Future Energy and Power Challenges
This paper highlights the range of energy and power challenges faced by the Ministry of Defence and the Singapore Armed Forces. Buildings, infrastructure and the whole range of military requirements in capabilities such as unmanned systems, soldier systems and platforms have their unique demands and hence require different solutions. This paper explores the use of alternative energies, energy management modes and even advanced composites to overcome challenges and meet the energy and power demands in a cost-effective manner.

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THE GLOBAL BACKDROP

In 2008, the world saw record highs in oil prices (see Figure 1) and various reasons proposed included diminishing oil reserves, instability in the Middle East, oil speculation and the weakening US dollar. Drilling of oil is also more complex and costly today as the more accessible oil fields are being depleted and much drilling now occurs at oil wells which are deeper or offshore. Figure 2 gives an indication of the extent of the increase in oil production cost over the years.

The rising cost of fossil fuels, coupled with the uneven global distribution of energy resources make energy security an important issue to oil-importing countries. In particular, political and social instability in the Middle Eastern countries is a cause for worry as approximately 70% of global oil reserves are found in these countries. The dispute between Russia and Ukraine over natural gas in 2005 to 2006 demonstrated how external energy supplies can be volatile, even to countries not directly involved – in this case, Western European countries. China, the growing giant, has also joined the competition for energy resources in the global market to propel its increasingly power-hungry economy. Russia, Kazakhstan, Iran, Saudi Arabia and Africa are some of the suppliers of oil and/or gas to China (Liu, 2006). In fact, in his speech on 23 August 2006, Australian Minister for Resources and Energy, A. M. Martin Ferguson, described the international competition for energy as the new Cold War.

Figure 1. Graph of crude oil prices from 1974 to 2008

Figure 2. Graph showing trend of oil drilling cost (figures obtained from American Petroleum Institute (May 2008), 2006 Joint Association Survey on Drilling Costs)
Singapore relies heavily on natural gas imported from Indonesia and Malaysia for about 80% of our electricity consumption\(^1\). In 2007, the Ministry of Trade and Industry (MTI) launched a ‘whole-of-government’ approach to deal with the increasingly complex energy issue, leading to restructuring that resulted in the formation of an Energy Division in MTI and the expansion of the Energy Market Authority. At the national level, the strategy is to diversify supply channels of energy resources, adopt renewable energy as well as maximise energy efficiency.

### ENERGY AND POWER CHALLENGES

Almost all the land, air and sea platforms of our military are dependent on oil-based liquid fuel in one form or another. Diesel fuel powers our armour brigades, heavy oil powers our navy frigates, kerosene fuel powers our fighter planes and even our command and control infrastructure runs on electrical power that is backed up mainly by diesel-powered generators.

In recent years, we have modernised as well as brought in new fighting capabilities that are more technologically sophisticated. We now have armoured fighting vehicles with better protection, new generation frigates equipped with sophisticated weapon and sensor systems and twin-engined F15s. The ongoing transformation will have a compounding effect on our total energy demand and thus our thirst for oil.

A key trait of the Third Generation transformation of the Singapore Armed Forces (SAF) is the increasing dependence on networks and electronic systems. A common vulnerability of electronic and network systems is their high dependence on continuous power and cooling. As the Third Generation SAF expands with exponential growth in computing and networking power, the energy and cooling requirements will follow suit. In 2003, the average power consumption of a legacy server was 2.5kW per rack. With the advent of high density blade servers, the average power consumption will grow to 8.5kW per rack. The introduction of high density blade servers are expected to reduce the server footprint by up to three times, yet our projected need for Data Centre space and power demand has continued to grow.

Unmanned warfare has begun to dominate the land, air and sea domains. The unmanned systems complement and supplement manned systems, and in some applications, they can replace humans and thus remove them from harm’s way. To fully exploit the potential of the unmanned systems, new energy sources are required to increase their endurance and safety. This would consequently lead to increased range and payload, hence operational flexibility.

Even as unmanned systems are increasingly being harnessed, soldiers continue to play critical roles in operations. Our Third Generation soldiers will be equipped with a myriad of sensor and communication devices to connect them to the sensor-shooter network, in order to increase their lethality and survivability. Unfortunately, the proliferation of these soldier portable systems also increases the demand for more batteries.

Taking a long-term view of our energy situation and challenges, we need to do more to address the problem of our ever-increasing energy demand.
TACKLING THE CHALLENGES FOR INFRASTRUCTURES

Since the 1990s, an Energy Management and Economisation Committee has been set up under the auspices of the Ministry of Defence (MINDEF) Economic Drive Committee to regularly review the energy and water consumption in all MINDEF building and infrastructure assets. Over the years, the committee has generated solutions such as energy thermal storage, sea water cooling, building integrated photovoltaic systems and coastal wind turbines. There is still much that can be done to reduce energy consumption, improve energy efficiency and conservation for MINDEF and the SAF.

