require equally exotic materials in the construction of the propulsion device in question (typically, nickel super alloys).

The fuels also require specialist handling techniques, as they are extremely reactive. These fuels are often used as additives to a parent fuel, forming a fuel 'slurry'.

D ALTERNATIVE MATERIALS

Spiders' silk has been known for many years to be very strong for its size and weight. Pound for pound the sturdiest spider silks are stronger than steel and more elastic than nylon. With such remarkable properties, many consider spiders' silk to be one of the most promising materials for investigation. The types of products that could be produced include medical sutures, high-strength composites, soft body armour and many others. All these applications could aid a defence force to operate at its full potential.

At present there are a number of problems that need to be overcome if silk is to be used commercially or in defence forces. The major problem is that spiders are territorial animals. Large-scale silk farming has so far failed for this reason. This could be overcome by genetically engineering other cells to produce the silks. A Canadian company, Nexia Biotechnologies, has reported some experimental success with coaxing mammalian cells to produce spinable proteins by equipping them with spider silk genes.

At present research is also being carried out to try and produce plastics from "green" or renewable sources. One of the largest efforts at present is a joint effort by two companies Cargill (an agricultural business giant) and Dow Chemicals (a large chemical firm). These two have developed a process that changes sugar from corn and other plants into a plastic called Polylactide (PLA). This process uses micro-organisms to transform the sugar into lactic acid, then a second step to chemically link the molecules of lactic acid into polymer chains. The result is a plastic with attributes similar to Terephthalate (PET); a petrochemical plastic used in construction of drinks bottles and clothing fibres. The process at present requires 20 to 50% fewer fossil resources than making plastic from oil. However at present all the extra power required to refine and run other associated processes means that the amount of fossil resources actually used is greater than those consumed by plastic production from oil. This can be shown when looking at a similar product called Polyhydroxyalkanote (PHA). PHA, a natural plastic, requires 300% more energy to produce then similar oil based plastic called Polyethylene (PE). At present PE requires 29 MJ of energy where as PHA requires 87 MJ.

The largest area of current research is Polymers. This is because while semiconductors and inorganic crystals are the basis for electronics and other technologies, only small changes can be made to their chemical properties. The possibilities for carbon based polymers are almost unlimited by comparison. Polymers can have the repeating chemical groups which make them up altered to suit a given application. One area most actively researched is the field of electronics. Polymers are being examined because they could replace current metal circuit board tracks. Less metal would be required, reducing fuel consumption. Some polymers could also allow light waves of certain wavelengths to pass though them. As light propagates faster than electronic signals, this would increase the speed equipment using the technology. Other possible uses for polymers are in magnetic storage media (hard disks) or magnetic coatings for various items. The technology at the moment is very young. New uses are being proposed all the time, although many of these ideas still require large amounts of research and development.