DEPARTMENT OF DEFENSE

DEFENSE SCIENCE BOARD

Task Force on Energy Systems for Forward/Remote Operating Bases

Final Report

August 1, 2016

OFFICE OF THE UNDER SECRETARY OF DEFENSE FOR ACQUISITION, TECHNOLOGY AND LOGISTICS
WASHINGTON, D.C. 20301-3140

OFFICE OF THE SECRETARY OF DEFENSE
3140 DEFENSE PENTAGON
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DEFENSE SCIENCE
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MEMORANDUM FOR UNDER SECRETARY OF DEFENSE FOR ACQUISITION, TECHNOLOGY, AND LOGISITICS

SUBJECT: Final Report of the Defense Science Board (DSB) Ad Hoc Committee on Energy Systems for Forward/Remote Operating Bases

I am pleased to forward the final report of the DSB Ad Hoc Committee (Task Force) on Energy Systems for Forward/Remote Operating Bases, chaired by Dr. Michael Anastasio and General Paul Kern, USA (Retired). The Task Force encourages the DoD at all levels to invest in future considerations for remote and forward operating bases and expeditionary forces, addressing energy demands and alternatives to improve energy effectiveness of our troops.

The Task Force concluded that there is an opportunity for exploration of the use of nuclear energy applications at forward and remote operating bases and expeditionary forces.

I concur with the committee's conclusions and recommend you forward the report to the Secretary of Defense.

Craig Fields
Chairman, DSB

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DEFENSE SCIENCE BOARD

MEMORANDUM TO THE CHAIRMAN, DEFENSE SCIENCE BOARD

SUBJECT: Final Report of the Defense Science Board Ad Hoc Committee on Energy Systems for Forward/Remote Operating Bases

Attached is the final report of the Defense Science Board Ad Hoc Committee (Task Force) on Energy Systems for Forward/Remote Operating Bases. The Task Force was tasked with examining the feasibility of deployable, cost-effective, regulated, and secure small modular reactors with a modest output of electrical power (less than 10 megawatts) to improve combat capability and improve deployed conditions for the Department of Defense. Furthermore, under the Terms of Reference, it was stipulated the Task Force should:

- assess different mechanisms to provide energy to forward and remote operating bases;
- identify the relevant factors of the energy sources;
- address these factors in a qualitative manner; and,
- provide quantitative analysis, whenever possible.

Moreover, the Task Force was requested to address the following:

- technical feasibility;
- policy oversight and regulation;
- robust safety and secure design features;
- logistics and resources;
- proliferation concerns;
- life-cycle costs;
- deployment policies and transportability;
- personnel costs; and,
- lessons learned from recent combat operations.

The Task Force offers recommendations which address energy requirements for future capabilities, energy efficiency of existing systems, the potential for alternative energy sources and technologies, and the case for very small modular nuclear reactors (vSMRs).

Overall, the Task Force concluded that energy usage on the battlefield is likely to increase significantly over the next few decades, therefore, making energy delivery and management a continuing challenge. Moreover, the study found that longer term energy solutions should support sustainment of technical superiority.

The study found alternative energy sources, such as wind, tidal, solar, and other sources, were unlikely to comprehensively meet current or future energy demands for forward operating bases, remote operating bases, and expeditionary forces. Furthermore, the Task Force found available energy can be used more efficiently by the Military Departments at forward operating bases, therefore, reducing the risks and costs of logistics. Locally available energy sources can also alleviate energy demand and risks, in some cases.

The Task Force recommends the Under Secretary of Defense for Acquisition, Technology, and Logistics (USD(AT&L)) and Military Departments should conduct a gap analysis of energy requirements for future capabilities and should improve efficiency of current deployable energy and drive efficiencies for future deployable energy. Moreover, Combatant Commanders should include the need for abundant and efficient energy technologies to enable future capabilities in their future requirements.

Finally and importantly, the Task Force observed that there is an opportunity to "invert" the paradigm of military energy. The U.S. military could become the beneficiaries of reliable, abundant, and continuous energy through the deployment of nuclear energy power systems. The Task Force identified a series of challenges to nuclear power; however, the Task Force did not consider any as "show-stoppers" to pursue engineering development and prototyping of vSMR capabilities.

Dr. Michael Anastasio
Co-chairman

General Paul Kern, USA Retired
Co-chairman

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Executive Summary

Energy is a critical enabling component of military operations and demand for it will continue to increase over time. In particular, energy usage on the battlefield, at the tip of the spear, will likely increase significantly over the next few decades. Energy delivery and management is a problem and will continue to be a challenge. We recommend a number of ways that this can be significantly improved.

Measures to increase the energy performance (a term which includes consideration of energy efficiency) in military platforms and base power systems can make a significant contribution to reducing demand for fuel for forward operating bases (FOBs), remote operating bases (ROBs), and expeditionary forces; however, the high and growing energy needs of current and future military operations are likely to outpace improvements to energy efficiency and management, such that the defense sector is likely to be characterized by higher and higher energy demands. Energy intensive capabilities are under development for which there is no parallel development for power sources. We are at a pivot point. Longer term energy solutions should support sustainment of technical superiority. It is not just about basing, but warfighting capability enabled by the assured supply of energy.

