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Alternative Fuels and Propulsion Systems: Some Technology Trends and Possible Implications for the Future Army

Peter J Dortmans

Land Operations Division
Systems Sciences Laboratory

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ABSTRACT

Alternative fuels and propulsion systems are key emerging science and technology areas that will impact on defence in the next two decades. This report explores some of the associated issues in order to gauge where and how they might influence the military within the Army-After-Next timeframe. Our analysis is built upon an environmental scan of New Scientist magazine, from which we identified a number of key emerging themes - Strategic Issues, Non-renewable sources, Renewable sources, Recycled energy sources, Novel materials, Miniaturised systems and Novel approaches to propulsion. For each of these, technological developments are captured and considered in terms of their implications, both on military systems directly, and the broader implications for the future context. The impacts on Land Force core skills within the Army-as-a-system framework of these technologies are discussed.

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Executive Summary

Alternative fuels and propulsion systems represent some of the key science and technology areas that will impact on defence in the next two decades. In this report we explore some issues associated with these technologies in order to gauge their possible influence on the military within the Army-After-Next timeframe. Our analysis is built upon an environmental scan of *New Scientist* magazine, from which we identify a number of key emerging themes - Strategic Issues, Non-renewable sources, Renewable sources, Recycled energy sources, Novel materials, Miniaturised systems and Novel approaches to propulsion. Within each of these we explore the technological developments and consider their implications, both on military systems directly, and the broader implications for the future context. For the former, the Army-as-a-System model is employed to determine possible implications of these technologies on seven Army core skills: Engagement, Protection, Sustainment, Information Collection, Decision Making, Movement, and Communication. In addition, expert opinions on realisation timelines are included.

One significant outcome of our analysis is that developments such as changing from the current dependency on liquid and solid fossil fuels to alternatives like hydrogen and solar energy are likely to create their own set of issues. Reductions in supply, increases in demand and the consequences of greenhouse gas emissions and global warming may force the focus of energy policy to change dramatically. Issues such as which are the preferable options for future fuel supply, how to support them and the changes to management strategies required will all need consideration. This could necessitate changes in the form of energy required by the military which will impact in turn on military systems, acquisition infrastructure and training. In addition, any impact on the strategic environment may shift the type and nature of any future operations.

The development of hydrogen as a major source of fuel in the future seems likely, with significant efforts from a number of countries to support its development. Interestingly, some consequences of this may have significant implications for other fuel sources (especially nuclear and solar/wind), as the production of hydrogen fuel necessitates new efficient energy processes. Currently there are quite divergent opinions on how hydrogen fuel can be produced on a commercial scale. This may have significant implications on the types of systems we maintain in the future. Certainly, if hydrogen fuels were to become prevalent, significant military infrastructure and training practices could become outmoded.

Renewable sources continue to generate significant research interest. While the cost and efficiency of current solar systems are sometimes questioned, new developments seem likely to make solar energy viable. New cell designs and materials are likely to

increase solar cell efficiency from the current band of 10-20% up to 40-50%, while increasing commercialisation is likely to drive down production costs. Such improvements are likely to make solar energy a viable option for providing energy in-theatre and overcome the difficulties that are arising over greater energy consumption to support increased digitisation of the battlespace

The scavenging of excess (latent) heat and its conversion into a useful energy source is likely to enhance solar systems, or even prove to be viable in its own right. In either case it promises to provide greater endurance and system efficiency, increasing future users' mobility and time in the field. Novel materials, such as those that create electrical current when heated or pressured, provide another way in which wasted energy can be converted into something that is useable without impacting on the systems. The capability of autonomous systems that are required to operate remotely for significant periods of time especially in environments where alternatives such as solar and wind power are not feasible (e.g. triple canopy jungle) would significantly benefit from developments in this area.

The capacity to develop miniaturised power sources and motors may also have some benefits, in terms of new systems that have the capacity to perform task that were previously impossible, or increased energy efficiency and stability of miniature systems. This has a number of obvious impacts for information collection and communication. In addition, however, miniaturisation will significantly impact on sustainment and protection of systems.

Of course, one major role of research into alternative fuels is to allow systems to run more efficiently and effectively. As such, the capacity to design novel approaches to propulsion is also considered. We note that there are many options which will, if they meet expectations, improve mobility and manoeuvrability. In particular, systems that can operate effectively in all terrains within the littoral environment show some promise.

Of course, the application of alternative fuels and propulsion systems will present a number of new issues for the military. Some that might need some consideration in the short term include the following.

- If the 'hydrogen economy' becomes a reality, it will necessitate significant changes to military platforms, and associated skills and training. Shortages may occur or be exacerbated by the need to train people to maintain such energy systems in the wider community.
- The timing of technology uptake and associated risk. If one changes too early, there may be significant upfront costs, teething problems and danger of focussing too heavily on a particular technology that might quickly become redundant. However, the risk of waiting is that if conventional fuel prices sharply increase as supplies decrease and organizations change focus, current military systems may cease to be interoperable with those Allies who have made such changes.
- The need to manage any unexpected consequences of introducing new power options. Certainly the impact of wind-turbine blades on radar has highlighted side effects that can potentially undermine our defence capability.

Author

Peter J Dortmans
Land Operations Division

Peter Dortmans obtained a PhD in Theoretical Physics at the University of Melbourne in 1992 and undertook post-doctoral research at the University of Melbourne and the Instituto Nazionale di Fisica Nucleare in Padova (Italy). He joined DSTO in 1999 and was subsequently posted to the Australian Army's Combined Arms Training and Development Centre in Puckapunyal to provide support to their capability development activities. Upon his return to DSTO Edinburgh in 2002, his work focus shifted to supporting future concept development.

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1. Introduction

One of the major emerging trends in technology is that associated with the provision and efficient use of energy. Certainly, the combination of: economic factors such as diminishing conventional fuel supplies in an atmosphere of increasing demand; ecological factors such as concerns over the impact of fuel emissions on the physical environment; political factors such as the US desire to become more self-sufficient; and technological factors such as novel energy needs associated with fields such as nanotechnology and biotechnology; have seen alternative fuels and novel propulsion systems become a central focus of technological development [1].

Within this subject area there are a number of competing focus areas. These range from improvements to current conventional fuel-based energy producing systems to renewable sources, such as solar and wind, hydrogen powered vehicles, and the new generation of nuclear systems. In addition increasing miniaturisation is creating ever-increasing energy needs, leading to the pursuit of flexible, long lasting and reliable power supplies. Another approach is to consider efficient fuel usage through research into improved vehicle and engine designs, both in terms of the useful conversion of energy into power and in the design of systems such that the energy demands are reduced. In short, there is considerable research being undertaken in alternative fuels and propulsion systems.

This report provides an overview of the developments in these areas with the view to informing the development of future concepts and capabilities by discussing ways in which energy usage could change within the next two to three decades. It is one of a series of technology reports [2] focussing on those technology trends that are mostly likely to have the greatest impact on the military (whether through direct changes to capability or indirectly through the socio-cultural changes to the operating context [3]). Other reports in this series focus on: biotechnology [4]; nanotechnology [5]; and information and communication technology [6]. This report does not aim to describe the field of alternative fuels and propulsion systems in great depth, nor capture all current research. Rather, it provides an overview of the topic that highlights key development areas, and their possible implications for the military. As such, it provides an overview of the topic that will be continually reviewed, refined and updated.

The study commences by cataloguing alternative fuels and technology trends through an environmental scanning [7] exercise over two years of the weekly science journal *New Scientist*. The resultant reports are categorised into various topics. Within each of these, the emerging applications are described and some of their potential consequences discussed. We also endeavour, where possible, to provide an indicative timeframe for commercial realisation of various applications, as suggested within the literature [8-12].

Finally we discuss the broader implications that technology innovations in this area may induce, by identifying how specific technologies will impact upon the core skills and capabilities of the Army. In addition, we identify a number of issues for the Australian Defence Force (in general) and Army (in particular) to consider. This is intended to give those developing future warfighting concepts and capabilities within Army some insight into the possible impacts and implications of alternative fuels and propulsion systems within the Army-After-Next timeframe, and inform their considerations.

2. Identifying emerging trends in alternative fuels and propulsion systems

2.1 Introduction

The field of alternative fuels, energy sources and propulsion systems covers a broad spectrum of scientific disciplines and commercial applications. In addition, contributing factors such as diminishing non-renewable fuel supplies, increased energy demands and international environmental policies means that the field is constantly evolving. Therefore, to gain insight into the field's impact within a specific frame of reference (such as the future Military paradigm), we need to identify, capture, collate and analyse scientific advances, technological developments and innovations. This will inform our understanding of the issues associated with the transformation and practical application of these to the Armed Forces. Therefore we have used techniques such as environmental scanning and emerging issues analysis to provide us with the capacity to gain meaningful insights into the field. From these we subdivide alternative fuels into meaningful (although not necessarily mutually exclusive) categories.

2.2 Defining 'Alternative Fuels and Propulsion Systems'

Before capturing the emerging trends associated with alternative fuels and propulsion systems, it is important to define what we mean by these terms. In effect, by 'alternative', we mean fuels and propulsion systems that are not commonly used in Australia and by the Australian military as present. This follows on from the definition given by the Alternative Fuel Data Center within the U.S. Department of Energy (DOE), which defines 'Alternative fuels' as being "substantially non-petroleum and yield energy security and environmental benefits" [13]. For completeness, we have expanded this to other energy sources that are substantially non-petroleum based. The DOE defines the following as energy sources [14] (with those included as 'Alternative Fuels' within this report italicised):

- *Bioenergy*
- Coal
- Fossil Fuels

- *Fusion*
- *Geo-thermal*
- *Hydrogen*
- *Hydropower*
- *Natural Gas*
- *Nuclear*
- Oil
- *Renewables*
- *Solar*
- *Wind*

We also expand the definition to include those fuels that the DOE 'Energy Policy Act of 1993' currently recognises as alternative fuels [13]:

- Mixtures containing 85% or more by volume of alcohol fuel, including methanol and denatured ethanol
- Natural gas (compressed or liquefied)
- Liquefied petroleum gas (propane)
- Hydrogen
- Coal-derived liquid fuels
- Fuels derived from biological materials
- Electricity (including electricity from solar energy)
- Biodiesel

Similarly, alternative propulsion systems focus on vehicles, engines and system designs that are fundamentally different to the vehicles currently employed by the Australian military.

2.3 Environmental scanning and emerging issues analysis

To gain an appreciation for how a particular field may evolve, it is important to capture the emerging research trends and associated development issues. One starting point for this is an environmental scanning exercise. This involves a systematic review of the relevant literature in order to determine the current status of a particular field [7]. Of course, if the aim is to gain a broad understanding of the impact, the source material should largely come from review material (often secondary sources) as this often sets any new science and technology (S&T) advances against the broader context of a range of applications and alternatives for achieving this.

Once completed, the environmental scan provides a basis to extrapolate ongoing trends into the future to gain an appreciation of how the environment may change. This, the emerging issues analysis [15], focuses on articulating plausible future trajectories of the field by identifying the pertinent trends. Emerging issues analysis contains three steps, issue framing, exploration and evaluation. The resultant analysis allows for a broad range of data to be sorted into categories and analysed in terms of options for commercialisation, possible impact and technical risk. It also enables determination of essential developmental requirements, whether they are concomitant technological developments (such as technology development from other scientific fields) or institutional drivers (such as financial support from military or commercial organisations).

For emerging issues analysis, it is essential to appreciate the relative technical maturity of given innovations. Obviously, the more mature and financially viable the technology, the sooner it will be commercialised and available. In addition, the closer a technology is to maturity, the easier it is to attribute functions to it. As such, as Figure 1 shows, near-mature systems are likely to be better defined. In addition, the form of the device and supporting requirements are often well defined. Importantly, the level of certainty for near-mature systems is relatively high, and risk is relatively low. Indeed, the only likely changes to the technology are in terms of adapting it to perform specific functions or operate within specific environments. At the other end of the spectrum is research-based (or laboratory) science where the focus is largely on the discovery of new properties and relationships. In terms of application, there is greater uncertainty and hence risk. However, it also provides an opportunity, as there are genuinely novel approaches to creating functions that may provide a unique capability. Between these lies the timeframe within which environmental scanning is best utilised, the possible transition from applied research to commercial application [9].

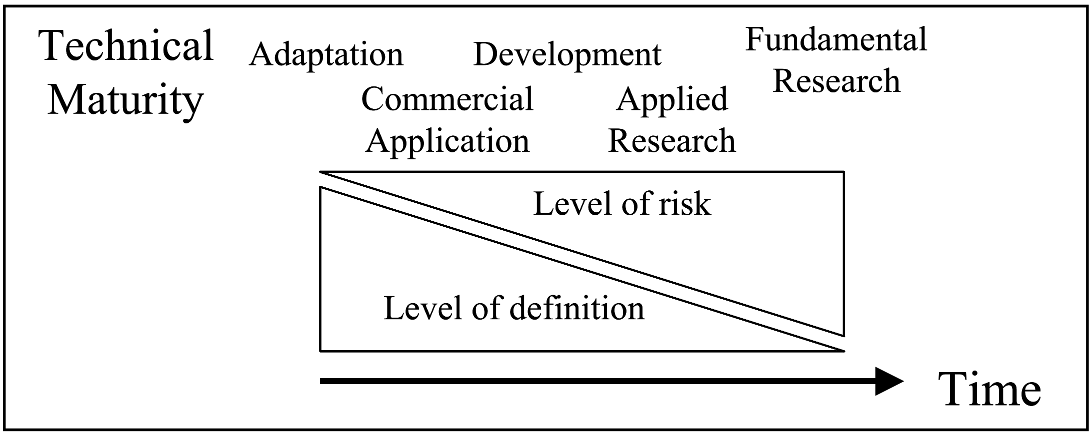

Figure 1: Relationship between time and technical maturity

Previously [3] we attempted to categorise the relative maturity of S&T by dividing it into four distinguishable areas:

- Scientific Concepts: scientific ideas/thoughts and discoveries of specific scientific properties;
- Enabling Technologies: application of (possibly aggregated) scientific concepts with a particular function in mind;
- Technology Concepts: effects-based prototype concepts which integrate features from multiple enabling technologies;
- Commercial Applications: devices that are at or near maturity and ready to be marketed within a short timeframe.

These can be roughly related as indicated in Figure 2, where the thicker lines indicate the typical pathway. We note that, from a technology-driven perspective, the arrows run from left to right (and initially evolve out of the scientific fields). However, it is also possible for some other imperatives, such as a perceived need, to drive development from application to concept (although in such cases one must then move back through concept to applications). In either case, this path provides a basis for assessing the maturity of the technologies being considered.

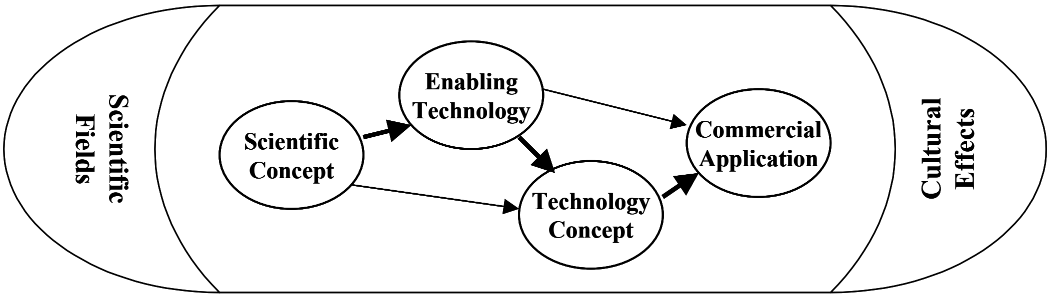

Figure 2: Science and technology evolutionary path

We note, of course, that the evolutionary pathway is book-ended by scientific fields at one end and by the cultural effects at the other. This environmental pull is a response to cultural (e.g. institutional and military) needs and must also be considered. Certainly, balancing these opposing, underlying, technology development pressures, 'technological push' (evolutionary momentum) and 'environmental pull' (decision-based formulation), is essential [16]. Obviously, such a system must be dynamic to be able to cope with ever-changing technologies, modes of warfare and operational contexts, while mediating the relationship between the scientist at one end and the user at the other.