Building Technologies

Mechanical & Electrical (M&E) systems in older buildings can be further optimised with the installation of energy management and control systems. MINDEF is taking steps to implement cost-effective measures to improve the energy efficiency of these buildings. There are many energy-efficient alternatives today which do not require high capital investments. Examples include variable speed drives for motor controls, motion-triggered lighting devices and white light-emitting diode (LED) lighting. Fluid dynamics simulation software can now be used to study airflow vectors to optimise the design of air ducting or under-floor cooling systems commonly used in data centres. A facility management system can be installed to enable an automated control of M&E systems which will better match the M&E system performance to the operation patterns in the building. Similarly for new buildings, an integrated building design approach can be adopted where the architecture and M&E systems of the building are designed in consideration of their impact on each other. The architecture of a building affects the solar heat gain, the amount of daylight entering the functional space and the amount of natural ventilation. The goal is to create an architectural design that minimises solar heat gain and yet allows the building to exploit the natural environment for day lighting as well as for natural ventilation to reduce air-conditioning requirements.

Renewable Energies

Renewable energy installations in MINDEF facilities provide us with a test bed for free energy exploitation by the SAF. They offset our growing dependence on and offer alternatives to grid power. There is much
potential for MINDEF to adopt renewable energy solutions to satisfy part of our energy demands, and in particular, solar energy has been identified as a viable alternative. MINDEF manages approximately 20% of mainland Singapore and 60% of offshore land, most of which are not densely built up. The long coastlines of naval bases and islands serve as good wind catchment areas which can be exploited. Figure 5 shows an example of small scale wind turbine systems (500W and 1kW) installed at the pier of a coastal facility.

Most of the army camps are also located in non-built-up areas and are suitable sites for the installation of solar arrays. Since the late 1990s, building integrated photovoltaic systems have been explored using solar panels as part of the building facade and the resultant cost savings help to offset part of the cost of the solar panels. In some sites, solar panels have been installed as part of the building facade, in place of glass or metal panels to harness energy, which is then fed back to the grid and used to power lights at the atrium.

Energy Storage

Energy storage is another important aspect of energy management. Wind energy, for instance, is highly variable and thus unsuitable to be fed directly to loads. Hence, an energy storage device for wind energy is needed. A reliable energy storage system enables the wind and solar energy harnessed to be used to support remote offshore installations.

Currently, computer applications are supported by uninterruptible battery power systems (UPS) for instantaneous backup power. The typical UPS is inefficient, consuming 10W for every 100W of power supplied to the computer data centre. To sustain the operability of the battery, an additional 15W to 20W is required to maintain the batteries in a cool ambient climate. Furthermore, most UPS systems are based on lead-acid battery technology which can be costly and has a relatively short operational lifespan. DSTA is currently studying the application of a regenerative fuel cells system as an alternative form of energy storage. The regenerative system consists of a Proton Exchange Membrane (PEM) fuel cells module coupled with a PEM electrolyser module. The PEM electrolyser module directs the electricity from a renewable or grid source to break the chemical bond of water to produce hydrogen for storage, while the PEM fuel cell module converts the energy released from the chemical reaction of hydrogen and oxygen into electricity. In collaboration with fuel cell manufacturer P21 Gmbh, DSTA has developed...
a prototype self-regenerative fuel cell system (see Figure 7) that is able to function as a backup power system, especially for remote applications. The prototype can either be connected to the grid or to renewable energy sources. There are two operating modes – Backup Power Mode and Energy Collection Mode.

Flywheel and super-conducting magnetic energy storage systems promise lower energy wastage and are also currently being explored by others as alternatives to the UPS.

Enabling Persistent Surveillance

It was shared at a Defense Advanced Research Project Agency (DARPA) conference in 2008 that a fleet of eight Global Hawks would be required to maintain constant monitoring of a point target located 3,500 miles away. It would be extremely costly and hence impractical to sustain such an operation. There are benefits to extend the endurance of unmanned systems so that they could operate with fewer platforms over a larger area of operations, yet achieving the desired persistence over targets.

Unmanned systems can be broadly classified into four categories: Unmanned Ground Sensors, Land Robots, Unmanned Aerial Vehicles (UAVs) and Autonomous Underwater Vehicles (AUVs). Today, these systems have power demands ranging from 10W up to 10kW and are likely to rise with more sophisticated systems. Yet, the payloads are not expected to become lighter. For robots, the energy source needs to be ultra-compact due to the limited space available. In addition, land robots are to be ruggedised and semi-submersible to enable use on all terrain. It is more demanding to power UAVs and AUVs as they require both compact and lightweight sources with a high degree of reliability. Furthermore, a UAV power system, for example, must be able to supply peak power surges at several times the nominal power during take-offs and dashes.