We have identified technologies with potential to meet this challenge of providing reliable, abundant, and continuous energy. Alternative energy technologies such as wind, tidal, solar and similar intermittent energy sources are unlikely to consistently meet current or future energy demands for FOBs, ROBs, and expeditionary forces, apart from very limited and highly specialized applications. The intermittent character of many alternative energy sources requires energy storage technology or redundant power supplies, and emerging technologies for improved energy storage do not appear able to keep pace with the growth of the DoD's energy needs.

The Task Force reviewed several nuclear reactor concepts that differ in size and technology from conventional commercial reactors and the small modular reactor (SMR) concepts currently under development for commercial use. Some of these reactors, very small modular reactors (vSMRs) with an output less than 10 MWe (megawatts-electric), may be transportable and deployable in FOB, ROB, and expeditionary force situations, and could eliminate the need for logistics fuel otherwise dedicated to producing electrical power. Such nuclear energy power systems present an opportunity to 'invert' the paradigm of military energy, where the extremities of U.S. military power could become the beneficiaries of reliable, abundant, and continuous energy, rather than the most energy-challenged segments. Supplying liquid fuel and water to military forces is a significant sustainment challenge, as the two commodities typically comprise the majority of mass transported to deployed locations, yet both fuel and water—and potentially other supplies (e.g., munitions and spare parts)—could be produced close to where it is needed with the necessary industrial technologies that could be powered by nuclear energy.

Without losing sight of the regulatory, policy, operational, and perhaps cultural changes needed to create such a new paradigm, the emerging nuclear energy technologies that the Task Force reviewed have a profound potential for enabling improvements in military operations. Many of the capabilities which the DoD is seeking to create for future military forces under its third offset strategy (i.e., increasing the competitive advantage of U.S. forces through investments in technology) will be more effectively supported by capabilities created by nuclear energy.

The Task Force offers the following recommendations, which address energy requirements for future capabilities, energy efficiency of existing systems, the potential for alternative energy sources and technologies, and the case for vSMRs.

Recommendations in This Report

Section 3.3: Advanced capabilities under development demand growing energy availability. Therefore,

- The USD(AT&L) and Military Departments should conduct a gap analysis of energy requirements for future capabilities.
- The Combatant Commands (CCMDs) should include in their future requirements the need for abundant and efficient energy technologies to enable future capabilities.
- The operational units of the Military Departments must be involved in developing and managing energy requirements and standards for their mission in order that requirements and standards are both realistic and meaningful for improved operations.
- The USD(AT&L), in conjunction with the Vice Chairman, Joint Chiefs of Staff, must ensure that future operational energy requirements are an explicit part of the Joint Requirements Oversight Council (JROC) process and Defense Acquisition Board (DAB) process.

Section 5.9: Available energy can be used more efficiently by the Military Departments at remote and forward operating bases and expeditionary bases, reducing the risks and costs of logistics. Therefore,

- The USD(AT&L) should incentivize the Military Departments to collaboratively develop future considerations for remote and forward operating bases and expeditionary forces that address energy demands and the alternative sources to meet demand, reduce risk, and improve efficiency.
- The USD(AT&L) and Military Departments should improve efficiency of current deployable energy and drive efficiencies for future deployable energy through standards and integration, contracting, measuring data, training, and operating behavior. Metrics to evaluate effectiveness should be established and annually assessed.

- Combatant Commanders should report annually on the status of tactical basing for operations. Then, the Secretary of Defense should evaluate after a period of time (recommend 18 months), in a static position, the change from a non-enduring to an enduring base.

Section 6.2: Locally available energy sources can alleviate energy demand and risks in some cases. Therefore,

- The USD(AT&L) science and technology (S&T) organizations and Military Departments should continue to invest in research, development, test, and evaluation (RDT&E) of alternative energy technologies with the potential to offer improved capabilities in remote and forward areas. In particular, these technologies should be measured in terms of reduced logistics, reduced signature during operations (i.e., survivability), reduced health and safety risk to warfighters (e.g., force protection) and the local population, and reduced overall cost (not an exhaustive metrics list).

Section 7.9: Some forward and remote bases may be suitable for vSMRs, where the challenges and risks associated with energy supply are significant. Therefore,

- The Secretary of Defense should designate the Army as the Executive Agent for all of the nuclear energy applications recommended in this study and provide adequate resources to accomplish the mission.
- The Secretary of the Army should direct the appropriate entity within the Army to investigate and invest in vSMR technology maturation and develop a demonstration program for application to forward and remote operating bases and expeditionary forces.
- The first deployment of a vSMR prototype should be to a remote site (e.g., Alaska or Guam) to develop personnel needs and concepts of operations (CONOPs).
- The Defense Threat Reduction Agency (DTRA) with the Department of Energy (DOE) should conduct a study to assess vSMR consequence management scenarios.
- The Joint Staff should incorporate vSMRs into scenario planning models and future wargames.