2.4 The *New Scientist* Environmental Scan

We used the recognised international weekly S&T publication *New Scientist* as the source of emerging trends data. This magazine provides an overview of the current activities across the whole spectrum of S&T. Each issue contains approximately 40 technology-related articles that range from single paragraph news items to topic-review papers, and provide comment on the implications of technology and the driving forces (including economic, societal and political) behind such research and development. Importantly, most articles discuss broader ramifications, quote independent 'experts' and often include indicative timeframes for realisation. Generally, these timeframes indicate widespread commercialisation of the technology in the 5 to 15 year timeframe. While we do not claim that a scan based exclusively on *New Scientist* will capture all developments, the nature of the magazine suggests that the areas of technological development are comprehensively covered with all major categories sufficiently covered. Indeed, one futurist recommends using such a magazine as one way of gathering information for futures planning, describing *New Scientist* as a source, stating that "important science news will often appear here first, while it is still navigating its way out of the fringes" [17]. Hence we believe it covers both the ranges of potential applications and the degree of maturity of research and development necessary for our survey.

We scanned approximately two years (100+ issues) of *New Scientist*, from issue 2306 (1 September 2001) to 2414 (27 September 2003), providing 75 articles of direct relevance.[1] These articles ranged in scope from scientific concepts, enabling technologies, actual or prospective applications, and underlying social, political, ethical and environmental issues. The articles collected were those deemed to be relevant within the military paradigm, including direct impact on current military systems (such as use of bio-diesels), novel applications that may allow new way of operating (such as self-charging batteries), or those that will indirectly impact on the Land Force through broader societal changes (such as new forms of nuclear power).

Although not necessarily experts in the field, we must not be uncritical towards the articles, and should be aware of and, where possible, manage the types of biases that could encroach into the articles. These include selection bias where the research scientists or article authors select information that fits preconceived models. Certainly seemingly unrelated but potentially relevant applications may have been missed. Extensive review provides the best means of overcoming such biases as it allows others to critique assessments and/or identify novel applications. In addition, the authors of *New Scientist* tend to provide an optimistic picture of the technology and so may be overstating its capacity. However the range of viewpoints sought along with on-going scanning of developments should allow some sense of realism to be injected.

Additional sources were used in cases where it was seemed useful to extend beyond (or clarify) some of the *New Scientist* material.

2.5 Overview of Emerging Themes

As indicated in Table 1, seven distinct (although not necessarily mutually exclusive) themes emerged from our scan of *New Scientist*. These are:

- Strategic Issues – In investigating alternative fuels and propulsion systems, there are a number of strategic issues which will impact upon national and international policy, such as: strategic fuel supplies, infrastructure, and energy and environmental policies. By and large, these represent the external pressures and 'non-technical' risks associated with the provision of efficient, effective, economic and reliable energy.
- Non-renewable energy sources – This generally focuses on conventional fossil and nuclear fuels and extends to those fuel sources that largely consist of fossil fuels

[1] We have not included articles that focussed directly on issues such as global warming which may indirectly have an impact on these technologies, such as by impacting on government policy or providing some impetus for research. Such articles do not, in our opinion, indicate technology solutions, only current problems.

(e.g. addition of ethanol to petrol) or as a replacement (bio-diesel, liquified natural gas) where there would be little requirement for modification of the system that extracts the energy from the fuel. This field is generally near or at maturity. There is some overlap with renewable sources.

- Renewable sources – Renewable energy is seen as the ultimate source of energy. It is likely to be cheap (once systems are constructed), clean and universally available. The major issue remains whether sufficient energy density can be achieved to meet needs.
- Recycled energy sources – The development and incorporation of energy efficient materials, and the capacity to efficiently transform latent heat energy into a useful energy source, has the potential to influence a large range of applications. In many cases the simplicity of the approach suggests a relatively smooth integration of such systems once some technical (engineering) issues are overcome.
- Novel materials – Material engineering is leading to the development of materials whose properties can enhance system efficiency or fundamentally change how energy is produced. In many ways this area is still maturing, and so there is a great deal of both promise and uncertainty associated with these materials.
- Miniaturised systems – Developments in nanotechnology and biotechnology demand miniature energy sources that are reliable and efficient, and produce a significant energy load. There are many developments along with lines which utilise a combination of novel material properties, efficient electrical and mechanical configurations, and current and emerging energy sources.
- Novel approaches to propulsion – As with altenative fuels, there are a number of novel approaches to propulsion. Some of these focus on improved structures that use energy more efficiently, such as devices which use biologically-inspired properties to move. Alternatives to the standard combustion engines have also been proposed. These generally aim to improve energy efficiency through better conversion of latent energy sources into available energy.

3. Emerging themes in alternative fuels and propulsion systems

3.1 Introduction

As outlined, there are numerous emerging areas of S&T that have the potential to significantly alter the ways in which to operate in the future. These themes are explored in greater depth by detailing articles captured in the environmental scan, and where necessary, supplementing it with further information. However, the intent is to provide an understanding of the potential of technology and the associated implications, not a detailed discussion of the technical aspects. Indeed, as recently pointed out [18], if we were to perform a key word search for 'fuel cells' in databases of conference papers and abstract lists, we would find about 50,000 relevant abstracts.

Table 1: Summary of Environmental Scan

Theme	Categories
Strategic Issues	• Infrastructure issues – infrastructure-related impacts of technologies such as future requirements, potential vulnerabilities and associated government policy • Supply and demand issues – the current and future level of supply and demand, drivers for these and mechanisms for managing these • Environmental issues –such as waste management, safety issues, pollution and environmental damage
Non-renewable sources	• Nuclear – both fission and fusion technology along with opportunities of scale and related safety issues • Liquid fossil fuels – the options for utilisation of current fossil fuels • Natural Gas – the options for transition from other conventional sources and along with environmental issues
Renewable sources	• Geo-thermal – identifying, accessing and utilising heat stored within the Earth's core • Hydrogen-based – developing viable sources for hydrogen fuel, effective storage mechanisms and options for hydrogen-based energy sources such as fuel cells • Solar – options for enhancing current solar cell efficiency and for producing the next generation of non-silicon solar cells • Wind, Wave and Tidal – constructing, locating and utilising wind, wave and tidal forces to create useable energy • Biological and Chemical – using biological and/or chemical approaches to create fuel sources or to directly deliver energy.
Recycled energy sources	• Heat conversion – techniques for converting latent or waste heat into useable energy • Ambient sources – capture of ambient vibrations or other natural motions to use as an energy source • Human-powered – devices to convert human effort efficiently into energy source
Novel Materials	• Advanced surfaces – surface properties that enable movement or enhance energy efficiency • Superconductivity – materials that transmit electrical energy with absolute efficiency • Electromagnetic properties – materials that use particular electromagnetic properties to create or maintain energy
Miniaturised Systems	• Micromotors – power sources for miniature devices • Miniature power supplies – techniques for creating power supplies for use in microscopic and nanoscopic devices
Novel approaches to propulsion	• Spacecraft propulsion – options for sending craft into space and maintaining and operating them once in orbit • Aircraft systems – options for novel approaches to air transport systems • Submersible vehicles – options for novel approaches to surface and subsurface travel • Land vehicles designs – options for novel approaches to land-based systems

Table 2: Summary of articles related to Strategic Issues

Categories	Article Summary	Maturity
Infrastructure Issues	**Vulnerabilities:** Security flaw allowed a computer worm to disable safety systems at a US nuclear power plant [20]	Current and on-going
	Vulnerabilities: Large scale power blackouts in US and Canada largely due to knock-on effect of minor failure upon a distributed power grid running at near capacity [21]	Current and on-going
	Vulnerabilities: UK MOD banned the construction of some off-shore wind turbines because of a fear that they would interfere with military aviation radar [22]	Current and on-going
	Infrastructure Development: Suggestions that British government is considering reviving nuclear power industry using new highly efficient light water fission reactors [23]	Short term
	Infrastructure Development: US, Japan and EU injecting significant resources into developing hydrogen-fuel infrastructure and energy sources, with each are taking significantly different paths. [24]	Medium term
	Infrastructure Development: US President 2003 State of Union address included a strategic shift in energy policy towards development of hydrogen economy, need for infrastructure and with focus on nuclear power to create hydrogen fuel [25]	Medium term
	Strategic Research: Continuing problems in creating a viable commercial-scale nuclear fusion reactor has led many countries to question their commitment to research in this area [26]	Current and on-going
Supply and Demand Issues	**Demand Management:** It has been suggested that without significant changes in energy usage patterns, energy demands will increase by 200% by 2050. However, this would deplete all fossil and nuclear fuel reserves [27]	Medium term
	Demand Management: Tokyo has commenced 'energy forecasts' in order to encourage lower power use in times of high electricity use [28]	Current and on-going
	Supply levels: Nuclear power currently supplies 16% of the world's electricity, having trebled over the last two decades. Nuclear fuel's energy density is nearly one million time that of coal [29]	Current and on-going
	Supply levels: Suggestion that heavy oil, an alternative to typical liquid fuels, is readily available in Canada and Venezuela, and may prove to be a reliable short-term alternative to falling crude oil supplies if issues of efficient extraction can be overcome [30]	Short term
	Supply/ Demand Projections: Growing belief that demand for crude oil expected to outstrip supply in a matter of years, creating significant price spikes and economic impacts unless appropriately addressed [31]	Short to medium term
Environmental Issues	**Waste management:** Issues of waste management for nuclear power may be overcome through transmutation of radioactive waste [32]	Medium term
	Pollution: The perceived greenhouse gas benefits of diesel fuel over petrol may be outweighed by the impact of soot from diesel causing heat to be retained within atmosphere [33]	Current and on-going

3.2 Strategic Issues

In his January 2003 State of the Union address, US President George W. Bush outlined what has been considered a fundamental shift in US energy policy. He announced that "Tonight I'm proposing $1.2 billion in research funding so that America can lead the world in developing clean, hydrogen-powered automobiles. A single chemical reaction between hydrogen and oxygen generates energy, which can be used to power a car – producing only water, not exhaust fumes. With a new national commitment, our scientists and engineers will overcome obstacles to taking these cars from laboratory to showroom, so that the first car driven by a child born today could be powered by hydrogen, and pollution-free" [19]. In this statement, the US President outlined a strategic vision for future fuels and propulsion systems. He also noted that there exist a number of issues beyond those associated with research and development.

This policy has significant implications in an environment of diminishing petroleum availability and increasing demand, with increasing pressure to reduce greenhouse emissions, and highlights the type of strategic issues that may have significant impacts in the years to come. As shown in Table 2, three broad types of issues emerge:

- Infrastructure – ranging from strategic research to infrastructure development and possible associated vulnerabilities;
- Supply and demand - comprising of remaining supplies of (mainly fossil) fuels, energy management issues and the implications for future demand; and
- Environment – focussing on technology issues associated with waste management and and pollution.[2]

3.2.1 Infrastructure development for production of hydrogen fuel

While the fundamental shift in US Energy Policy identified in the State of the Union address placed a particular emphasis on the development of viable hydrogen power systems, it was framed within an environment of decreasing oil reserves coupled with increasing demand, and the fact that the majority of crude oil stocks lies in the Middle East. Indeed, the US DOE predicts that the US output will peak in 2007, but will reduce by 0.4% between 2000 to 2025 [34]; it expects demand to rise at an average of about 2% per annum during that period [35]. So while the US currently imports only 14% [19]of its oil from the Middle East, this is likely to increase significantly in that time. This limits the long-term US capacity for energy self-sufficiency.

Others are likely to be even more affected, with Europe (30%) and Japan (75%) already significant consumers of Middle Eastern oil [19]. As such, all three appear to agree on the need to develop alternative power through such fuels as hydrogen. However, they are taking quite disparate approaches [24].

USA: The majority of the 5-year energy funding associated with the January 2003 State of the Union address, is designated for an initiative dubbed 'FreedomFUEL'. The focus of 'FreedomFUEL' is the development of a national infrastructure for producing and delivering hydrogen fuel. The aim is to phase out the need for petroleum fuel, and hence reliance on other states to provide this. However the capacity to produce sufficient hydrogen will be a major challenge, with the US policymakers believing that

[2] We have not included environmental policies such as the Kyoto Protocol and issues such as global warming as these were seen only as potential drivers for strategic issues and technologies.

most alternative energy sources (such as solar, natural-gas, hydroelectric) will be unable to meet the demands [19, 25]. They suggest that the only alternative is nuclear and that “FreedomCAR and FreedomFUEL cannot be had without FreedomNUKES” [19].

The first version of an energy bill that resulted from the State of the Union address assigned around 80% of funds from the US$20+ billion[3] bill to be spent within the nuclear sector. While Congress rejected this, it emphasizes the nuclear energy is central to US efforts for creating the hydrogen society [25]. The philosophy underpinning this is that nuclear power is the only viable way to create the amount of hydrogen necessary to support such a policy [19, 25]. With the Kyoto Protocol in mind, CO_2 emissions would be very low within such a system. The intention is to support the development and construction of new nuclear plant designs, although there remains some scepticism about whether some of the designs being explored are viable. There also remains the issue of how to effectively dispose of spent nuclear fuel [25].

Europe: is looking to renewable sources. However wind and solar may be problematic due to intermittent availability and the feasibility of storing large amounts of energy. Consequently, hydrogen sources are being pursued. Indeed, the European Commission President, Romano Prodi, recently (June 2003) outlined a plan for Europe to, by 2050, produce all the energy needed to produce hydrogen from renewable sources, and supported it with a commitment of US$2 billion to be spent over the next 5 years [24].

Japan: is looking to have 50,000 hydrogen-powered vehicles on the roads by 2010 and 5 million by 2020. The focus of all this is fuel cells. While cars make an obvious case for fuel cell, it is believed that initial market penetration will come through small fuel cells such as those to power laptops. In these cases, fuel cells are advantageous as they have a considerably longer lifetime between recharging than conventional battery. Another possible application is the 'premium power' market — those services where uninterrupted power supply is crucial. Indeed, one US bank is using fuel cell technology to power its credit card transaction system [24].

UK: The British Government is taking the middle road. On the one hand, it is considering reviving the nuclear power industry and is currently looking to some new, highly efficient light water fission reactors [23]. On the other hand, it has set a target of 20% electricity generation from renewable sources by 2020 [36].

Issues for Australia: Two issues are important from the Australian perspective. Hydrogen powered fuel cells are likely to be the next generation of vehicle power and are likely to be widely available within 20-25 years. Therefore we have to be able to effectively

[3] Note that this is more than 10 times more funding than the US President stated in his 2003 State of the Union speech.

integrate this technology within our own infrastructure and develop policy accordingly.