Hybridisation

It is our aim to power and sustain our UAVs to extend their persistent envelopment. In the short-term, this can be achieved through a hybrid power system based on a smart power manager capable of optimising power usage. This hybrid system uses a battery and fuel cells while simultaneously harnessing solar energy through photovoltaic membranes on the body of the UAV. A fuel cell-battery hybrid exploits the high energy density of fuel cells for long endurance glide and the high power density.
of a battery to provide peak power during take-off. Hybrid systems have the potential to satisfy power demands and at the same time reduce the gross take-off weight of the UAV. In addition, the harnessing of solar energy further reduces the demands on the fuel cells and batteries.

Fuel Cells

In the longer term, there is a need to develop new power generation technologies for higher efficiency and reliability. Solid oxide fuel cell (SOFC) technology is a potential enabler to ultra-efficient electric motors. The primary advantage of SOFC is its ability to use a wider range of fuels, as opposed to other fuel cells in the market today. However, SOFC requires long start-up times and it operates at high temperatures of 800ºC to 1000ºC. These unfavourable operating limitations must be overcome before it can be useful to military applications. DSTA and Nanyang Technological University are now experimenting with the idea of microtubular SOFCs, which have the potential for higher power densities than what can be achieved presently. The aim is to develop small and lightweight energy solutions to achieve flight persistence for the UAVs.

Advanced Composites

With the same given energy solution, the lighter the UAV, the longer it can stay in flight. Reducing the weight of platforms is therefore a revolutionary approach to achieve breakthroughs in power efficiency. Lightweight steel alloys and polymer composites will soon replace conventional materials, hence allowing lighter platforms to be realised (Lovins, Datta, Bustnes, Kooney and Glasgow, 2005). Currently, such advanced materials are expensive. We need to develop new processing and fabrication technologies to drive down the costs for such materials. DSTA understands the benefits of low cost composite materials and has partnered with DSO National Laboratories and the local universities to develop new

Figure 8. An illustration of a tri-brid UAV system that exploits solar cells, fuel cells and lithium-polymer technologies
fabrication techniques. Combined with highly integrated innovative structures with net shaped composite parts, the aim is to reduce the number of component parts and assembling procedures and work towards lightweight and cost-effective platforms.

**SUSTAINING SOLDIERS’ PEAK PERFORMANCE**

The Third Generation soldiers will be equipped with an array of advanced soldier systems for sensing, fire, protection and communications. A Third Generation soldier equipped with the Advanced Combat Man System (ACMS) alone will need to carry a sizeable amount of batteries for his missions. Apart from his basic combat load the soldier needs to be supported by a long logistic train. For a seven-day mission, the battery weight is much greater at 23kg. This energy load is too heavy for our Third Generation soldiers and we need lighter and more efficient solutions to enable peak soldier performance during sustained operations (Chua, Tang and Ho, 2007).

**Battery Technology**

Battery technology has evolved over the years with new chemistry and higher energy densities continuously being achieved. Before the advent of lithium-ion (Li-ion) technology, the use of rechargeable batteries was limited as compared to primary batteries due to low energy densities. Nickel cadmium (Ni-Cd) and nickel metal hydride (Ni-MH) batteries have energy...
densities below 100Wh/kg. Li-ion batteries, with an energy density (approximately 160Wh/kg) comparable to that of primary batteries, changed the scene. Their introduction encouraged the use of secondary batteries and gradually replaced primary batteries. DSTA recognises this emerging trend and has initiated the replacement of primary alkaline batteries currently used in 900 series radios to provide weight reductions to combat soldier loads, bringing about significant cost savings for the SAF.

Unfortunately, the current Li-ion batteries are engineered to lower capacities due to safety issues and are still too heavy to support the ACMS. Research on improving the performance of lithium-based batteries is intensive and nanotechnology could be the new answer to this challenge. Going small increases the active surface area and also enhances the intercalation of metal-ions between the electrodes. A123 Systems, for instance, has developed a form of Li-ion battery that incorporates nanophosphate electrodes. The improvements brought about by this new concept include a high discharge rate and fast charge capability. Nanotechnology holds the promise of increased storage capacity, higher power, longer life and improved safety due to lower heat generation. In the near future, these ‘nano-batteries’ will be a viable energy solution for our Third Generation soldiers.

**Forward Field Charger**

For special operations, the primary concern is getting re-supplied. Batteries should be recharged in situ by drawing on available energy resources. The aim is to plug-and-play with any type of available power source and distribute power optimally to a myriad of equipment. Through this mode, emerging high energy sources such as fuel cells can be exploited to recharge field batteries. Solar energy harvesting devices can also be used to sustain prolonged operations which will reduce overall mission weight and cost without compromising their capability and endurance.