1 Introduction

1.1 Background

The increasing energy demand and logistics support forces needed to enable and sustain the projection of U.S. military power has never been a more compelling dilemma. Even though the first decade and a half of the 21st century has been an extraordinary period for the development of energy resources at home in the U.S. civilian energy sector, the U.S. military consistently purchases the majority of the energy it consumes for operations outside of the United States.[1] U.S. military bases in the continental United States (CONUS) will benefit from the increased availability of domestic fossil and renewable energy resources, but military bases abroad must still rely on market-based availabilities of fuel supplies.

The transition of the U.S. from being a net oil importer to a state of relative energy abundance as an overall energy exporter has had profound economic and geostrategic consequences; however, the Task Force believes that these trends do not discount the U.S. military's need for improved electrical power and fuel supply approaches and technologies to project power abroad. Even if the market price of fuel were zero, the military would still need to invest heavily in protecting and transporting fuels to remote austere locations, especially during combat. As such, energy is both a significant combat enabler and vulnerability.

The modern battlefield has amplified the need for electrical power as well as the demand for fuel to provide mobility in the air and on the ground. Recent operations in the Middle East have brought the demand for fuel to record high levels and created lucrative targets for our adversaries. Although the efficiency of fuel delivery and management has increased over time—as the military standardized fuel quality requirements, improved engines, and began utilizing larger fuel tanks and bladders—energy has increasingly become a profound source of vulnerability and a limitation on U.S. freedom of action. Although the Task Force was discouraged from referencing convoy casualty factors which have been estimated in several reports, it is well-known that a significant number of casualties in Iraq and Afghanistan were associated with resupply logistics—much of which was attributed to fuel and water.[2] The logistics supply chain to sustain deliveries of energy to remote, forward, and expeditionary sites is an attractive target to an adversary and a burden on our military capabilities to provide

[1] ASD(OEPP), "Fiscal Year 2014 Operational Energy Annual Report" (Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, June 2015), http://energy.defense.gov/Media/Reports/tabid/3018/Article/615164/department-continues-to-increase-warfighting-capability.aspx.

[2] Noblis, "Sustainable Forward Operating Bases" (Strategic Environmental Research and Development Program (SERDP), May 21, 2010), http://www.dtic.mil/docs/citations/ADA571503; Barbara Brygider et al., "Energy to the Edge (E2E) U.S. Army Rapid Equipping Force" (Washington, DC: Barbaricum LLC, March 21, 2014), http://www.dtic.mil/docs/citations/ADA622120; AEPI, "Sustain the Mission Project: Casualty Factors for Fuel and Water Resupply Convoys" (Army Environmental Policy Institute, September 2009), http://www.dtic.mil/docs/citations/ADB356341.

effective protection. Storage facilities for fuel enlarge the footprint and tactical signature of the facility, thus contributing to the vulnerability of the site and military and contractor personnel stationed there.

1.2 Scope

Recognizing this continued and resource-intensive problem, Senate Report 113-044, accompanying S. 1197, the *National Defense Authorization Act (NDAA) for Fiscal Year 2014*, requested the DoD to submit a report to the congressional defense committees "on the challenges, operational requirements, constraints, cost, and life cycle analysis for a small modular reactor of less than 10 megawatts…" As a result, in February 2014, the USD(AT&L) signed the Terms of Reference (TOR) for the establishment of the Defense Science Board Ad Hoc Committee ("Task Force") on Energy Systems for Forward/Remote Operating Bases.

The TOR called for the Task Force to address the needs of the most energy-deprived sectors of the U.S. military establishment—forward and remote operating bases at the terminus of the U.S. military logistics system—by assessing small modular reactors and other potential mechanisms to provide sufficient energy to these locations. The Task Force convened a series of meetings to receive briefings on relevant topics from subject matter experts in the DoD, the broader United States Government, and industry. A list of the offices and entities that spoke to the Task Force is included in *Appendix C*.

The Task Force focused its discussions and this report on what it believes are the most salient, current energy issues for the DoD's forward and remote operating bases, and expeditionary forces where applicable.

2 Setting the Stage

2.1 Our working terminology

In DoD doctrine, bases may be categorized as either enduring[3,4] or non-enduring (also known as contingency[5,6]) locations. Locations where the DoD intends to maintain access and use of that location for the foreseeable future are considered enduring; characteristics of enduring locations (and installations) inside the United States and in host countries outside the United States have remained consistent over the years. The nature of contingency locations associated with forward-deployed and expeditionary military operations has been evolving, as the operational experiences over more than a decade of war experience in Iraq and Afghanistan have blurred many previously held distinctions in military basing. Contingency locations expected to be in place for only months have evolved into semi-permanent locations; some of these "temporary" bases have been in existence for more than a decade, with gradually evolved base infrastructure supporting constantly changing assigned forces. More established "hub" bases have supported smaller peripheral sites, established with inherently mobile unit organic equipment. In order to use terminology consistent with language included in the NDAA and TOR leading to this report, below we provide definitions of three basing concepts using layman's language and language reflective of contemporary DoD doctrine.