The second issue is not so clear-cut. Australia needs to decide which road to take for development and production of hydrogen fuel — the European approach of sourcing fuel from renewable sources or the US approach of using nuclear energy to produce commercial quantities of hydrogen. Alternatively Australia could choose to become a net importer of hydrogen fuel. From the Australian perspective, this poses a significant dilemma. Australia has experience in developing renewable sources. However, if these prove to be insufficient to create a commercially viable hydrogen economy, as some suggest, Australia would have to pursue the nuclear option if it intended to be self-sufficient. Up until now, Australia has not been involved in the nuclear energy industry and any change in that direction would raise issues of public acceptance. As hydrogen fuels develop, Australia will have to either change that philosophy or find alternative means for producing hydrogen fuel.

Much of this is long-term planning, focussing out to beyond 2020. In the short term, however, most countries' energy policy strategies for oil usage (especially for vehicles) are a combination of low-sulphur diesel, ethanol-blending or natural gas with an eye on potential renewable sources such as fuel cells and hybrid vehicles [37].

3.2.2 Infrastructure to support mass-transit systems

Creating a viable industry for hydrogen production is only one part of any solution. It is also necessary to provide sufficient infrastructure to support any mass-transit system that utilizes alternatives to traditional fuels. This, in itself, will impact significantly on the rate at which society changes to these alternatives [19]. However, there are some plans on how such infrastructure could be built up and the transitions involved [38].

3.2.3 Infrastructure Vulnerabilities

Of course, the development of infrastructure to support future technologies is not the only concern. We must also maintain the capacity to support the current one. As indicated below, recent events indicate the vulnerability of failing to sufficiently resource the infrastructure necessary to provide reliable, effective, efficient and economic energy.

Dangers of Internet connectivity: It has been revealed recently that a nuclear power station was endangered when a computer worm disabled a key safety system. Fortunately, the system was offline at the time but this had the potential to create significant problems. It indicates the vulnerability of integrated power systems (regardless of the type of power system) and stresses the need for comprehensive risk management strategies [20].

Failure of infrastructure maintenance: The August 2003 blackouts in North Eastern US and South Eastern Canada highlights how a distributed electricity supply system can become vulnerable, especially if policies such as industry deregulation lead to degradation in the infrastructure either through a failure to maintain the system or by using practices which that infrastructure was not designed for (and so cannot always) support.

The blackout incident was due to a failure in a 345-kilovolt line in Ohio. This caused a cascade effect as the diversion of electricity to other already near capacity power lines caused them to fail, further overloading the system. The electricity distribution infrastructure was designed when electricity was produced and delivered locally. However, industry deregulation led to electricity being sourced from greater distances, stretching the system's capacity to maintain electricity flow. To prevent this kind of problem, either power needs to be derived locally or somewhere between US$50-100 billion needs to be spent on infrastructure [21]. Australia may face this problem as the power is transported greater distances on a system designed to send smaller loads over shorter distances.

Of course, strategies for effective use of electricity will overcome this. Simple ideas such as switches in household meter boxes which turn off water and household heating for short periods of time during peak demand is but one approach. On a larger-scale, an 'electric power forecast' service to encourage people to reduce electricity usage, especially in hot weather, has been developed for Tokyo. Tokyo has particular problems resulting from the shutting down of 17 aging nuclear reactors due to safety issues. The forecast is based on the assumption that a one-degree rise in temperature causes an increase of 1.7 million kilowatts in electricity demand [28].

Unexpected side effects: UK MOD banned the construction of five offshore wind turbines for fear they would interfere with military aviation radar. However, some saw this as an over-reaction as the radar shadow is thought to be 100 m high and for a distance of 500-700 m behind the turbine [22]. This indicates that even renewable sources are not immune to such unexpected side effects when implemented, especially if the consequences are seen to have a negative environmental outcome, such as habitat changes or animal deaths.

3.2.4 Supply and Demand Issues

There is an emerging consensus that, within the next few years, demand for oil will outstrip supply for the first time. Indeed, some experts suggest that oil production has already peaked and is on the wane. Even the best-case scenario in a recent review of oil supply suggests that oil production will peak within 20 years [31]. According to this optimistic outlook, by 2030 production levels will be a little over half the current ones. However, there is some uncertainty, as attested by earlier US DOE reports that forecast peak global oil production in 2037 [37, 39]. Recent DOE reports continue to use this latter date [35]. However, they are based on the recent inclusion of heavy oil as a form of petroleum oil. Some challenge this inclusion, raising questions about the commercial viability of heavy oil as an energy source [30].

One reason for this uncertainty is the level of pessimism regarding the discovery of new oil reserves. While in the past the expectation was that untapped reserves would be discovered, it is now believed that all major oil deposits have been discovered. Indeed, the amount of oil discovery on a decade-by-decade basis has decreased by a factor of 4 from the 50s to the 90s, while the vast majority of reserves (64.5%) are to be found in the Middle East [31]. One consequence is that as the demand for conventional fossil fuel grows, market forces may cause substantial increases in fuel prices during the next 20 to 30 years. Some suggest that unless other forms of energy become viable, the best-case scenario would be global recession and worst-case could be war, famine and mass-migration [31].

The new approaches to energy supply generally take two forms, renewable and nuclear. Certainly in defining the UK Energy policy for the next 50 years, the British Government has indicated that the combination of nuclear power and renewable sources is their preferred strategy. The British government has set renewable energy electricity production targets of 10% and 20% for 2010 and 2020 respectively; uncertainty and flexibility means that they are looking to maintain a broad mix of energy sources. Given that nuclear power currently provides over 23% of British electricity, it appears that such a combination might provide the majority of electricity in Britain by 2020 [36], with hydrogen power, natural gas and low sulphur diesel supporting vehicle transportation [37]. However, some have questioned the adequacy of this [27].

The global demand for energy is projected to increase by 200% by 2050. This has led a number of influential energy analysts to suggest that the identification and development of truly revolutionary energy generation technologies are essential if future power needs are to be met and/or if there is a desire to reduce the environmental CO_2 concentration to a manageable level. They note that currently 85% of the 12 trillion watts of power provided globally on an annual basis is derived from fossil fuels. To stabilize the environment, the 2 trillion watts currently produced from CO_2-emission free sources needs to be increased to 30 trillion per year by 2050. Nuclear power may not be the answer as some say there are only sufficient nuclear fuel reserves to produce 10 trillion watts per year for between 6 to 30 years. However, if breeder reactor technology becomes viable, nuclear power may partially meet the projected power requirements. In addition, renewable sources such as biomass, wind and solar power may not be sufficient as about 10% of the Earth's surface is required in order to meet the 2050 energy demands [27].

3.2.5 Environmental Issues

Another set of strategic issues relates to waste and pollution problems associated with fuel usage and production. Cleaner fuels (such as low-sulphur or bio-diesels [37]) are an obvious option to reduce pollution emission levels, as are engines which more efficiently burn fuel or convert heat into usable energy. Even in these cases, the results are not necessarily as clear-cut as first thought. For instance, research suggests that the soot from diesel may be more damaging to the atmosphere than petrol, which is at odds with conventional wisdom. While diesel produces 6% less CO_2 per kilometre than petrol, diesel engines emit between 25 and 400 times the amount of soot compared to petrol ones. This is crucial since, gram for gram, soot produces 360,000 to 840,000 the level of global warming compared to CO_2. So, while CO_2 persists in the atmosphere considerably longer than soot, the latter has a greater short-term impact. Even 'green diesels', designed to produce 30% less soot than normal ones, are more damaging to the atmosphere in the short term [33].

Nuclear waste is also problematic in that it creates long-term storage and safety issues. However, developments in nuclear physics research may be able to address this problem. Recent developments in nuclear physics indicate that it may be possible to artificially transmute radioactive waste into less dangerous materials. The process is based on using high-powered lasers to knock protons or neutrons out of a nucleus. Indeed, the researchers have already converted ^{129}Iodine (half-life in the order of millions of years) into ^{128}Iodine, which decays within minutes. Currently, the power necessary is extremely high. However, future refinement might make this a viable technology [32].

3.3 Non-renewable energy sources

Non-renewable energy sources fall into four categories, nuclear, liquid fossil, solid fossil and natural gas. Interestingly, as Table 3 indicates, there were no reports of technological developments for solid fossil fuels. This is not a surprise since these fuels have been in widespread commercial use for more than a century, so future technology development is likely to be minimal.

Table 3: Environmental scan of non-renewable fuel sources

Categories	Article Summary	Maturity
Nuclear power	**Nuclear Fusion:** Efforts to control nuclear fusion reactions so that energy delivered exceeds energy supplied continues to be beset with technical problems that are unlikely to be overcome in the short to medium term [26]	Emerging Technology
	Transmutation: Laser-induced approach to decreasing the long-term radioactive danger of nuclear material has been prototyped [32]	Technology Concept
Liquid Fossil fuels	**Oil extraction**: Investigations suggest that bacteria could be used to increase the amount of oil extracted from wells (typically 30-40%) because bacteria can plug cracks allowing water to then be pumped into the well causing more oil to come to the surface [40]	Emerging Technology
	Artificial Fuel Creation: Researchers have created some fossil fuels by bubbling carbon dioxide through hydrochloric acid, although the technique has not yet been extended to petrol and diesel [41]	Technology Concept
	Heavy Oil: The extraction of heavy oil may provide an alternative to crude oil although current extraction processes mean current extraction levels are relatively low [30]	Commercial Application
Natural Gas	**Power conversion systems**: Combined power and heat systems which use natural gas to heat houses and convert waste heat into electricity, thus reducing energy consumption by up to 35% are on the market [42]	Commercial Application

3.3.1 Nuclear fuel energy systems

Some believe nuclear power is the only viable option for future energy needs [19]. Certainly it has some significant advantages over conventional fossil fuels. For instance, six grams of nuclear fuel yields the same amount of energy as one ton of coal. Reactions in nuclear power plants are based on nuclear fission – normally the breaking up of ^{235}Uranium with a release of energy which is converted into electricity in much the same way as convention coal-powered systems [29].

Since the first nuclear power plant commenced operations in 1956 (Calder Hall in England), a total of 30 countries have come to rely on it as a source of power [29]. Worldwide there are 400 operational nuclear power stations, which generate 16% of electricity worldwide (2% of total energy produced). The use of nuclear power is expanding with a trebling of energy produced between 1980 and 2000. Within Asia and Oceania (excluding former Soviet Union), the level of energy generated in this way has increased five-fold in that time. By way of comparison with other energy sources, in 2000, nuclear energy provided the UK with 12 gigawatts of electricity. This represented 25% of the total electricity produced and over 6 times that provided by renewable sources [36].

In recent years, however, the focus has shifted from further development of nuclear power systems (at least in the developed world) [34]. As modern combined-cycle gas-fired power stations have proved to be more efficient and cheaper to operate than traditional nuclear power plants, no new nuclear power plants have been built since 1995. In addition, waste management remains an issue, with current projections indicating that the global level of radioactive heavy metal waste will double within twenty years [29]. There is also some suggestion that there are insufficient reserves of fissile material to meet energy demands out to 2050 [27]. Such an estimation is quite pessimistic as it assumes no significant improvements to nuclear fusion systems and that demand will increase at a constant rate.

One long held view has been that nuclear fusion could supplant nuclear fission for nuclear energy production. Nuclear fusion power is the fusion of hydrogen isotopes (such as deuterium or tritium) together at high temperatures and pressures, releasing large amounts of energy. It offers significant benefits in that the energy density of such reactions is high, reactions can be more easily controlled than in nuclear fission reactors, and it produces almost no significant radioactive waste. However, the technical problems of creating a viable commercial-scale nuclear fusion reaction continue and seem, to some, to be insurmountable. The ability to create a commercially viable system for achieving and sustaining the temperatures and densities necessary continues to elude researchers [26]. Indeed, within the scientific community, there is a joke: "Limitless fusion power is just 40 years away - and always will be" [26]. This changing view can be seen in the most recent George Washington University Futures Forecast (from 2000) [43], which predicts that if nuclear fusion technology becomes commercially viable, it is most likely to occur by 2032. However, their confidence for this is occurring is only 29%. Their forecast three years earlier put these numbers at 2026 and 50% [9].

Fundamentally, the problems seems to be the model on which the fusion ideal is based, namely the Sun. In the sun the power density is about 1 watt per cubic metre, insufficient for commercial production. While there are possibilities for creating a greater power density, such reactions operate at temperatures of about 100 million°C. This condition creates numerous technical challenges. Even if these are overcome, the viability remains uncertain. This, along with the high cost of research, has led to the US leaving the major international fusion power project in 1998 [26]. Indeed, a recent British Government policy review ('Policy Review of Fusion') suggests that, based on current understanding, commercialisation of nuclear fusion would be expensive and unlikely to work [23].

While there are some new suggestions for making fusion viable, it remains to be seen whether these will amount to any substantial progress in the next few decades [26]. Certainly, after 50 years of research, engineers have failed to even come close to delivering a commercially viable fusion power station. This has led to a more recent focus on new approaches to nuclear fission reactors, with fission-based techniques being refined [19] and approaches to overcoming nuclear waste are being developed [32]. However, these are still in the develoment phase.

3.3.2 Liquid Fossil fuels

As noted, current predictions suggest that the availability of conventional liquid fossil fuels will become increasingly limited. However, there are options for either extending the lifetime of conventional fuel supplies or even ‘creating’ fuels. One option is simply blending substances such as ethanol to conventional fuels [37]. This will certainly extend the lifetime by a short amount although there are some queries as to whether such fuels damage vehicle engines and produce greenhouse gases and other airborne pollutants at similar rates to conventional liquid fuels.

Some have suggested that ‘heavy oil’ (comprising excessively long hydrocarbon chains) might have the potential to replace conventional crude oil. Certainly there are large reserves in countries such as Canada (which holds the second largest global oil reserves when heavy oil is included [34]). However, there are some problems creating conventional fuel from heavy oil, as it requires a great deal of processing and energy to extract and convert the heavy oil into a useable form. It appears that the amount of energy that can be liberated from heavy oil is less than the energy required to extract the oil itself (using current technology) [30].

Of course, one option is to extract more oil from each well, as typically only a third of oil in an oilfield can be extracted. Part of this process entails pumping water into the well to force more oil out. However cracks in rocks allow the water to gradually seep away, lowering well pressure. Some microbiologists suggest that certain types of bacteria have the capacity to clump together to form biofilm that block these cracks, allowing the water level to increase thus allowing extra oil to be extracted [40].

Another option is to create your own fuel. Researchers claim to have produced heavy hydrocarbon simply by bubbling waste CO_2 gas through hydrochloric acid at high temperature and pressure. Although currently petrol cannot be made, refinement of the technique may allow this. Scavenging discharged CO_2 in such a way could reduce the amount of CO_2 discharged into the atmospheric [41]. The technique is yet to be proven but provides another opportunity for more efficient and more environmentally friendly conventional fuels.

Alternatively, one could synthetically produce liquid fossil fuels from other types of fossil fuels. For instance, natural gas and solid fossil fuel (e.g. coal) can be converted into synthetic diesels through the Fischer-Tropsch process [37]. This has the advantage of having greater energy density and lower sulphur content than diesels extracted from crude oil.

3.3.3 Natural Gas

Compressed natural gas is being investigated as a serious option for replacing or supplementing fossil fuels for vehicles in the medium term. Many countries are developing policies to encourage its use [37]. Given the short timeframes for the commercial implementation of this technology, it may prove to be a temporary measure as society transitions from using fossil fuels to other options currently under development, as the technical expertise and infrastructure should be able to be adapted relatively easily.