Although high energy sources such as fuel cells are promising alternatives, batteries will remain the dominant solution for the army’s energy needs in the near future as they are the most reliable and rugged. An annual increase of approximately 5% in terms of energy density can be expected for lithium battery technology. On the other hand, fuel cell technology is more relevant for supporting lengthy missions and energy intensive operations. In the longer term, the goal is to have each soldier totally self-sustained. Imagine low-cost, printable solar

![Figure 11. Graph comparing energy densities attained by some batteries today](image)
cells with over 50% efficiency woven onto every soldier’s uniform, harvesting power in situ. This is not an impossible feat and we will continue to work closely with the various national solar initiatives and overseas solar research centres to realise this dream.

**ENHANCING MOBILITY AND POWER RESILIENCE**

Our Third Generation command posts and critical nodes in the battlefield must have the flexibility to disperse and co-locate expeditiously according to the operational tempos and scenarios. For critical nodes such as communication nodes that may be deployed in isolation (such as on a hill top), a high level of self-sustenance is essential. This may require the power sources to be built and sustained within the individual platforms. Although conventional diesel generators may be the immediate solution, the vibration and intolerable noise level at close proximity to these generators undermine the operating conditions and could compromise the locations of command posts and critical nodes. Furthermore, the need for a large fuel re-supply remains, thus curtailing the operational tempo and flexibility of operations and at the same time, presenting windows of vulnerability that could be exploited by the enemy.

**Silent Generators**

One of the short-term solutions to provide silent and efficient on-board power is the free-piston Stirling engine (named after its inventor, Robert Stirling). Stirling converters were originally developed for NASA space applications, and the technology has translated into power generators that are highly efficient, reliable, maintenance-free and quiet. At the

![Diagram of a field charger system](image)

*Figure 12. An illustration of the benefits of a forward field charger for the advanced soldier – the charger can be built upon various forms of fuel cell technologies*
DSTA has initiated the development of a smart power management system capable of dynamically switching in and out of power sources and loads for minimum disruption of power supply. The system is being developed to operate at varying engine speeds in response to the loads so as to maximise energy efficiency. The development of a high resilience power distribution system will provide superior field power surety and fuel savings, hence reducing logistic footprint. In addition, the ability to plug-and-play with renewable sources will also be advantageous for extended disaster relief missions.

**Mobile 'Microgrid'**

The resilience of future command posts can also be improved by making use of a smart power management system, as depicted in Figure 14. Currently, the internal combustion engine-based diesel generators deployed are switched on continuously and their capacities are specified to handle peak output requirements. This is an inefficient use of energy as the generators are mostly running on part load. Furthermore, the excess power capacity of individual generators cannot be shared with adjacent generators to improve the overall system resilience.

43rd Power Conference, the US Army presented its focus on this emerging technology and also announced that it has achieved a gross fuel-to-electric efficiency of up to 22%. This is substantially higher than the conventional diesel/gasoline engines operating in the 1kW to 3kW power range at an efficiency of 10% to 15%. External combustion Stirling engines have the advantage of quiet operations which is essential for military action requiring low signatures. They also have the capability to accept a multitude of fuels – besides military diesel, any combustible fuel will work.

**Figure 13. Next generation 3kW free-piston Stirling Generator by Infinia Corporation contract by US Army**

**Figure 14. An illustration of power management for field command posts**
CONCLUSION

From the peacetime load growth of buildings and infrastructures to the operational sustenance of the soldier, the energy and power demands of MINDEF and the SAF are wide-ranging and challenging. It is hoped that this article will initiate further discourse on the relationship of energy to our defence ecosystem. This paper has attempted to suggest a variety of energy solutions customised for infrastructures, soldiers, vehicles and some forms of unmanned systems. Through innovations, energy management and adoption of alternative energies, the operational performance of our fighting forces can be boosted. There are many other areas of energy and power management that have yet to be explored, especially for naval and air platforms. To manage these issues, DSTA and MINDEF will continue to innovate, harness and exploit science and technology, as well as adopt an integrated and systems solution approach, to reduce consumption, eliminate wastage, improve efficiencies and also power and sustain the SAF’s capabilities in the battlefield.

REFERENCES


ENDNOTES

1 Speech by Prof S Jayakumar, Deputy Prime Minister, Co-ordinating Minister for National Security and Minister for Law (8 Nov 2006) at the Singapore Energy Conference, Island Ballroom, Shangri-La Hotel, Singapore.

2 Though current LED lighting performance is 80lumens/Watt, lower than that of fluorescent lighting at 90lumens/Watt, its compact size enables it to be located nearer to the illumination target and hence allows more flexible applications. DSTA is exploring the wider applications of LED technology as its performance is expected to match that of fluorescent lighting in one to two years’ time.

3 A123 Systems, one of the largest lithium-ion battery manufacturers for specialty vehicles.

4 In 2007, DARPA announced a break-through world record performance of 42.8%.
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