Remote Operating Bases (ROBs) that are remote and austere are the main type of enduring locations considered by the Task Force. Even though ROBs are often permanent, many share the challenge of power insufficiency since they are far from established power grids. For example, ROBs located in places such as Kwajalein and Guam, or remote Alaska and Fort Greeley, are costly and difficult to provide with adequate electrical power.

Forward Operating Bases (FOBs), for this study, include both enduring locations with varying degrees of permissiveness, remoteness, and austerity, as well as semi-permanent contingency locations. These may be large, but are not expected to be permanent. FOBs may be characterized by portable or semi-permanent shelters and are often established around existing airfields. Units may rotate through these bases and bring their own portable power and/or may utilize existing power from sources such as the Air Force's Basic Expeditionary Airfield Resources (BEAR) and the

[3] A location is enduring when DoD intends to maintain access and use of that location for the foreseeable future.
[4] DoD Instruction, "DoDI 4715.05, Environmental Compliance at Installations Outside the United States" (Defense Acquisition Portal, November 1, 2013), https://dap.dau.mil/policy/Lists/Policy%20Documents/DispForm.aspx?ID=2793.
[5] A contingency location is a non-enduring location outside of the United States that supports and sustains operations, and are classified as initial, temporary, or semi-permanent.
[6] DoD Directive, "DoDD 3000.10, Contingency Basing Outside the United States" (Defense Acquisition Portal, January 10, 2013), https://dap.dau.mil/policy/Lists/Policy%20Documents/DispForm.aspx?ID=3357.

Army's Force Provider. These may include semi-permanent billeting, logistics facilities, operating centers, and may extend support to smaller, more remote locations, which could be characterized as patrol bases. Many battalion-size or larger FOBs are sustained by contractors through contractual vehicles such as the Army's Logistics Civil Augmentation Program (LOGCAP) or the Air Force Contract Augmentation Program (AFCAP).

Expeditionary or Expedient Bases, for this study, can rapidly aggregate or disaggregate in contingency locations that comprise any combination of remote or austere and permissive or non-permissive characteristics. Such bases are established and supported entirely with unit organic assets and are typically powered by tactical diesel generator sets. These expeditionary bases are intended to be mobile, while also serving as a hub for operational needs such as fuel, ammunition, food, water, communications, medical, and maintenance. They are capable of moving rapidly, often daily, and therefore can provide only basic life support.

Looking ahead to the future, it is likely that deployed base concepts will continue to adapt to unique operating situations, in particular emerging plans for future operations calling for more agile basing solutions. For example, new concepts under evaluation include cluster basing and sea basing. The one trend expected to continue into the foreseeable future is the increased demand for electrical power at all base types.

Additional energy and power definitions, terms, and discussion can be found in *Appendix D*.

2.2 Understanding the problem

A great deal of the urgency in reducing energy demand for operational uses at FOBs, ROBs, and expeditionary bases has been driven by more than a decade of combat experiences in Iraq and Afghanistan. In these operational environments, delivery of supplies became combat missions in and of themselves, because unsecured supply lines offered the enemy the opportunity to interdict convoys, in particular with ambush attacks and improvised explosive devices. In order to prevent that interdiction, the operational commander had to divert significant ground and air combat resources to protect those convoys.

The Task Force found that the scale of the energy supply problem is affirmed by estimates that, in Iraq and Afghanistan, between 70%[7] and 90%[8] of the volume of goods delivered to forward bases and expeditionary forces were accounted for by fuel and (to a lesser extent) water. The percentage of fuel used to support base operations (in comparison to mobile platforms) at five

[7] AEPI, "Sustain the Mission Project: Casualty Factors for Fuel and Water Resupply Convoys."
[8] Noblis, "Sustainable Forward Operating Bases."

forward-deployed locations was estimated in 2008 to range from 13% to 78%.[9] Recent Tactical Fuels Manager Defense (TFMD) System estimates from Afghanistan show that "installation energy" (the energy consumed from on-site energy sources) increased from approximately 40% of fuel demand in 2013 to over 60% of fuel demand in 2014.[10] Energy needs and vulnerabilities vary throughout the theater of operations.

The Task Force received briefings and held several discussions on the fully burdened cost of energy (FBCE). The takeaways were that the fully burdened cost of any commodity, to include fuel or any form of energy, water, and even munitions, is very much scenario dependent. Costs of up to $400 per gallon of fuel have been reported in the media for air-dropped fuel, though the FBCE of truck-delivered fuel during combat is more typically reported to be between $10 and $50 per gallon. No one dollar value is universally applicable to every situation, and therefore no one FBCE calculation can be used to model any one technology in all situations.

For example, in a deployed military mission situation where the host nation fuel assets are readily available across an area of operation, the fully burdened cost may essentially be just the costs out of the pump from a station or commercial delivery truck. However, in situations such as Afghanistan or Iraq where the distribution lines are severely limited or highly interdicted, the fully burdened costs of delivering sustainment commodities to the user may be substantially higher, as security assets and/or aerial delivery have to be factored into the equation. Because of these situation-driven differences, the Task Force was encouraged by the development of FBCE modeling tools that will aid in illustrating the cost burdens of different distribution choices in various scenarios.