Of course natural gas can also be used to heat and/or create electricity. One such example is Combined Heat and Power (CHP) units. These can burn natural gas to create both heat and electricity for their house, cutting fuel consumption by up to 35%, as the CHP converts waste heat into electricity. Such units have already been used for larger entities such as schools. However household-scale CHP units are not currently available as they are not large enough to safely reach the temperature necessary to achieve a sufficient level of efficiency (1200^{o}C). However, novel materials and production processes make this possible. Extensive prototyping is occurring and commercial production and sales have commenced [42]. This technology may provide a simple way to produce considerable amounts of electricity in-theatre to meet operational requirements.

3.4 Renewable energy sources

Some see renewable energy sources as the only viable option for a sustainable future, given diminishing conventional fuel supplies coupled with increasing demands, environmental impact of burning conventional fuels, and current and long-term risk from nuclear sources. Given their accessibility, renewable sources are seen by some as empowering poorer nations, as they should be able to become largely energy self-sufficient. It is noteworthy that articles associated with renewable sources are the most prevalent within our environmental scan (Table 4). These fall into five distinct areas:

Table 4: Renewable energy environmental scan overview

Categories	Article Summary	Maturity
Geo-thermal power	**Hot rock technology:** Australia [44] and Germany [45] are prototyping geo-thermal heat-exchangers to produce high pressure steam energy to power turbines	Technology Concept
Hydrogen-based power	**Storage:** Development of an approach to the safely store hydrogen fuel at low-pressures, which is necessary for next generation of vehicles [46]	Scientific Concept
	Storage: Containing hydrogen within water molecules using pressure and titanium dioxide is being developed as a feasible fuel storage mechanism [47]	Enabling Technology
	Hydrogen production: US government focussing on using nuclear energy as mechanism for converting water into hydrogen for fuel [25]	Enabling Technology
	Hydrogen Production: Proposal to use solar energy to power space-based lasers that create hydrogen from water [48]	Enabling Technology
	Methanol fuel cell: Methanol-based fuel cells are being developed as a replacement for common (lithium) type batteries [49]	Commercial Applications
	Micro-fuel cells: Commercial sales in man-portable hydrogen and ethanol-based fuels cells have commenced [50]	Commercial Applications
Wind and tidal power	**Tidal turbines:** British companies are developing large-scale tidal power turbine prototypes which work with relatively low currents [51]	Technology Concept
	Wind turbines: 'Stealth' turbines blades that cause radar waves to destructively interfere are under development [52] and should overcome military concerns about wind turbine interference on military aviation [22]	Enabling Technology
	Wave turbines: Four power generators which convert wave energy into electricity are undergoing off-shore testing with the view to developing an effective means of commercialising wave power [53]	Technology Concept
	Tidal turbines: Development of large-scale tidal power which uses hydrofoils to affix the structure to the seabed [54]	Technology Concept
Solar Power	**Cell design and production:** New production and design techniques promise considerably cheaper, more efficient silicon-based solar cells [55]	Technology Concept
	Cell design and production: Failure of BP Solar thin-film solar cell design is likely to increase cost of traditional cells as demand for silicon outweighs supply [56]	Commercial Applications
	Conversion efficiency: Special crystals developed that tune electromagnetic radiation to optimise the conversion of light into energy within solar cells [57]	Scientific Concept
	Conversion efficiency: High purity Indium-gallium-nitride based solar cells will be two to three times as efficient as silicon-based solar cells [58]	Enabling Technology
	Application: In long distance trials, typical average speed for specially designed solar cars is 60 km/hr with peak speeds about 100 km/hr [59]	Commercial Applications
	Applications: Flexible solar cells may support a range of alternative uses to that of traditional rigid solar cells, such cells embedded within clothes [60]	Technology Concept
	Application: Proposal for using satellites to collect and transmit energy to earth via laser specifically to create hydrogen from water [48]	Enabling Technology
	Application: Integration of solar cells within materials such as cladding for houses will prove to be a cost-effective way of accessing solar power [61]	Technology Concept
Biological and Chemical processes	**Natural Oils:** Tests have shown that jojoba oil mixed with small amounts of methanol is a viable diesel-like source of fuel [62]	Technology Concept
	Bacterial: Bacteria within an African lake bed have produced significant amounts of methane that could meet long-term fuel needs [63]	Technology Concept
	Bacterial: Biologically-inspired fuels cells that use bacteria to convert waste products[64] or sugars [65] into energy are under development	Enabling Technology
	Waste products: British attempts to create a viable biomass industry seem to have foundered, due largely to the failure of unproven techniques to meet expectations [66]	Commercial Applications
	Cold Fusion: While the broad scientific consensus is that cold fusion is not a real effect, some are still pursuing it due to a few, as yet unexplained, anomalous results [67]	Scientific Concept

- Geo-thermal – obtaining energy by effectively converting the Earth's subterranean heat into (usually) high-pressure steam
- Hydrogen-based power[4] – using the reaction between hydrogen and oxygen to produce electricity (with water and heat as the only by-products)
- Wind, wave and tidal power – harnessing the energy of meteorological conditions
- Solar power – transforming electromagnetic radiation from the Sun into useable energy
- Biological and chemical process – utilising specific biological and/or chemical properties to manage or create energy[5]

3.4.1 Geo-thermal power

Geo-thermal efforts focus on obtaining energy by converting the Earth's sub terrain heat into (usually) high-pressure steam and running turbines. Efforts are underway in both Australia [44] and Germany [45] to use a form of deep geo-thermal heat-exchanger technology ('hot rock' technology) to create useable energy. The idea is to drill pairs of connected bores into the earth, inject water into one hole and harvest high pressure steam from the other. The steam is then used to power a turbine and create electricity. This technique is thought to be superior to other typical geo-thermal techniques as it is self-contained and does not need to be in areas of geo-thermal activity.

These techniques have some potential especially if combined with applications that efficiently convert heat into electricity and this will expand its capability and the efficiency of the process. If proven feasible, such techniques could be expanded to areas such as the great Artesian Basin, going some way to meeting future electricity production requirements. However, drilling such boreholes may be expensive. Even so, the relative maturity of the associated research and development should provide some indication of the viability of 'hot rock' technologies within the next few years.

3.4.2 Hydrogen power

Hydrogen fuels and fuel cells focus on the replacement of traditional fuel sources (such as coal and petroleum) with hydrogen-based systems. This field has gained some recent impetus from various governments and is seen by many as the best alternative to traditional fossil fuel sources [19, 24, 25]. Hydrogen-based fuel cells have existed since 1839 [68]). However it has only through technological advances in the last decade that efficient fuel cells that run at usable temperatures can be produced at commercial levels.

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[4] It is uncertain whether hydrogen-based power will actually be renewable. This will depend on the energy source used to produce the hydrogen. It has been included in this section as it is probable that, within the foreseeable future at least, if Australia were to commercially produce hydrogen, it would come from renewable sources such as solar, wind and tidal energy, rather than nuclear sources.

[5] One might correctly assert that hydrogen energy sources should be included within this category. However, given it is a particular focus, we felt it more instructive to separate it out into its own category.

Current research is focussed on finding the most appropriate type of fuel cell for particular uses [69], hydrogen production and storage [70], designing fuel-cell powered vehicles [37, 38, 71] or looking to other types of usage (such as in place of standard batteries [71, 72]. Hence there are some development and infrastructure issues that need to be addressed, especially those related to the production and storage of hydrogen, and the mass production of efficient fuel cells.

Hydrogen-powered vehicles[6]: Integrating fuel cells into vehicles is close to maturity [38, 71], with such cells already being prototyped in common transit vehicles such as taxis [72], although in some cases fuels such as ethanol are also used [49]. The result is a different type of motor that is longer lasting, lighter, quieter and more efficient than current ones. For instance, it has been suggested that helicopter power plants would be half the size and use 40% less fuel than currently [73]. For land vehicles, there are suggestions that expeditions in the range of 1000s of kilometre could be viable with systems that are 20-50% lighter than currently used [74]. It may also be environmentally friendly, depending on how the hydrogen fuel is produced.

Micro-Fuel Cell: Portable fuel cells have started to be sold commercially. The current options run on either hydrogen or ethanol, producing mainly water as waste. They are lightweight and largely silent, giving them a number of practical applications [50]. The major limiting factor at present is that fuel cells need to be replaced every few hours and replacement cartridges are very expensive. Even so, as demand increases and new models appear, price and lifetime are likely to be significantly improved.

Researchers are developing a micro-fuel cell based on extracting hydrogen from methanol. However, this is most efficient at temperatures of the order of 250°C, which is not ideal for mobile devices as insulation and heat dissipation become a problem. Recently, direct methanol fuel cells that use a platinum catalyst have been developed to work at room temperatures [49]. These cells will have lifetimes in the order of a month (for a mobile phone) before requiring recharging. It is expected that such fuel cells are about to reach the market.

The implications of embedding such technology are considerable. Certainly it is easy to access or even produce methanol or ethanol in-theatre (at least in the rear area) and source the ingredients locally. As such, self-sufficiency during operations becomes a strong possibility. In addition, longer-life rechargeable micro-batteries will enhance the mobility of troops.

Storage: One major problem with hydrogen fuel is that it is a gas at room temperatures and pressures. Indeed, it is only at temperatures of below –253°C that hydrogen becomes a liquid. In addition, hydrogen is a very reactive gas and must be stored with some caution. Currently, hydrogen fuel cells require storage at 300 times atmospheric

[6] The technology scan did not include any items that directly focussed on fuel cell and engines. However, they implied their usage.

pressure and containers weigh between 7 and 20 times as much as the fuel they hold [46]. However, researchers appear to be coming closer to developing safer, practical storage systems for hydrogen. One approach is to create 'clathrates' (ice molecule traps for hydrogen), which use a combination of pressure and a special titanium dioxide catalyst to allow hydrogen to be trapped inside ice cages of water molecules at a temperature of –24°C [47, 70]. Hydrogen gas can then be stored at near room temperature, and released when the fuel is needed.

Similarly, other oxygen-based crystalline compounds may also perform this function. In this case, cubic, cage-like molecules called metal organic frameworks (currently zinc and oxygen-based metals combined with aromatic molecules) allow hydrogen molecules to be absorbed at room temperature and pressure and require only 20 times atmospheric pressure (about twice that of a cigarette lighter) to release them. While the process is currently not very efficient, it is believed that dramatic improvements are possible with other similar materials [46, 70].

3.4.3 Wind, wave and tidal power

Wind, wave and tidal power focus on harnessing the energy of meteorological conditions. The associated technologies are not novel, however developments in power conversion technology have led to wind, wave and tidal flows becoming viable sources of energy. In addition, increasing commercial interest has meant that costs have come down, and an increasing number of governments and private sector organizations are installing such systems [75], with the British government recently announcing the world's largest expansion of wind power [52].

As part of a separate initiative, the British Government has given a grant to a company to build a 150-kilowatt prototype tidal power station off the coast of Britain. It consists of a pair of 15 metre long mounted hydroplanes that oscillate with the tide, driving a hydraulic motor to generate electricity. Full-scale devices will be 20 metres tall and weigh about 35 tons, working in currents of 4-6 knots. While the prototype will only work for tides moving in one direction, later versions will be able to rotate to maximise energy production. Another company is building a windmill-shape underwater power generator (based on a similar principle) and aimed at producing 300 kilowatts [51]. Estimates are that locating 40 such power generators at key positions along the British coastline can supply up to a quarter of the country's electricity needs. One might suggest that a scaled-down version of this technology may provide a useful means for units operating within the littoral environment and in supporting the development of infrastructure during the post-conflict stages of an operation.

One drawback with tidal systems is the difficulty in fixing them to the ocean floor, especially in deeper water. To overcome this, a new form of tidal power generator is being tested. It consists of two parts: a set of hydrofoils that generate downward force, thus holding the structure onto the ocean floor; and a power-generation turbine (which converts tidal flows into electricity) fixed to the top. The advantage with the design is that it can be lighter and cheaper than alternatives which are fixed by either having a significant weight (in the order to 200 tonnes) or attached to pillars driven into the seabed [54].

Trials are commencing off the Scottish coast to investigate ways of generating power from waves. Four different approaches are to be tested concurrently, ranging from a floating 150 metre snake-like structure that generates energy as the different compartments of the snake bend relative to one another to a buoy that uses wave energy to pump air through tubes, causing a turbine to rotate [53]. The stated aim of these trials is to incorporate the promising characteristics of each system into future options. The operating environment has created major difficulties in the past since the combination of waves, tides and salt water have coupled to break or weaken the equipment. All options have been developed to overcome such problems [53].

The implementation of wind, wave and tidal power technologies are not problem-free. For instance, after the British Government suggested a number of off-shore sites for wind turbines, their Ministry of Defence opposed 34% of all proposed sites due to concerns about the impact of the wind turbines on radar [22]. Indeed it is suggested that such turbines return a signal many thousand times that of a small plane. However, British company Qinetiq is developing 'stealth' turbines blades that are nearly invisible to radar. The basis is the placing of thin layers of both radar absorbing and reflecting material on the turbine blades so that returning radar signals are separated and retransmitted in such a way that they effectively cancel one another out. Hence the overall signal is significantly diminished, without compromising the strength or cost of the turbines [52].

3.4.4 Solar power

Solar power focuses on transforming solar electromagnetic radiation into useable energy. It is probably the most contentious potential source of power in the future in terms of its feasibility. There are those who are adamant that solar cell technology can never be sufficiently efficient or sufficiently cheap to become a significant source of power in the future [19, 24, 25]. Indeed, current solar cells efficiency is about 15% [58] and production costs an order of magnitude more than conventional sources [56].

Others believe solar power to be the major (and only) real alternative to diminishing energy supplies and environmental degradation [24, 61], and point to organizations such as British Petroleum (BP) which are changing business practices to encompass solar power. BP is investing in photovoltaic cell technologies with BP Solar being currently the world's second biggest producer of solar cells [56]. In terms of expense, those in favour of solar power claim that a combination of government support, the development of new types of solar cells, more flexible applications of cells and greater commercialisation should make the production of solar power as cost effective as other sources [61]. However, excluding any environmental costs, solar electricity is currently ten times as expensive to produce as fossil fuels, although this is half what it was a decade earlier, and by 2010 the demand for silicon (a major component of conventional solar cells) is expected to outweigh supply by a factor of three [56].

One approach to increased efficiency is that by placing the positive and negative contacts at the back of the cell, thus leaving greater areas to absorb incoming radiation, efficiency can be increased to between 20% and 33% a significant enhancement upon the 15% efficiency of conventional cells. In addition, such a design will reduce production costs by 95% [55].

Another option is to manipulate the incoming solar radiation so that is it focussed at the wavelengths where solar cells operate most efficiently. Photonic crystals have been developed which provide a way of shifting (and hence tuning) the frequency of beams of electromagnetic radiation. In effect, incoming light trapped within a crystal is Doppler shifted as it interacts with a shock wave that moves through the crystal. This allows for the creation of a crystal that could focus light at particular wavelengths where solar cells operate optimally [57].

To overcome silicon supply being a limiting factor, another option is to develop solar cells based on other materials. For instance, researchers suggest that indium gallium nitride (InGaN) compounds are likely to increase solar cell efficiency up to 50%. This is because the energy band within which the sun is most energetic is where InGaN absorbs energy. Technical issues remain about creating this compound due to the high state of purity necessary for efficient operation in a cost-effective manner [58].

Researchers are also attempting to produce a flexible silicon-based solar cell where current is created by tiny (1 mm) semi-conducting silicon spheres set in a thin flexible aluminium and plastic composite. This provides more flexible options for collecting solar energy than the traditional rigid cell. Also, these solar cell are likely to be approximately 65% more efficient than traditional ones [60]. This opens up the possibility of more imaginative approaches to source solar power, such as having solar cells organic to building materials. For instance in areas such as housing design, photo-voltaic cells could be built into exterior cladding with little additional expense [61].

Possibly the most imaginative suggestion is using satellites to collect solar energy and convert it into laser energy which is then beamed down to earth. Performing this function from space is advantageous, as the Earth's atmosphere prevents the majority of solar energy reaching the Earth's surface. Indeed, researchers claim, "a 10-megawatt satellite could make the equivalent of a litre of petrol for 9 p" [48]. Of course, allowing high-power laser systems in space may not be an acceptable option, both from the security (potential for the weaponisation of space) and safety points of view.

While there are a number of options for developing more efficient and/or cheaper solar cells, a salient point to note is that one such previous option seems to have proved not to be viable. BP Solar has closed down production of thin-film cells, as they could not produce a stable functioning cell, to revert back to 'traditional' crystalline silicon (currently

85% of solar cells) [56]. However, BPSolar has not entirely written off thin-film cells, stating that "while the thin-film technology continues to show promise, lack of present economics does not allow for continued investment" [76]. Other companies are now developing processes to extract silicon from silane (SiH_4), which is likely to be cheaper and easier to do. However, this is likely to take four years, putting some pressure (in the short-term) on silicon-based solar energy [56].

The other issue worth noting is whether sourcing solar energy will become viable beyond that from static installations. For instance, typical speeds for specially designed (and largely impractical) solar cars in long distance trials average around 60 km/hr and peak at around 100 km/hr [59]. This suggests that devices such as solar cars are likely to be impractical for some time to come.

3.4.5 Biological and Chemical processes

One alternative to conventional fuels is to synthesise hydrocarbon-based products utilising specific biological and/or chemical properties to manage or create energy.[7]As a recent DSTO report pointed out [37], there are many options for this for conventional vehicle engines, such as vegetable oil, animal fat, biodiesel and ethanol, used either on their own, or in conjunction with other fuels.

Flora and fauna sources: Jojoba oil has recently joined other natural oil sources, such as vegetable oil and sunflower oil, as a viable source of fuel. Tests have indicated that jojoba-fuelled engines emit fewer pollutants, run more quietly and for longer than diesel fuel, when jojoba oil is combined with a small amount of methanol and an appropriate catalyst. In addition, when burnt, jojoba releases a large amount of energy by weight, and is chemically stable at typical engine temperatures and pressures. It also has a higher flashpoint than diesel meaning it is safer to store and transport. Given jojoba plants live for approximately 150 years in warm climates, it is a feasible alternative to conventional fuels in poorer nations [62].

Bacteria sources: Another biological option is to utilise bacteria to convert fuel sources (such as sugars) into energy. For instance, a recently discovered bacterium (*Rhodoferax ferrireducens*), efficiently converts sugars (in particular xylose, a waste product from paper manufacturing) into electricity, although the energy output is currently limited by an inability to get the bacterium to pack tightly enough on electrodes [65]. Even so, microbial (or bacteria driven) batteries are being developed. An inexpensive sugar-fuelled version has been used to power a robot, and about 50 g of sugar can power a 40-volt battery for eight hours [64]. This may prove to be a very simple way of producing power in unusual environments (so long as some form of natural sugar is present).

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[7] One might correctly assert that hydrogen energy sources should be included within this category. However, given it is a particular focus, we felt it more instructive to separate it out into its own category.

Production of methane is another option for bacteria-driven energy sources. For example, Lake Kivu on the Rwanda-Congo border has such a large amounts of methane absorbed within its water that it is believed that it could meet Rwanda's fuel needs for 400 years. This methane has built up over time, being the by-product of bacteria that reside on the lakebed. Efforts are now underway to access it, both to provide power and to alleviate the risk of a massive gas explosion [63].

Biomass: Britain's attempts to use energy produced by burning biomass (trees, plants, organic waste) have floundered. Initially the UK intended that by 2010 10% of British electricity would come from renewable sources, half of which would be biomass. However, biomass currently contributes less than 1%. Similiarly the US gains only 1.6% of electricity from biomass, but it is 20% in Finland and 15% in Sweden. The problems were due to using two unproven techniques that proved to be inefficient, and led to biomass companies failing. The UK government has stated it is keen to pursue biomass, although probably through a lower-tech (less efficient) process [66].

Cold Fusion: While the idea of cold fusion (room temperature fusion due to chemical reactions between palladium electrode and deuterium in heavy water) was largely debunked after it was proposed in 1989, some researchers at the US Office of Naval Research have found some anomalous results, such as repeated unexplained (in conventional terms) rises in heat within the 'cold fusion' experiments. However, the broader community is largely unconvinced and the work is not being pursued further within the US, although some research continues in Japan [67]. Cold fusion remains an enigma. While the majority of the scientific community believes it is a fiction, some are still continuing to research. However, within the next 4-5 years the remaining anomalies should be clarified. If cold fusion proves to be a true effect that can be commercialised, the unprecedented access to large amounts of energy at negligible cost is likely to provide the impetus for fundamental changes in how systems are designed, developed and employed. However, current evidence suggests that this appears to be extremely unlikely.

3.5 Recycled energy sources

One approach to alternatives for powering systems is to look at ways of improving the efficiency of converting a latent energy source into useable energy. Recycling energy provides an opportunity to do this and there is some interest in this, with the focus being more than the engineering issues associated with improving the efficiency of engines. As Table 5 indicates, there is a great deal of research and development focussed on converting latent energy or excess heat into electricity, especially for smaller-scale energy sources. In addition, options for efficient and convenient conversion of physical effort into energy are becoming readily available, thus providing a mechanism for small-scale sustainable electrical devices.

Table 5: Recycled energy sources from environmental scan

Categories	Article Summary	Maturity
Heat Conversion	**Heat to electricity converter:** A small scale power system that converts excess cooking heat into electricity is now available on the market [77]	Commercial Applications
	Heat to electricity converter: A device based on piezoelectric[8] components such that it functions without moving mechanical parts has been developed to convert heat into electricity [78]	Technology Concept
	Heat to electricity converter: A device has been developed which uses heat rather than light to create electricity by directing heat created by infrared radiation to a filament which emits only a specific wavelength designed to correspond with that of silicon solar cells [79]	Technology Concept
	Heat to electricity converter: Researchers have derived a process by which heat from gas, created from combusted fuel and found within vehicle afterburners, is converted into electricity [80]	Enabling Technology
	Heat to electricity converter: US Defense is supporting research into the development of a microchip which harnesses excess heat (from engines, computers, etc.) and converts it into electricity for powering electronic appliances and batteries [81]	Enabling Technology
Ambient sources	**Electricity 'hot spots':** Proposal for the use power 'hot spots' embedded within roads to maintain charge in electric bus engines simply by having the bus pass over them [82]	Enabling Technology
	Ambient light-powered laser: Doppler shifting of incoming light trapped within a crystal allows the light to be focussed at particular wavelengths thus allowing lasers to be created from any incoherent beam of light [57]	Enabling Technology
	Natural Vibrations: Suggestions that energy can be harvested from everyday vibrations (such as moving vehicles) using piezoelectric devices tuned to the particular frequencies [83]	Scientific Concept
Human powered sources	**Wind up devices:** The development of a range of electrical devices using hand and foot power that efficiently convert work into stored energy and are relatively inexpensive is ongoing [84]. A new generation of wind-up and pedal-powered electricity generators that can recharge a battery in 30 seconds is already on the market [85]	Commercial Applications

3.5.1 Heat conversion

Even in the most efficient engines, a large amount of energy is lost through heat emission and so not converted into mechanical effort. Indeed in some cases, this excess heat actually damages the system providing or transporting the energy (such as in microscopic electrical devices). Therefore the ability to convert heat into electricity can increase both the sustainability and longevity of systems. There is some interest, with this environmental scan uncovering five separate (and relatively mature) approaches to converting excess heat into useable energy.

The relative maturity of this research is evident in the commercialisation of a gas-burning boiler heat and power system (based on the Stirling external combustion). This system transforms excess heat from cooking into electricity [77], so it converts a higher percentage

[8] The physical composition and structure of piezoelectric materials means that they have special electrical properties, that as they expand and contract a voltage differential is created within the material. Significantly the technology is rapidly maturing and being embedded within more and more applications.

of (although not all) latent energy into a useable form. The availability of such a product may lead to higher efficiency of energy usage within an operational environment and so improve sustainment.

Other researchers have developed generator without moving parts, which converts heat into electricity. It is based on a layer of material expanding when heated which in turns causes a layer of piezoelectric material to stress and create a voltage difference and hence a continuous current [78]. If scalable, this type of device has significant applicability for both powering systems and reducing thermal signature.

An egg-shaped energy concentrator is being developed for use in conjunction with solar cells that use heat rather than light to create electricity. Heat (in the form of infrared radiation) causes a filter to emit a particular wavelength that matches those converted by solar cells. This is likely to prove to be highly efficient as the majority of energy is converted into a usable form. Such a cell has broader utility than traditional solar cells as it can use anything that generates heat (i.e. recycled waste energy) to create electricity [79].

Research funded by US Navy and Air Force has derived a way of extracting energy from combusted fuel by using lasers to convert pure gas (afterburner) heat into coherent light. While the long term aim is to incorporate such a device into vehicles, those developing it believe that nanoscale motors might be the first systems likely to benefit from it [80]. Certainly, the application to nanoscale motors is important as converting ambient heat into electricity could make such systems very efficient and need less ongoing support.

Massachusetts Institute of Technology, with US Defence funding, has developed a microchip that transforms heat into electricity. They believe it will convert excess heat (produced by engines, computers, or from exposure to the sun) into power for electronic appliances and batteries. This microchip is a semiconducting thermal diode that operates at 200°C and is based on the principle that heating an electrode can cause electrons to jump a small gap to another electrode, creating an electrical current. While there is some further research required into making the process more efficient and/or reducing the operating temperature, currently the major issue seems to be affordability [81]. If such a microchip became commercially viable, it would significantly enhance energy efficiency for devices and may well deliver a new range of options for solar power. In addition, it could act as a heat sink allowing greater integrated circuit density, leading to more powerful and/or significantly smaller computers.

3.5.2 Ambient sources

Within the environment, there are many ambient sources of energy. These sources may be deliberately created or are an unintended by-product of other activities. Even activities such as walking or car movement can be tapped as energy sources. To access these, some are developing options where the very infrastructure produces useable energy. For instance, in Boston, electric-powered buses whose batteries are recharged as they move through electrical 'power points' laid beneath the surface of the road are about to be prototyped. This reduces the weight of batteries within a typical bus from 480 kg to 90 kg. The technology is relatively simple (effectively two plates acting like a coil in a transformer), and estimates are that only 1-2% of roadways would need to contain charging strips to make them viable within a typical city [82].

Some researchers believe it is feasible for energy that is produced by commonplace events such as moving cars, vibrating machinery, or stray radio waves to be harvested. This is because the natural frequency at which most of these vibrate is between 75 and 150 Hz. So for small-scale devices, pairs of thin piezoelectric strips stuck together can create electrical energy through continual expansion and compression creating a voltage, which can deliver power of approximately 80 microwatts. Similarly, piezoelectric materials have been placed in shoe heels to produce up to 2 watts of power [83].

Another suggestion is placing liquid filled bladders beneath roads or in speed bumps. These compress and relax as cars travel over them. This could be used to pump a turbine and produce 80 watts of electricity for each car that travels over. Scaling this up, gigawatts of power can be produced relatively easily. Similar approaches could be used on footpaths to produce energy from pedestrians [83].

Other ambient sources include environmental radiation. As noted earlier, photonic crystals have been developed that can tune the frequency of beams of electromagnetic radiation by converting an incoherent set of wavelengths into a selected one. Hence a laser can be created from any incoherent beam of light [57].

Piezoelectric materials can also be employed to scavenge energy. Researchers have used pairs of thin piezoelectric strips to convert ambient vibrations into electrical energy, or in shoe heels where the changes of pressure from walking contracts and relaxes the material, creating electrical energy [83].

In a similar vein, the US Defense Advanced Research Projects Agency (DARPA) is funding research into tuneable antennas that capture stray electromagnetic waves and convert them into electricity. Finally there are suggestions that 60 watts of power could be generated simply from the pulse or body warmth. Some are even developing tiny fuels cells that can generate energy from the glucose and oxygen within the bloodstream [83].

All of these techniques lend themselves to making energy production more self-sufficient, at least for systems with low power requirements. In addition, they would allow people and systems to operate remotely and/or independently for extended periods of time. They also provide a significant advantage over solar power systems in areas where exposure to sunlight is limited, such as in triple-canopy jungles.

3.5.3 Human powered

The concept of converting human effort into electricity is certainly not new. Wind-up devices from clocks to radios have long been available, although the energy conversion efficiency for such devices is traditionally quite low. The typical energy requirements of modern electrical systems far exceed the time and effort necessary to power them from human effort using the typical traditional devices. However, new forms of hand- and foot-cranked electrical devices are being marketed which are significantly more efficient. Applications range from torches to radio and small electrical devices. These are generally cheap to produce and are seen to be an option for places where there is poor infrastructure or after major disasters [84]. One specific example is a set of wind-up or pedal-powered medical devices specifically aimed for Third World countries. SA user simply turns a crank to generate electricity that can fully charge a rechargeable battery in under 30 seconds [85]. These devices would have significant benefit to forces that need to operate remotely for long periods of time. Also, such technology may have significant benefits in post-conflict in areas with limited infrastructure or as backups when power supplies are threatened.

3.6 Novel Materials

The development of materials whose novel electronic, magnetic or mechanical properties lend them to new and more efficient ways for creating, storing or transporting of energy, is another approach to the development of alternative fuels and associated systems. These include surfaces that reduce energy requirements, wires that transport electrical current at 100% efficiency, and materials that create currents when they are stretched and contracted (see Table 6).

Table 6: Novel materials environmental scan results

Categories	Article Summary	Maturity
Advanced surfaces	**Light-focussing surfaces:** Surfaces that focus light through holes smaller that the incident wavelength could be used to power microscopic mechanical systems, as high energy density can be achieved as specific site such as internal micromotors [86]	Scientific Concept
	Low friction surface: Suggestions have been made that covering vehicle surfaces with tile carrying millions on tiny jet nozzles can reduce drag by up to 30% [87]	Enabling Technology
Superconductivity	**Room temperature material:** Claims that room temperature superconductivity was achieved will lead, if true and able to be commercialised, to an order of magnitude increase in efficiency of electricity transmission [88]	Technology Concept
	Electricity transmission: Superconducting wires cooled to –196°C have been used to supply power to households in Denmark and Detroit in the first commercial usage of this technology [89]	Commercial Application
Electromagnetic properties	**Energy efficiency:** Discovery that special types of tungsten filaments has 10 times the efficiency of common tungsten filaments used in light bulbs [90]	Enabling Technology

3.6.1 Advanced surfaces

Creating and implementing surfaces with specialist properties have a range of applications. For instance, 'plasmonic' materials focus light through arrays of holes considerably smaller than the light's wavelength. Importantly, the majority of light is transmitted through at very precise points [86]. Radiating plasmonic surfaces could be used to concentrate, intensify and focus a light beam only on a predetermined location, such as a micromotor. As such, plasmonics could be used to efficiently power nano-technology devices.