Realistically, each military operation from disaster relief, to stability operations, to counter-terrorism, to full-scale ground conflict will generate different situations with wide variability in the challenges associated with supporting energy and water. That said, the "costs experienced" in Iraq and Afghanistan have rightfully illuminated the need to redouble efforts to drive down demand for fuel through best practices in power generation and energy management in base operations. Beyond the high dollar cost of delivering fuel and water to the battlefield, which are often seen in headlines, it is important to measure the operational drawbacks associated with dedicating manpower and equipment assets to resupply (including receiving and storing materials), and the associated risks which include injuries and loss of life. Through adopting better technologies and management practices, reduction in logistical activity can reduce costs,

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[9] US GAO, "Defense Management: DOD Needs to Increase Attention on Fuel Demand Management at Forward-Deployed Locations" (US Government Accountability Office, 2009), http://www.gao.gov/products/GAO-09-300.

[10] DCSLOG, *Joint Sustainment Command (JSC) Consumption Report*, version 8.0.3.6, Tactical Fuels Manager Defense (TFMD) System (Afghanistan, 2014).

reduce risks to warfighters, and free up warfighters and assets to improve warfighting capabilities.

In planning for the future, the impacts of power demand on the sustainment of the operational force must extend well beyond applying lessons learned, and provide for the ever-increasing energy demand of modern warfighting systems—to include provisioning for emerging weapons systems that will require more power for continuous, reliable, high density energy. In a future where directed-energy lasers, for example, could be the critical base defense system for defeating threats such as enemy unmanned aerial/aircraft vehicle (UAVs), the extraordinary energy demands of such systems must be part of today's developments of operational energy systems.

3 Future Capabilities Will Require More Energy

The electrical demands of forward operating bases, remote operating bases, and most expeditionary bases have increased over time, but are still relatively modest with respect to commercial power systems. Future plans may call for a different approach to FOBs, ROBs, and expeditionary bases, which will likely have smaller physical footprints but greater electrical demands.

3.1 Technologies

Although the military—and society—are far from eliminating or substantially reducing demand for liquid fuels, demand for electrical energy is increasing in existing applications (e.g., information and communication technology (ICT); intelligence, surveillance, and reconnaissance (ISR); and heating, ventilation, and air conditioning (HVAC)), and in emerging additional applications (e.g., electric vehicles (EVs), directed-energy (DE), and electromagnetic (EM) weapons). Electrical power is often safer, more easily controlled, and more efficiently converted to useful work than conventional liquid fuels, but storage of electricity—in space-efficient, mass-efficient, and cost-efficient ways—has been limiting its adoption for existing and novel uses. New technologies for storing electrical energy will help to accelerate growth in demand for electrical energy.

New technologies that could at least in part alleviate the burden of moving fossil fuels in contingency circumstances continue to emerge and mature. These technologies range from improvements on the demand side (behavior changes, best practices, LED lighting, insulating materials, etc.) to improvements in energy supply with microgrids and alternative energy sources, such as solar and wind.

The Task Force based a majority of its analysis on recent U.S. experience, from 2001 to 2015, in supporting military operations in Afghanistan and Iraq. In order to anticipate future energy requirements in FOBs, ROBs, and expeditionary bases, military planners must consider and account for the evolving energy needs of the U.S. military forces from chemical to electrical energy as the primary source of power for military vehicles and base operations. Electrical energy demands have been increasing on ground, air, and sea platforms, as evidenced by the upgrading of platforms and replacement of vehicle alternators to support onboard vehicle power requirements and the increased sophistication and complexity of air and sea platforms and capabilities.

While demand for electrical power is increasing across all platforms, electric propulsion technologies are increasingly characteristic of maritime platforms, as illustrated by the DDG-1000 all-electric Zumwalt-class destroyers and the Ohio-class Replacement strategic ballistic missile submarine. The electric power on the destroyer (as with most platforms other than submarines and aircraft carriers) is derived from combustion of fuel in engines, while the electric power on the Ohio-class Replacement is provided by steam turbine generators powered by running steam generated from a nuclear reactor through turbine generators. In both cases, the transition to electric propulsion enables these sea-based platforms to meet increasing on-board electric power demands (notably when demand for thrust does not require all of the generator's capacity).

Applications of electrical energy-intensive technologies—such as DE weapon systems, tactical EVs, unmanned platforms, communications, and other operations—make it necessary to attempt to anticipate the shape of future needs beyond recent experience.

The extraordinary effectiveness of advanced DE weapon systems depends on energy intensive power sources. Even systems that have historically not been very energy intensive, such as sensors and ISR, are becoming very energy intensive, as a combination of pervasive sensing and processing very large data sets produced by modern sensor networks will require significant power. Since such capabilities are likely to be associated with the deployment of FOBs, ROBs, and expeditionary bases, prime power[11] needs are likely to grow.