Reducing surface drag is another way to better utilise the available energy. Researchers suggest that covering the surface of cars and ships with tiles that carry millions of tiny jet nozzles can reduce drag by up to 30%. These jets expel up to 1000 pulses of water or air per second, breaking up the vortices that create drag. The tiles would incorporate pressure sensors that detect near-surface vortices and switch on the jets. This is based on the same principle as smart skins, however it is likely to have greater durability, as smart skins have moving surface parts which can break off or corrode [87]. A deciding factor on the viability of this technology will, of course, be whether the energy savings due to reduced friction are sufficiently greater than the energy required to power the micro-jets.

3.6.2 Superconductivity

Even before it reaches the end user, on average 7% of all electricity is lost during transmission [91]. With the trend towards electricity being transmitted over greater distances to supply more distant end users, this problem may be exacerbated. Even in microelectronic surfaces, this loss of electricity (such as in the form of heat) becomes an issue as it interferes with the operations of circuits. As such, the application of superconducting materials to transmit electricity at 100% efficiency at useful and useable temperatures has significant value. There is significant research in this area.

While there have been a number of technical difficulties in achieving this, superconducting electricity transmission systems have recently been prototyped. In 2001, superconductivity was used to supply power to 150,000 households in Denmark and a further 30,000 in Detroit, marking the first commercial use of superconducting wires to transmit electricity. However, in both cases liquid nitrogen-carrying cables were used to cool the ceramic superconducting material to –196°C [89], which is not currently practical for everyday use.

Even so, it is conceivable that room-temperature superconducting materials will become a commercial reality within the next decade or so. Recently a material able to achieve superconductivity at room temperature was reported. The design is based on drawing out a superconducting layer of electrons from a diamond doped with oxygen atoms within a vacuum [88]. The idea is controversial, has yet to be repeated, and some definitive tests that test for superconductivity are yet to be undertaken.

If researchers can produce superconducting materials that operate at commercially practical temperatures (up to room temperature), it will be a fundamental advance in (electrical) energy transmission at all scales.

3.6.3 Electromagnetic Properties

Other novel material properties may also be used. Research indicates that ultra-thin stacks of tungsten filaments can produce light bulbs which are 10 times as efficient as common tungsten filaments and twice as efficient as fluorescent tubes [90]. While not revolutionary, an improvement on such a scale would have implications for battery life and energy consumption in the field.

3.7 Miniaturised systems

The potential from the ongoing development in nanotechnology will largely be realised when efficient, reliable and durable miniature power sources are available [5]. There are two dimensions to this, namely the capacity to create viable micromotors, and the capacity to power them. As shown in Table 7, there are a number of research programs underway to tackle these issue.

Table 7: Miniaturised systems environmental scan

Categories	Article Summary	Maturity
Micromotors	**Molecular motor:** Smallest functioning motor has been developed, comprising a single molecule that cycles between two states in the presence of a variable light source, creating energy with each stroke [92]	Technology Concept
	Thermal motor: A micromotor has been postulated, which uses contracting and expanding of a material powered by heat, thus powering the cogs of a motor. It is considered to be considerably more powerful than standard electrostatically powered micromotors. [93]	Enabling Technology
	Chemically-driven engine: Efficiency of using hydrogen peroxide to generate steam to power a small robot was shown to be 50 times that of best electrical motor of similar weight and size [94]	Technology Concept
	Laser pump: Non-mechanical laser motor pump, which works by rapid rotation of small ball causing fluid to flow; may be used as power source for applications such as a 'Lab-on-a-chip' [95]	Technology Concept
	Laser-driven motor: A laser has made a shape-changing material move suggesting potential application for propelling microscopic entities around an environment [96]	Scientific Concept
Miniature power supplies	**Laser circuit etching:** A 'laser typewriter' that can print tiny batteries directly onto electronic circuits, thus reducing weight and size of electronic devices while increasing energy efficiency is under development [97]	Technology Concept
	Nuclear batteries: The use of batteries using nuclear energy is being investigated as it is reliable and can be scaled to any level thus providing a power source for micro- and nanoscopic devices [98]	Enabling Technology
	Ethanol fuel cell: Ethanol-based fuel cells are being developed as a replacement for common (lithium) type batteries [49]	Commercial Application

3.7.1 Micromotors

The challenge of producing a miniature motor is to design a system that is able to deliver sufficient energy density, and is compatible with the system it is powering. As such, the size of the system becomes the limiting factor and a driving force for development. Indeed, our environmental scan found examples that covered the entire spectrum from the microscopic to beyond the nanoscopic[9].

At the millimetre level, new types of micromotors are being designed to power devices such as autonomous and semi-autonomous systems. One example uses hydrogen peroxide to generate steam and power a robot. This provides about 50 times the power of the best electric motor of a similar weight and size. Such a motor extends the activity time of the prototype robot from 15-25 minutes to 10 hours [94]. As the emissions of such systems are only water and oxygen, this may be useful for drones or other autonomous and semi-autonomous systems.

A rubber-like liquid crystal that reconfigures its shape when exposed to laser light is being investigated with the view to developing small-scale objects that can be propelled by light beams. The phenomenon could be used to pump liquid through micrometre chambers or even scaled up to make flexible hulled boats which are propelled by light [96].

For devices orders of magnitude smaller, Microsoft is developing the generation of micromotors based on using buckle beam thermal actuators, which expand and contract creating energy. Heat is then periodically applied to drive cogs around. These are expected to outperform the current micromotors by a factor of 2000. However, they do create a great deal of heat, an issue that must be addressed [93].

A prototype non-mechanical pump, powered by a series of parallel spiralling laser beams, has been developed. These laser beams cause parallel rows of polystyrene balls to spin, causing liquid to be drawn through the device. It is suggested that these can be employed to pump fluids around microscopic devices. A current limitation is that interactions between rotating spheres limit flow rate to 10 micrometres a second [95]. Some potential uses include high-speed chemical and biological analysis using 'Lab-on-a-chip' devices [4]. Miniature pumps to power tiny devices are becoming more practical, although some technical hurdles (such as integration and stability) need to be overcome.

At the molecular scale and in the earliest stages of development are motors to power molecular systems. Indeed, the smallest motor ever built, comprising of a single molecule and powered by a beam of light, has been operating in Germany. Varying wavelengths of UV light switch an azobenzene molecule between a short and long form. This could be used to do work although the process produces only a miniscule amount of work for each stroke ($4.5*10^{-20}$ joules) [92]. While a number of issues (such as practical applications,

[9] Nanoscopic defines systems whose sizes are measured at the nanometre scale (10^{-9})

durability and efficiency) need to be addressed, such a motor has the potential to power many nanotechnology applications.

3.7.2 Miniature power supplies

If the capabilities of miniaturised systems are to be fully realised, it is essential to provide stable and long-lasting power sources that have little adverse impact on the operation of the system. In addition, the capacity to effectively integrate the battery within the system, such as making it an integral part of the circuitry, is being developed.

US Naval Research Laboratory is developing a 'laser typewriter' that can print tiny batteries directly onto electronic circuits. This would provide significant gains in terms of reducing weight and size of devices as most current electronic devices use a signal central power supply that requires extra components to transmit and control voltages around circuits. An added advantage is that there is likely to be a reduction in interference. All this contributes to a more efficient and more compact system [97].

Researchers in the US (supported by the US DOE) are investigating using nuclear batteries to operate microscopic electro-mechanical systems (MEMS). Given that nuclear radiation can be accessible on any scale, such options are practical. Two options are to use heat from a radioactive substance to generate electricity at a thermocouple junction or to use beta-decay to knock electrons out of a lattice, creating an electrical current. Given the size of MEMS, there are some health concerns of the potential ingestion of the system and subsequent radiation exposure [98]. Issues remain about getting the right balance of radiation energy and material to create the electricity, but in principle, there is nothing to limit such batteries.

Researchers are developing a micro fuel cell that they believe can replace the common (lithium) battery. Like fuel cells, they use hydrogen and water to create electrical energy. However, given the difficulty in storing hydrogen, fuel cells use solutions such as methanol, and extract hydrogen from it. While previously such devices have worked at temperatures in the order of 250°C, a new form of methanol fuel cell that works at room temperatures using a platinum catalyst has recently been developed. These cells will have lifetimes in the order of a month (for a mobile phone) before requiring recharging. Such cells are expected to be on the market soon. Indeed companies such as Motorola, Samsung and Toshiba have accelerated development programs in recent times. There remain a few issues to be solved such as power density, weight, storage of methanol and ventilation, meaning that initially at least, such cells will used in only a few specially adapted devices such as 3-G phones [49]. The implications of embedding such technology are considerable, as methanol is readily available (and can even be easily produced) in-theatre.

3.8 Novel approaches to propulsion

Producing alternatives to traditional fuels and power sources that use these are only some of the aspects to be considered in the design and development of future capabilities and systems. Another aspect is novel approaches to vehicle propulsion systems. This is an essential component because such systems may provide a different range of functionalities that alternative fuels do not. As shown in Table 8, alternative propulsion systems fall into four categories: space, aircraft, submersible and surface. Of course, developments in any one of these areas is likely to be transferred to another.

Table 8: Novel approaches to propulsion environmental scan results

Categories	Article Summary	Maturity
Spacecraft propulsion systems	**Nuclear spacecraft:** NASA is developing a new generation of nuclear-powered space craft, as nuclear propulsion offers greater energy to weight ratio and is more controllable than chemical rockets [99]	Technology Concept
	Plasma engine: NASA is in the early stages of developing plasma-based engine with 300 times thrust of conventional chemical rocket and only a fraction of the fuel mass [100]	Technology Concept
	Airborne rocket deployment: In future, US Air Force has suggested deploying spacecraft by dropping the craft out the back of the plane and then firing the booster rockets [101]	Scientific Concept
Aircraft systems	**Hypersonic jet:** NASA is developing and testing very fast jets (>8300 km/hr) built around a new type of propulsion system that uses the jets speed, rather than conventional blade, to drive air through engine [102]	Enabling Technology
	Laser power aircraft: Suggestion that supersonic planes could be powered using ground-based lasers to heat metal on an aircraft, thus creating a metal vapour which can be channelled to produce thrust [103]	Scientific Concept
	Hybrid fixed-rotary wing aircraft: Development of aircraft whose wing doubles as a rotors for vertical take-off [104]	Commercial Application
	Mini-UAV: Development of prototype of small disc-shaped UAV powered by single jet engine providing increased functionality such as vertical take-off, speed and agility of movement and hover capacity [105]	Technology Concept
Submersible vehicles	**Finless submarine:** Development of steering and stability mechanisms that do not require fins or tails may significantly enhance the manoeuvrability and stealth of submersible devices [106]	Technology Concept
	Shape-changing propulsion: US Navy developing stealthy submarine that uses shape memory alloys, not propellers, to generate thrust [107]	Scientific Concept
	Heavy-duty underwater vehicle: Underwater vehicles that can travel underwater to carry and place wind turbines out to sea to depths of 20 m, have been designed [108]	Commercial Application
Land Vehicles	**Land-water car:** A car which can travel 160 km/hr on the road and 50 km/hr on water, using a standard 2.6 litre petrol engine has been launched for sale [109]	Commercial Application
	Steam engine: Engineers have tested in automobiles a highly efficient steam engine which releases virtually no pollution [110]	Commercial Application

3.8.1 Spacecraft propulsion systems

Given the cost and relative inefficiency of ground-launched chemical-based rockets (typically only 1% of lift-off weight relates to payloads [111]), NASA and the US Air Force are investigating a number of alternatives for lifting craft into space orbits [112]. Certainly the further utilisation and commercialisation of space may be retarded until such obstacles are overcome [113]. As indicated below, at least three distinct approaches are being considered.

Under Project Prometheus, NASA recently commenced a US$3 billion program to develop a new generation of nuclear-based space vehicles. Nuclear propulsion offers obvious advantages over chemical rockets, as it has a significantly greater energy to weight ratio (e.g. a 10 cm diameter ball of nuclear material can, gram for gram, deliver 50 times the energy of a Space shuttle fuel cell) and is more controllable (in that it can be turned on and off at will). However there is considerable public concern over the safety of launching spacecraft with nuclear fuel. NASA is considering potential options, with potential solutions being fielded from 2009 [99]. These may significantly enhance flexibility and durability of space missions, especially to the outer solar system where solar power is ineffective.

NASA is also currently developing a plasma-based space-flight engine which will generate 300 times the thrust of conventional chemical rockets and use only a fraction of the fuel mass. The basis is to use microwaves to heat plasma sufficiently so that nuclear fusion occurs which releases alpha particles, which can then be fired from a magnetic nozzle to power the craft to give thrust [100]. In a similar vein, others are investigating using electromagnetic energy to strip charged particles from a plasma gas to create thrust [111]. Having prototyped the system, the next step for NASA is to develop a functional model (approximately 100 m long), which the NASA team expects to be ready within 20 years. Such a rocket would cut the time to travel from Earth to Mars from 6 months to 6 weeks making interplanetary travel more feasible [100].

For more immediate use is a US Air Force proposal to deploy future spacecraft by launching them from standard cargo planes. The spacecraft is ejected from the back of the plane and then set off by deploying wings and firing an attached booster rocket. This should significantly reduce the cost of rocket launches and increase safety [101].

3.8.2 Aircraft systems

A new generation of fast, efficient and flexible aircraft are also being developed. These range from hypersonic planes to fixed-rotary wing hybrid aircraft to micro UAV. In addition, there are even suggestions for powering aircraft using ground-based lasers. However, it is noteworthy that, while there are currently a great deal of interest in the practical use of UAV [1], only one article focussing on them appeared within the two year environmental scan.

Supersonic Combustion Ramjet (or 'Scramjet') technology provides an option for high-altitude, high-speed, and high efficiency flight [114]. This technology uses speed rather than compressor blades to power the engine and create thrust. NASA will soon test its own scramjet, the Hyper-X, which has an expected speed of 8300 km/hr (twice that of the current fastest jets). At this rate it would take two hours to travel from New York to

Tokyo. However there remain many technical issues. At hypersonic speeds, every edge and curve can create shockwaves and hence disable the craft. Indeed, a previous attempted failed in 2001, when the prototype spun out of control [102]. However, if hypersonic jet technology becomes viable, it will have a significant bearing on the delivery of airpower within the military context.

Boeing and DARPA are developing the Canard Rotor Wing (CRW) aircraft whose wing doubles as a rotor for vertical take-off. This should provide a more efficient and longer-range alternative to aircraft such as the Harrier. In addition, the CRW does not have a tail rotor, which both reduces its weight and reduces the CRW radar signature. CRW is seen as an advance on Boeing's MV-22 Osprey as its wing and rotor set is distinct from the Osprey's tilt-rotor design. It is envisaged that CRW will have a crew of one or two and be used mainly for reconnaissance [104].

The development of a disc-shaped UAV (SiMiCon Rotor Craft) may significantly increase the functionality of UAV. This craft, currently prototyped at 4.5 m but with 1.5 m models under development, has a single jet engine underneath the craft and a tail fin. As such, it can take-off vertically, manoeuvre with speed and agility, and hover; three functions current UAV cannot perform. Projections are that such craft will be operational within 5 years [105]. This type of propulsion and design for UAV will significantly increase their utility, especially as the advanced prototype is likely to be man-portable and capable of functioning in the range of environments the Australian military is likely to encounter.