Table 1 is a non-exhaustive list of future weapons and other capability-enhancing technologies that the Task Force considered in terms of advancing the fight, all of which may increase electrical energy requirements.

Table 1. Future Energy-Intensive Capabilities (see Appendix E for more details)

Future Capabilities	Description
DE Weapons	DE weapons refer to a class of weapon systems that convert electrical energy into highly focused energy. Examples under development include active denial systems (e.g., "heat rays" designed for crowd control and security), high-power microwaves (to create an "e-bomb" or conduct a non-lethal attack on electronic devices), and high-energy lasers (to disrupt sensors and destroy adversary weapons or other targets).
Electromagnetic Pulse (EMP)	EMPs entail a short burst of electromagnetic energy which may occur as the result of a radiated, electric, or magnetic field or as the result of a conducted electric current (which may be natural or man-made). EMP interference is generally disruptive or damaging to electronic equipment, though a powerful EMP event can damage physical structures.
Railguns	Railguns use electricity rather than chemical propellants to launch projectiles, and comprise three basic parts: power supply, parallel rails, and a moving armature. High electrical currents are applied to create electromagnetic fields; once created, the electromagnetic fields accelerate a sliding metal conductor (armature) between two rails.

[11] Prime power sources are capable of serving as the sole source of power for an application with varying demand for an unlimited amount of time.

Future Capabilities	Description
Additive Manufacturing	Also referred to as "3D printing," this entails the multi-layer "printing" of an object from a three-dimensional electronic model, using a computer controlled process. Essentially, with an industrial robot, the necessary materials (e.g., plastic or metal), and a source of power, many parts could be manufactured at remote sites (reducing resupply needs).
Water Treatment and Production	Treating water on site—whether from groundwater, surface water, or recycling used water—would reduce demand for water resupply. The energy intensity of water treatment depends on the water location, input quality, and output quality requirements. Water can also be produced via dehumidifying ambient air or combustion exhaust.
Fuels Production	Beyond the production of liquid hydrocarbon fuels from energy- and carbon-containing feedstocks other than petroleum (e.g., coal, natural gas, and biomass), technological approaches are being developed to synthesize fuels using electricity as the primary energy input; for example, NRL is developing processes to produce fuels from seawater.
Data Centers/Computing/ISR	Digital innovation and technology have been used to develop new capabilities in data collection, computing, and surveillance. Used in disaster relief and hostility operations, these tools are critical to informing policy decisions and fulfill mission priorities. As collection capabilities expand, greater energy inputs—ranging from a few kW to dozens of MW—are required to manage, store, and disseminate data.
Autonomous Systems	Autonomous weapon systems may include UAVs, unmanned ground vehicles (UGVs), unmanned surface vehicles (USVs), and unmanned underwater vehicles (UUVs). These systems employ modern ISR and advanced weapon systems that require an increasing quantity of tactical energy.

3.2 Operational considerations

As new technologies are developed for DoD contingency applications, it is essential to ensure primary consideration be given to the environments in which such technologies must operate, so that the energy production systems do not become a limitation to operations but rather an enabler. Specifically, the United States' ability to responsively deploy to any necessary location despite the austerity of that location (i.e., infrastructure, road networks, landing fields, ports) or the hostility situation (e.g., full-scale combat, counterterrorism) cannot be limited by the type of power generation technology chosen for the future. Similarly, the ability to sustain deployed forces must remain agile and mutable to keep pace with an operational maneuver.

Energy technology acquired by the Military Departments and operated by uniformed forces have to be deployable, re-deployable, and suitable for the range of potential hostility levels, operating environments, and missions in which soldiers, sailors, airmen, and Marines will be required to engage. Missions may range in intensity from large-scale armed conflict to counter insurgency or counterterrorism, to humanitarian support, to disaster recovery situations. Indeed, any given operation may scale radically between intensity levels of conflict. The Task

Force found the need to span such a wide range of environments and conditions, and training undergone by current operators, as limiting factors on the selection of energy generating technologies and generally results in acquisition of the "lowest common denominator" of equipment—the individual (spot) diesel generator being the standard electrical power source.

To ensure military operations are not constrained by selection of energy sources, the Task Force believes decisions on energy technologies must include the following considerations across the range of conflict environments and capabilities:

- *Transportability:* ability to get the system into and out of a location with available transport systems.
- *Deployability:* ability to take the system to and legitimately emplace it in foreign countries, considering host countries' rules and regulations.
- *Compactness:* contribution to the base's footprint, which must be protected.
- *Logistics Supportability:* ability to support with existing logistics capabilities.
- *Simplicity:* ability to be operated by personnel with limited training, and comparable to current energy systems in terms of force structure.
- *Safety:* threat posed to military personnel and surrounding community, and ability to survive various types of potential attack.
- *Security:* consequences of rapid abandonment or penetration, or capture or breach by the enemy while operational and occupied.
- *Reliability:* expected ability to operate with minimal down time and maximum operational availability.