One of the more curious proposals for providing propulsion in future air vehicles involves using ground-based lasers to power supersonic aircraft. Based on a technique called Laser Ablation, lasers are used to heat metal plates mounted in planes, thus producing a metal vapour that, in turn, expands, producing forward thrust. Currently Japanese researchers have successfully produced a paper prototype. The major issue the developers see in scaling this up is in providing sufficient 'fuel' to power a plane. They believe that water can be harvested from the atmosphere and then used as a secondary fuel as the metal vapour heats the water [103]. The utility of such a system is unclear. However, permanently airborne UAV might be one possibility.

3.8.3 Submersible vehicles

US Navy is developing a stealthy submarine based on shape memory alloys. Traditional propellers are noisy and leave a highly visible wake. The new submarines replace traditional propellers with shape memory alloys that shrink when heated and expand when cooled, creating a flexible craft which bends along its spine to generate thrust. Some issues remain such as devising an appropriate power supply [107]. US Researchers have adapted techniques used for steering orbiting satellites to create submersibles that are steered and kept stable without fins or tails. The 'reaction wheel' consists of three flywheels, each set in a different plane, that move to give the submersibles the desired orientation [106]. If successful, they will make such devices more energy efficient and more manoeuvrable. The potential implications for submarines and underwater unmanned vehicles are significant.

Dutch engineers have developed an underwater tractor capable of transporting and placing giant wind turbines out in the sea to depths of at least 20 m. Such machines make it considerably easier to develop such structures [108]. In future they could be adapted to augment operational functions for the littoral environment.

3.8.4 Land Vehicles

A UK company is starting to market an aquatic sports car that can travel 160 km/hr on the road and 50 km/hr over water, for a price tag of £50,000. Previous aquacars were constrained as their design meant they had to push through water giving maximum speeds of 10 km/hr. The new design, built from lightweight carbon composite and powered by a 2.5-litre petrol engine, works by using a water jet pump engine to lift most of the vehicle out of the water so that the vehicle aquaplanes [109]. This sort of design may be of some benefit for military vehicles working in the littoral.

German engineers have developed a steam engine that can power automobiles and have tested it in a standard car chassis. The engine is as fuel efficient and reliable as traditional motors but releases little or no pollution. Traditionally stream engines have been unable to efficiently convert steam energy into power due to drag on cylinders. However, the new engines are based on a material that has an extremely low coefficient of friction. Also it contains a special ceramic block for burning fuel cleanly [110]. While unlikely to replace conventional engines in the near future, such technology may eventually become a standard if agreed emission targets are to be met.

4. Technology timelines

4.1 Introduction

To gain a full appreciation of the technology trends, it is important to have an awareness of the timeframes within which such technologies may be realised. This enhances the capacity to incorporate such technological development within a long-term planning strategy. Technology timelines generally focus on broader technology themes and concepts, with the assumption that some of the current research and development activities (technological-push) will reach maturity and be able to be effectively commercialised. Consideration is also given to the impact that social and cultural demands (environmental-pull) will have on the rate at which technologies mature. In addition, assumptions are made about the time taken for society to integrate the technology (and any requisite forerunner technologies) within everyday life. Here, we look at five different forecasting activities from three distinct groups; those undertaken by

George Washington University (GWU Forecasts) in 1996 [9, 115] and 2000 [43]; those undertaken by the Japanese National Institute for Science and Technology Policy (NISTEP) in 1996 and 2001 [12]; and that undertaken by BTExact Technologies in 2001 [11].

4.2 Current 'best guesses'

The results for the technology forecasts of three distinct groups have been used. The GWU Forecasts are performed biannually by analysing information collected from interested parties [9, 43, 115]. The results are collated and refined using a Delphi process where both the date and likelihood is established. Similarly, the NISTEP surveys also use Delphi but use a more formal information collection process [8, 12]. In addition to predicting the date for realisation, they indicate the perceived importance of the technology (according to those surveyed). NISTEP perform their forecasts every 5 years, having now completed seven. The driver for both GWU and NISTEP is to identify when the technology is likely to be commercially available. The BTExact forecast is based on a different approach [11]. In this case, the views of a select few (two) technologists are used to identify the earliest opportunity for that technology to become viable. The BTExact futurists admit to deliberately taking a very optimistic view and, as such, their survey provides a nearer (or lower bound) for the technology realisation timeframe.

The results of these surveys pertaining to alternative fuels and propulsion systems are shown in Table 9. The relevant themes areas are indicated, along with where they may be found within this report. We note that not all themes are covered in this report. For GWU and NISTEP, an estimation of technology maturity date is shown, along with likelihood for GWU only. For BTExact, the earliest date of commercialisation is noted.

Note that in virtually all cases, the BTExact forecasting is about a decade earlier than the other surveys. Indeed, if this survey were to prove accurate, the majority of technologies discussed would be realised by 2015. For both GWU and NISTEP we have included results from two surveys, four and five years apart respectively. This provides an opportunity to see whether the technology has really advanced over the time period. In many cases the predictions have remained essentially static; the time period to realisation and commercialisation remains the same. However, in some cases, it appears that technology is progressing as expected, such as for the routine use of hydrogen. Unfortunately, there seems only limited consistency between these two surveys, suggesting that most forecasts have an error range of five or so years. However, previous analysis of an earlier NISTEP survey indicated that approximately 30% of predictions were fully realised and a further 40% partially realised [116], suggesting that these surveys do provide reasonable insights.

Table 9: Technology timeline summary

Technology Theme (section)	Forecasts				
	GWU 1996 [9, 115]	***GWU 2000 [43]***	***NISTEP Survey [12]***		***BTExact 2001[11]***
	Date (Likelihood)	Date (Likelihood)	6th (1996)	7th (2001)	Date
Energy efficiency improves by 50% (3.2)	2016 (61%)	2021 (41%)	2013	2016	
Fission provides 50% electricity (3.3.1)	2020 (46%)	2046 (44%)			
Commercial use of nuclear fusion (3.3.1)	2026 (50%)	2032 (29%)	2026+	2031+	2040
Large-scale gas-turbine power station (3.3.3)				2015	
Widespread use of renewable sources (3.4)	2010 (77%)	2017 (45%)	2010	2014	
Commercial magma power station (3.4.1)					2012
Practical use of hot-rock technology (3.4.1)			2021	2023	
Hybrid vehicles common (3.4.2)	2006 (69%)	2013 (63%)			
Fuel-cell converting fuel to electricity common (3.4.2)	2017 (53%)	2019 (48%)		2015	2005
Hydrogen routinely use for energy (3.4.2)	2020 (50%)		2021	2022	2020
Clothes collect and store solar power (3.4.4)					2005
Solar cells > 20% efficiency (3.4.4)			2013	2015	
Solar cells at 50% efficiency (3.4.4)			2016	2019	2008
Biochemical storage of solar energy (3.4.4)					2020
Space solar power generation (3.4.4)			2026+	2031+	
Widespread use of methanol as fuel (3.4.5)			2015	2015	
Recycling of waste into fuel common (3.4.5)			2016	2017	
Commercial energy production from organic sources (3.4.5)	2011 (60%)		2020	2019	
Synthetic fuel created from CO_2 (3.4.5)			2019	2020	
Power generated from waste heat (3.5.1)			2014	2018	
Superconducting materials commonly used to transmit electricity (3.6.2)	2015 (56%)	2025 (48%)	2025	2029	
Ships with super conductive electromagnetic thrust (3.6.3)					2005
Mini-nuclear power systems (3.7.1)			2022	2026	
Miniature gas turbine for portable devices (3.7.2)					2010
Scram Jet aircraft (3.8.2)					2008
Vertical take-off and landing aircraft (3.8.2)			2014	2019	
Hypersonic air travel used for majority of long flights (3.8.2)	2025 (48%)	2030 (54%)	2016	2024	
Electric cars common (3.8.4)	2011 (70%)			2015	
Fuel-cell cars commonly available (3.8.4)	2016 (58%)	2012 (60%)	2013	2018	2004
High-speed magnetic levitation train common (3.8.4)	2017 (58%)	2032 (60%)	2011	2017	

Analysis of the timelines indicates that it will take in the order of 15-20 years before most of the technologies described become widely used. Interestingly, it can be seen that:

- Both GWU and NISTEP believe it will take about this time for significant increase in energy efficiency;
- While both GWU and NISTEP predict high-speed magnetic levitation trains to be common, there are no technologies identified within the environmental scan that would be a major contributor to realising this;

- Both fission and fusion are seen to be diminishing sources of future power (due to both political and technical issues);
- Renewable sources, whether they be hydrogen-based fuel cells, solar, etc. are likely to become increasingly dominant as a source of power;
- Solar is likely to become viable in the 2015 timeframe if the projected levels of efficiency can be achieved;
- Biological and chemical sources of energy are progressing well and likely to have increasing importance;
- Superconductivity is not living up to its early promise; and
- Earlier timeframes for many of the proposed advanced vehicle systems (excluding the fuel-cell car) were very optimistic.

5. Implications for the Military context

5.1 Introduction

The ramifications of societal and cultural changes wrought by technological advancement are likely to be significant and far-reaching. Obviously the incorporation of some technologies will lead to new opportunities and vulnerabilities depending on who employs the technology, how they employ it and to what end. In addition, the way in which technology develops and is adopted impacts on the rate and form of those changes and drives aspects such as infrastructure development and operating practices. This means that the future context will be impacted by such changes. By implication, the future Land Force will be affected indirectly, as these new environments will shape how the future military will need to operate.

Therefore an understanding of the implications of alternative fuels and propulsion systems on the military context is valuable. As such, we have identified a number of ways in which these technologies may impact on the environment along with a number of implications on the development of military capability. We also identify some issues that may need to be addressed. This study does not aim to be comprehensive. However those issues that are identified provide a basis to review theories of warfighting and assist in the development of future warfighting concepts.

5.2 Generic Core Skills

One way of assessing the impact of technologies such as alternative fuels and propulsion systems is to look at how the Army currently operates and attempt to envisage where such technologies would be utilised. To do this, we use the 'Army-as-a-System' model [117-119]. Here, the competencies of the Land Force are decomposed into seven distinct (although not totally independent) core skills: sustainment, movement, engagement, protection, information collection, communication, and decision making. Each core skill is deconstructed, through a set of influence diagrams, to establish those elements that have a significant impact on the core skills (both positive and negative). Establishing relationships between these elements then allows for an understanding of knock-on and feedback effects. From this we can identify where and how technology may impact by identifying the technology-based variables and key technology features of the system.

Relating technology advances to these influence diagrams provides an opportunity to assess their impacts on Land Force. A previous application of this approach (in a study of nanotechnology [5]) has proved beneficial to indicate opportunities for both the military and technologies. One limitation of this approach is that the changes identified are largely incremental as we are basing the analysis on the current concept for the Land Force. Therefore, insights into changes that fundamentally change how the military operates or is constructed may not emerge.

Sustainment: The fundamental measure for sustainment is satisfied requests [118]. As such, this core skill would be expected to directly benefit from a number of the technology areas described in this report. As shown in Table 10, only two technology based variables are related to alternative fuels and propulsion systems. However, these are both high payoff for which a number of key technology features are relevant. In terms of sustainment, technologies that enhance endurance, efficiency and renewability directly impact on force reach and range, and the capacity to sustain and maintain the system. Most technologies identified here contribute to this area.

Table 10: Possible technology based enhancements to sustainment

Technology based variables	Key technology features	Possible technology enhancements
Wastage Rate	<u>Ruggedisation</u> 1. System durability 2. System survivability	• Captured renewable energy lowers risk of fuel contamination • Hydrogen, electric and hybrid engines, with fewer moving parts, could be less likely to breakdown
	<u>System efficiency</u> 1. Energy efficiency	• Miniaturisation allows systems to run more efficiently and last longer • Recycling waste and ambient heat reduces energy supply demands
Efficiency of usage	<u>Renewability</u> 1. System endurance 2. System design 3. Regenerative power <u>Low Usage Rate</u> 1. Greater endurance 2. System lifetime 3. Increased Range	• Captured renewable energy decreases refuel rates • System designs can be optimised to scavenge energy from surroundings • Recycling excess heat can increase lifetime • Creating electricity from ambient sources gives weapons platforms greater range • Replacing traditional fuels and propulsion systems with alternatives in munitions may allow lighter and smaller projectile systems or increase range due to a greater effective fuel load • Batteries printed on circuits allows for more efficient component design

Movement: Effective and efficient transfer of capability is an essential core skill for any future force. Hence, technologies that facilitate enhanced movement are advantageous. Alternative fuels and propulsion systems contribute to extending range, speed, carrying capacity, reliability and mobility (Table 11). New types of engines appear to give considerably more range, while the capacity to access renewable power sources suggests that (especially smaller) systems are likely to have greater endurance.

Table 11: Possible technology based enhancements to movement

Technology based variables	Key technology features	Possible technology enhancements
Vehicle carrying capacity	Miniaturisation 1. Smaller vehicles 2. Projectiles	• Smaller system components (micromotors and miniature power supplies) increase space within vehicle or for smaller vehicle design • Replacing traditional fuels and propulsion systems with alternatives in munitions may allow lighter and smaller projectile systems
	Power Management 1. System efficiency 2. Regenerative power 3. System design	• Miniaturisation allows systems to run more efficiently and last longer • Renewable energy to maintain or supplement energy requirements • Batteries printed on circuits may deliver more efficient energy usage
Vehicle Range and Speed	Fuel Efficiency 1. System design 2. System endurance 3. Propulsion efficiency	• Increased heat-to–electricity conversion would increase fuel efficiency • Energy density of alternatives means lighter weight and/or smaller vehicles • Increased fuel efficiency provides greater range and/or speed • Lower fuel usage decreases sustainment requirements
	Lightweight vehicles 1. System design 2. Lighter vehicles 3. Enhanced protection 4. Miniature systems	• Hydrogen, electric and hybrid engines as they are lighter than compatible traditional ones • Energy density of alternatives means lighter weight and/or smaller vehicles • Recycling excess heat may reduce weight of vehicle • Creating electricity from ambient sources gives platform greater range • Miniaturisation may allow systems to perform typical tasks using lighter components
Mobility over terrain	Route mobility 1. System design 2. Movement flexibility	• Hydrogen, electric and hybrid engines that are lighter than comparable traditional ones give greater operations options • Novel vehicle may be designed to provide greater flexibility in using terrain to ones advantage
Breakdown Rates	Reliability 1. System endurance	• Hydrogen, electric and hybrid engines, with fewer moving parts, may be less likely to breakdown

Engagement: The fundamental measure for engagement is own force firepower [118]. In order to enhance this, there are a number of high pay-off areas, such as blue safety and positioning, that could be enhanced by some of the technologies discussed in this report (see Table 12). Hydrogen, electric and hybrid engines may provide a major advance given they are more compact, lighter and have greater endurance. In addition, they may have a low maintenance overhead, due to their design. Converting excess to useful energy also has value as it not only increases the range of vehicles, but also increases its own-force safety by reducing the thermal signature. Also, different forms of propulsion benefit range and accuracy of military munitions.