3.3 Recommendations

Advanced capabilities under development demand growing energy availability. Therefore,

- The USD(AT&L) and Military Departments should conduct a gap analysis of energy requirements for future capabilities.
- The Combatant Commands (CCMDs) should include in their future requirements the need for abundant and efficient energy technologies to enable future capabilities.
- The operational units of the Military Departments must be involved in developing and managing energy requirements and standards for their mission in order that requirements and standards are both realistic and meaningful for improved operations.
- The USD(AT&L), in conjunction with the Vice Chairman, Joint Chiefs of Staff, must ensure that future operational energy requirements are an explicit part of the Joint Requirements Oversight Council (JROC) process and Defense Acquisition Board (DAB) process.

4 We Have an Opportunity

The Task Force found much of the attention on this subject has been given to the vulnerability of energy—to include two previous Defense Science Board task forces and reports. This Task Force, however, saw its study as an opportunity for a forward-looking approach, specifically: "What if future U.S. operating bases could benefit from reliable, abundant, and continuous power that required little or no resupply, and energy could transform from logistics liability, security challenge, and operating constraint to a reliable asset and assured enabler? What then could happen?" Then,

- The DoD could provide power for assured communications.
- The DoD could produce water and aviation fuel on location and eliminate or reduce deliveries to remote and forward bases.
- The DoD supply chain could be reduced and resources devoted elsewhere.
- The DoD could provide both offensive and defensive weapons capabilities, such as high-powered microwaves, electric guns, high energy lasers, and high-powered jammers.
- The DoD could produce spare parts in forward locations by employing additive manufacturing technologies, thereby reducing inventory of parts and munitions.
- The DoD could maintain autonomous systems for extended periods.
- The DoD could provide power to installations and critical urban areas.
- Then—but more speculatively the Task Force acknowledges—the DoD could provide wireless delivery of energy to energy-deprived entities such as small special operations units, supporting terrestrial sensors, and UAV swarms.
- The DoD could better support power for humanitarian relief around the world.

The Task Force believes the DoD has a unique opportunity to move toward this future. The key is to move, if possible, from inefficient use of low-energy density fuel that is common practice today to a much higher-energy density fuel. While we do not know what the future battlefield will be, we can with confidence project it will require energy power solutions that are mobile, fast ramping (up and down), reliable, secure (against physical and cyber-attack), on-demand, and efficiently and reliably delivered.

The Task Force quickly concluded that the DoD can overcome the energy liabilities and challenges by adapting a view and implementing an approach focused on three pillars of action: energy efficiency, alternative energy technologies, and new energy source capabilities. All three have a role and need not be mutually exclusive.

5 Energy Efficiency

The Task Force recognizes the commitment of the Department to respond to the challenge of power and related fuel consumption, largely led by the Office of the Assistant Secretary of Defense for Operational Energy Plans and Programs which was established in 2010 (and combined with another office in 2015 to create the Office of the Assistant Secretary of Defense for Energy, Installations, and Environment) "to strengthen the energy security of U.S. military operations ... [and] to help the Military Departments and combatant commands improve military capabilities, cut costs, and lower operational and strategic risk through better energy accounting, planning, management, and innovation." Several new DoD policies draw attention to improving the DoD management of energy at forward and remote locations.

- *DoDD 3000.10, Contingency Basing Outside the United States* (signed in 2013), states that it is "DoD policy to pursue increased effectiveness and efficiency in contingency basing by … [p]romoting scalable interoperable capabilities that support joint, interagency, intergovernmental, and multinational partners, … establishing standards for equipment, base operations, and base transition or closure, … [u]sing operational energy efficiently, … (and) [m]inimizing the logistics footprint by optimizing the delivery of materiel solutions, contracting practices, and services."[12]
- *DoDD 4180.01, DoD Energy Policy* (signed in 2014), states that it is DoD policy to enhance military capability, improve energy security, and mitigate costs in its use and management of energy.[13]

Although movement toward more efficient use of energy in the theater of operations has been made in the past decade, these positive signs have barely scratched the surface of the problem. The Task Force finds aggressive action is required on the part of the DoD in the area of energy efficiency at its bases. Efficiency of current electrical generation through efficient load management, microgrids, and reducing demand through smart systems engineering; efficiency in contracting for energy; and standardization and interoperability were but a few areas that the Task Force assessed for efficiency improvements.

The Task Force found current energy sources used by forward and remote operating bases and expeditionary forces are characterized by very low efficiency with consequences further magnified by reliance on liquid petroleum fuels. Generators are typically not networked in a manner employing modern best practices for energy efficient microgrids. As a result of this low-efficiency approach, current CONOPS require a far larger logistics infrastructure than would be required if best practices were employed. Furthermore, the DoD does not use

[12] DoD Directive, "DoDD 3000.10, Contingency Basing Outside the United States."
[13] DoD Directive, "DoDD 4180.01, DoD Energy Policy" (Defense Acquisition Portal, April 16, 2014), https://dap.dau.mil/policy/Lists/Policy%20Documents/DispForm.aspx?ID=4107.

available power efficiently. The Task Force believes that current efforts to provide a standardized, managed in-theater power/energy architecture are somewhat fragmented, not well coordinated, and inefficiently operated, and, although DoD efforts are underway to address these issues, have not taken advantage of potential opportunities to increase the effectiveness of available energy generation resources, and are driven by outdated policies and procedures.