Table 12: Possible technology based enhancements to engagement

Technology based variables	Key technology features	Possible technology enhancements
Blue safety	Low signature 1. Lighter vehicles 2. Smaller thermal footprint 3. Active camouflage 4. Miniature systems	• Hydrogen, electric and hybrid engines that are lighter than compatible traditional ones • Heat-to–electricity conversion would decrease the amount of excess heat emitted • Longer battery life and greater energy densities could meet the energy needs of active camouflage systems • Smaller system components (micromotors and miniature power supplies) decrease system visibility
	Remote Actions 1. Unattended systems 2. System endurance 3. Regenerative power	• Miniaturisation allows systems to run more efficiently and last longer • Recycling waste and ambient heat to maintain system when at low level of activity • Capture renewable energy to maintain energy • Hydrogen, electric and hybrid engines, having fewer moving parts, are likely to need less maintenance and have greater endurance
Blue positioning	Generic Movement Issues 1. Smaller size 2. Lower weight 3. Greater endurance 4. Movement flexibility	• Hydrogen, electric and hybrid engines take up less space and are lighter, providing greater deployability • Creating electricity from ambient sources (solar, movement, etc.) might reduce amount of fuel to be carried • Greater endurance will lessen need for system to move from camouflage • Greater endurance will provide increased reach • Vehicles such as aquacar provide greater flexibility to overcome distinct terrain types
Blue weapon capability	Blue range 1. Movement flexibility 2. Lower weight 3. Propulsion efficiency	• Creating electricity from ambient sources gives weapons platform greater range • Light weight of propulsion system and fuel can allow for more and heavier firepower systems to be carried • Replacing chemical engines with alternatives allows for smaller projectile systems or gives them a greater range
	Accuracy 1. Projectile velocity	• Replacing chemical engines with alternatives allows for systems with greater velocity • Energy efficient surfaces allow for greater terminal velocities
Blue targeting capability	Acquisition capability 1. Self-sustaining sensors 2. Miniature systems	• Creating electricity from ambient sources will increase life-time of remote sensors • Miniaturisation will allow for enhanced sensor capability, both in terms of range of sensors and internal processing power
	Blue reach 1. Lower system weight	• Hydrogen, electric and hybrid engines take up less space and are lighter • Light weight of propulsion system and fuel can allow for more and heavier firepower systems to be carried

Protection: Alternative fuels and propulsion technologies do not appear to have the same level of impact on protection as they do on engagement, movement and sustainment. However, as shown in Table 13, protection is enhanced through the impact on how 'visible' the force is to the enemy, that is the inherent own-force signature. One novel approach to enhancing capability is the reduction of a system's thermal signature by reducing the overall amount of excess (usually infra-red) heat the system produces. The capacity to convert such excess heat into electricity means that the amount of heat emitted decreases, thereby reducing the thermal signature. In addition, the capacity to capture energy from the atmosphere or to miniaturise systems further reduces the 'visibility' of systems and hence the force.

Table 13: Possible technology based enhancements to protection

Technology based variables	Key technology features	Possible technology enhancements
Inherent own-force Signature	Reduced signature 1. Lighter vehicles 2. Smaller thermal footprint 3. Active camouflage 4. Miniature systems 5. Movement flexibility	• Hydrogen, electric and hybrid engines, as they are lighter than comparable traditional ones. However, such systems may produce greater heat, impacting on the signature. • Improved heat-to–electricity conversion would decrease the amount of excess heat emitted • Longer battery life and greater energy densities could meet the energy needs of active camouflage systems • Smaller system components (micromotors and miniature power supplies) decrease system visibility • Novel vehicle may be designed to provide greater flexibility in using terrain to ones advantage

Information Collection: The technologies discussed here are likely to directly impact on the information collection core skill to a less extent than those discussed previously. However, as shown in Table 14, there is some capacity to enhance this core skill indirectly by improving the capabilities of the platforms which carrying information collection assets such as sensors. The capacity to increase the length of time a sensor can operate has merit, as does miniaturisation of the platform. As such, the modes of operation for information collection assets could be modified so as to significantly enhance this core skill. This, in turn, would impact other core skills. This indicates how the indirect effects of technologies, such as alternative fuels, can have on the military capabilities.

Communication: The analysis shows that there are no direct applications of alternative fuels and propulsion systems for communication. This is not to say that the capacity for communication would not be enhanced. Indeed, smaller and lighter communication platforms with greater endurance would allow existing communications systems to operate with greater effect.

Table 14: Possible technology based enhancements to information collection

Technology based variables	Key technology features	Possible technology enhancements
Sensor volume coverage rate	Capability of vehicles 1. Vehicle safety 2. System endurance 3. Movement Flexibility 4. Miniature System 5. Enhanced protection	• Excess heat-to-electricity conversion would decrease thermal signature • Longer battery life and greater energy densities could meet the energy needs of active camouflage systems • Novel vehicle may be designed to provide greater flexibility in using terrain to one's advantage • Miniaturisation can enhance an information collection asset's capacity to remain undetected • Renewable energy to maintain or supplement energy requirements
	Capability of unattended sensor 1. Regenerative power 2. System endurance 3. Greater endurance 4. Miniature systems	• Renewable energy to maintain or supplement energy requirements • Improved heat-to-electricity conversion allows systems to operate remotely for extended periods • Greater energy density of alternatives means lighter weight and smaller vehicles • Lower fuel usage decreases sustainment requirements

Decision Making: As with communications, decision making is not likely to be directly impacted by alternative fuels and propulsion system technology. However, as information technology systems become increasingly energy intensive, advances in power sources and miniaturisation are likely to have flow-on effects here. Situational awareness, visualisation and data interrogation can all benefit from such advances.

In summary, alternative fuels and propulsion technologies are likely to have the greatest impact on the core skills of engagement, movement and sustainment. Certainly, these would provide an initial focus for changes to current practices. Protection is likely to also be impacted. However, it is possible that implementation of technologies such as hybrid engines, might have a negative impact on protection. Information collection impacts are largely associated with the endurance of the sensors platforms, while communication and decision making are only likely to experience secondary impacts.

5.3 Potential military implications

Historical evidence suggests that the arrival and maturation of new technologies creates both opportunities for significant enhancement, and vulnerabilities from an (initial) inability to effectively incorporate them within current operating practices [120]. There is also the added complication that potential threats may also have access to these same technologies or be adapting their own operating practices to counter the impact of them. Therefore, as potential applications are identified, consideration can be given as to how they might impact on the way the military operates in the future to achieve results. So, the earlier one achieves such an understanding, the better informed the long term capability planning can be. Alternative fuels and propulsion systems provide a number of options for change, which, if effectively and efficiently integrated within military systems, will provide a significant enhancement to capability.

One area of significant promise is the conversion of excess (latent) heat to produce useable energy. Many groups using a variety of techniques are pursuing this. This is likely to significantly increase energy efficiency and endurance of systems. Force sustainability and the capacity of troops or autonomous defence systems are likely beneficiaries from harvesting energy from one's surrounds. In addition, it would overcome one of the major limiting factors for miniaturisation, that is power sources that are compact, durable, reliable and cost-effective. Other recycling options include the efficient conversion of waste using chemical and biological processes to significantly reduce external energy demands in-theatre and post-conflict.

Novel applications of renewable sources also provide some opportunities. Integration of solar cells into clothing and/or building materials may allow for energy collection to be a continual process, increasing the flexibility of deployment and impacting on sustainment strategies. Certainly, this and other similar approaches to sourcing energy from renewable sources may allow for power infrastructure to be more easily maintained or more rapidly developed during conflicts and in post-War transitions. Options for creating synthetic fuels also provide some opportunities, as energy can be sourced locally. However, significant amounts of energy may be necessary to create these, limiting their utility.

The integration of novel materials, such as those with piezoelectric properties, is likely to provide continual sources of energy. Even superconductivity would have a major benefit in terms of improving energy efficiency, if it can be realised.

Miniaturisation continues to gain greater significance for military capability. So the development of miniature motors and associated power supplies, which support new ranges of miniature devices, is likely to be beneficial. In particular, autonomous and semi-autonomous systems that are significantly smaller and lighter than current systems are likely to improve areas such as surveillance, chemical, biological, nuclear and radiological detection and health maintenance.

An ongoing aim for defence capability development is the development of platforms that have greater mobility, stealth and manoeuvrability, and that are more efficient to operate. Therefore, developments such as super-fast, super-efficient aircraft are likely to have a major impact, especially in the capacity to deliver payloads safely, in a timely manner and with a lower risk of casualties.

Similarly, vehicles that can travel on land and water at high speeds and with little time required to transition between these environments are likely to provide some new opportunities for light-weight highly mobile forces operating in the littoral environment. Also, heavy vehicles that can operate in and below the water surface may enhance the capacity to protect shoreline, de-mine costal areas and create difficulties for less sophisticated threats. Such future vehicles are likely to provide a significant enhancement to the way in which the Land Force operates within the littoral, and allow for a seamless change between the terrains encountered.

5.4 Impacts on the environment

Fundamental changes to the strategic environment may be, in part, a response to the way in which current and future transit and power generation systems function. This may be a consequence of new and emerging technologies and their applications, or due to the ongoing influences of current policies and systems on the present situation. For instance, the Kyoto Protocol and the impacts of global warming may require Australia to change how it generates and utilises power or the type of transportation. In addition, export markets may be impacted, both in terms of what we are able to produce (due to climatic changes) and the associated demand (due to changes in energy policy).

Given the possibility that hydrogen vehicles will become a commercial reality within the next 15 to 20 years, significant energy policy and infrastructure development changes may be necessary. Importantly, the impact will vary depending on the energy policy undertaken. For instance, Australia could choose to produce hydrogen locally using renewable sources of energy. However, there is an inherent risk that this might not be sustainable. Australia could elect to consider the US approach and use nuclear power to produce hydrogen. While access to energy is unlikely to be a problem, public safety concerns are likely to be raised. Of course, we could choose to become a net importer of hydrogen fuel, and hence give up some level of self-sufficiency. Each of these has significant ramifications for research and development, development of infrastructure, training, and economic self-reliance.

The choice of energy strategy will also impact on how defence provides security to national infrastructure. Solar would be likely to occupy exposed systems in large expanses and at numerous sites in remote areas. This may stretch our capacity to protect this infrastructure. Nuclear plants maybe be more easily protected but the consequences of accidents or deliberate acts of sabotage are likely to be significant. Being a net importer of fuel may create problems in time of economic and regional instability.

Continuing to use conventional fuels is likely to create its own problems. The stated likelihood that demand for conventional liquid fossil fuels will outstrip supply within the next decade or so is likely to cause a significant rise in fuel prices, creating economic hardship and greater instability especially in poorer nations. This may mean that Australia finds itself in an area of significant instability with an associated greater demand for offshore defence operations.

Of course, conventional liquid fuels could be supplemented with renewable sources such as ethanol. Large quantities of this can be produced relatively cheaply from products such as sugar and wheat. This would increase Australia's self-sufficiency and may provide some economic advantage in terms of external demand and export potential for these products. However, there have been some concerns expressed about the damage such products may cause to engines, leading to a 10% limit being imposed on the amount of ethanol allowed in petrol.

Our increased dependence on power and the economic changes, which has seen the industry deregulated, may also have consequences. Three recent large-scale blackouts (in US and Canada, UK and Italy) and computer-virus attacks on power plant safety systems indicate the vulnerability to deliberate or accidental damage to infrastructure as redundancy is reduced and distance from power source to consumer is increased. If this were to become an issue for Australia, the cost of replacing and maintaining essential infrastructure could have significant economic ramifications. In addition, it may necessitate a different role for defence in terms of supporting domestic activities in response to changes to the way energy is supplied.

5.5 Future issues to be considered

All these opportunities and impacts raise a number of issues, such as:

- Changing to hydrogen economy will mean significant changes to military platforms, and associated skills and training. Shortages may occur or be exacerbated by the need to train people to maintain such energy systems in the wider community.
- The risk associated with any such transformation is that if we change too early, there may be large upfront costs, teething problems and danger of focussing too heavily on a particular technology that might quickly become redundant. The risk of waiting is that conventional fuel prices may increase sharply as supplies decrease and organizations change focus, and current military systems may become inoperable with those Allies who have made such changes.
- Unexpected consequences of introducing new power options need to be managed. The impact of wind-turbine blades on radar has highlighted side effects that can potentially undermine our defence capability.

6. Summary and Conclusion

Alternative fuels and propulsion systems is one of the key areas of technological development that will impact on defence in the next two decades. In this report we have explored these issues. Our analysis is built upon an environmental scan of *New Scientist* magazine, from which we identified a number of key emerging themes - Strategic Issues, Non-renewable sources, Renewable sources, Recycled energy sources, Novel materials, Miniaturised systems and novel approaches to propulsion. Within each of these we explore the technological developments and consider their implications, both on military systems directly, and the broader implications for the future context. In addition, expert opinions on realisation timelines are included.

One significant outcome of our analysis is that developments such as changing from the current dependency on liquid and solid fossil fuels to alternatives such as hydrogen and solar energy create new problems. Reductions in supply, increases in demand and the consequences of greenhouse gas emissions and global warming may significantly alter the focus of energy policy. Issues such as which are the preferable options for future fuel supply, how to support that and the changes to management strategies will need consideration.

In addition, the development of hydrogen as a major source of fuel in the future seems likely, with significant efforts from a number of countries to support their development. Interestingly, some consequences of this may be significant development in nuclear and renewable sources, as the production of hydrogen fuel necessitates other new, efficient energy processes.

Renewable sources continue to generate significant research interest. While the cost and efficiency of current solar energy systems are sometimes questioned, new developments seem likely to make solar energy viable. Such new cell designs and/or new materials are likely to increase solar cell efficiency from the current range of 10-20% up to 40-50%, while increasing commercialisation is likely to drive down production costs.

The scavenging of excess (latent) heat and its conversion into a useful energy source is likely to enhance solar systems, or even prove to be viable in its own right. In either case, it promises to provide greater endurance and system efficiency, and increase both mobility and the time that troops can stay in the field in the future. Novel materials, such as those that create electrical current when heated or subjected to mechanical shock, provide another way in which wasted energy can be converted into something that is useable without impacting on the systems.

The capacity to develop miniaturised power sources and motors may also provide some benefits, in terms of new systems that have the capacity to perform tasks that were previously impossible, or else increase energy efficiency and stability of miniature systems.

One major role of research into alternative fuels is to allow systems to run more efficiently and effectively. As such, the capacity to design novel approaches to propulsion is also considered. We note that there are many options, which will, if they meet expectations, improve movement, sustainment and engagement. In particular, systems that can operate effectively in all terrains within the littoral environment show some promise.

We conclude that alternative fuels and novel propulsion systems are likely to have some significant impacts on defence in the future, both directly in terms of the implications for platforms and indirectly, in changes to the environment in which they operate. Therefore, an understanding of them will benefit the development of future military capability.

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Peter J Dortmans	Systems Sciences Laboratory PO Box 1500 Edinburgh South Australia 5111 Australia

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19. ABSTRACT

Alternative fuels and propulsion systems are key emerging science and technology areas that will impact on defence in the next two decades. This report explores some of the associated issues in order to gauge where and how they might influence the military within the Army-After-Next timeframe. Our analysis is built upon an environmental scan of New Scientist magazine, from which we identified a number of key emerging themes - Strategic Issues, Non-renewable sources, Renewable sources, Recycled energy sources, Novel materials, Miniaturised systems and Novel approaches to propulsion. For each of these, technological developments are captured and considered in terms of their implications, both on military systems directly, and the broader implications for the future context. The impacts on Land Force core skills within the Army-as-a-system framework of these technologies are discussed.

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