Each Military Department has developed unique power generation system requirements to support tactical operations by its field units during initial entry into a theater and the conduct of Phase I (Deter), Phase II (Seize Initiative), and early Phase III (Dominate) operations. Typically these are portable, low voltage generators sized for the level of the unit that will require power to operate its organic equipment. For example, tactical power is produced at user (low) voltage levels not requiring transformers or extensive distribution. Under asymmetrical warfare environments, the phasing of these events may not be as linear as many current publications indicate.

5.1 Operators must be linked in with power management planning

The Task Force believes more can be done to ensure operators and power managers are involved in developing and managing energy requirements and standards to realize efficiencies. These personnel are integral for determining requirements, developing the power system solutions, and managing the energy consumption for forward and remote locations. Overarching strategy supports this conclusion. For example, the U.S. Army's *Operating Concept: Win in a Complex World 2020-2040* and the *Army Operating Concept* (AOC) state that "[t]he U.S. Army's differential advantage over enemies derives, in part, from the integration of advanced technologies with skilled Soldiers and well-trained teams;" it is further stated that "power saving and generation technologies may reduce sustainment demand and strategic lift requirements," implying that the value of a power manager will likely become more important as advanced power system technologies are integrated into future Army operations. However, gaps in the strategy implementation remain.

The Task Force considered the Army's *Initial Capabilities Document (ICD) for Operational Energy for Sustained Ground Operations*, which states the "force lacks the ability to correctly assess, plan, design, and manage tactical power load, distribution and conditioning systems" and "lacks the ability to accurately monitor and manage energy demand and supply processes." The Task Force also reviewed the gaps in the Army's inability to execute power management elements (e.g., the Army's *ICD for Operational Energy for Sustained Ground Operations*; the *Joint ICD for Contingency Basing*; the Army's *Operational Energy Management: Electrical Power and Distribution Whitepaper*).[14] The absence of well-trained power managers will

[14] The capability gaps documenting the Army's inability to execute these power management elements have been documented in the *Joint Initial Capabilities Document (ICD) for Contingency Basing*, where it is stated that "[t]he future force lacks the ability to correctly plan and design power generation and distribution systems," "to

continue to exacerbate the inefficiency of current power system operations, and hinder the integration of advanced power systems into future Army operations. The Army is not alone in its challenges for effective power management to realize energy efficiencies.

A power manager is essential for efficient life-cycle management of contingency power systems, and would be integral to the process of developing and managing energy requirements. A power manager would also serve as a subject matter expert to assist in developing the standards (doctrine) for future contingency power systems. However, the Army has not identified responsibility for management of contingency power systems, and does not currently have the power management expertise to effectively manage those power systems throughout the Army organizational structure. The absence of well-trained power managers will continue to exacerbate the inefficiency of current power system operations, and hobble the integration of advanced power systems into future Army operations. Below is a list of roles and (necessary, but not necessarily sufficient) responsibilities of an effective power manager.

- *Power Manager:* Personnel responsible for the entire "cradle to grave" life cycle of a contingency power system. Power management consists of the following elements:
    - *Analyze Requirements:* Gather mission information and define the requirements
    - *Plan:* Develop concept based on requirements, considering command priorities
    - *Select:* Choose equipment based on availability, affordability, suitability, etc.
    - *Design:* Develop physical layout of equipment-based physical parameters
    - *Procure:* Purchase, order, or select equipment
    - *Employ/Construct:* Move, lay out, and connect equipment
    - *Operate:* Start and stop equipment based upon varying requirements
    - *Sustain:* Refuel, inspect, and maintain fluid levels for continued operation
    - *Maintain:* Periodically service and repair
    - *Recover:* Disconnect, service, repair, and repackage equipment for future missions
    - *Final Disposition:* Ensure proper disposal and site clean-up

These power management elements are integral components for determining requirements, developing the power system solution, and managing the energy consumption for contingency

construct power distribution systems," and "to maintain power generation and distribution systems." Furthermore, in the *Army Operational Energy Management: Electrical Power and Distribution Whitepaper*, it is stated that, "[i]n its current form, the Army lacks the necessary personnel, training, and materiel solutions to optimize energy use at both the production and end-user stages."

or remote bases. The Task Force found the power manager role to be of even greater importance as advanced power system technologies are integrated into future Army operations.

5.2 Contracts lack incentives to minimize excessive demand

Over more than a decade of operations in Iraq and Afghanistan, most of the large base camps have been constructed by contractors. The Task Force concludes this is likely to continue to be the case. As such, not only does modularity and efficient power planning have to be embedded in base camp master plans, but tactical system enablers, such as the Army's 249th Engineer Battalion (Prime Power) and Force Provider, must also be embedded in the contracts written with our industry contingency construction and logistics providers. These contracts should include incentives for minimizing excessive electrical demand and maximizing electrical power system efficiency. In the current environment, where the DoD is often paying cost-plus reimbursement for base establishment and is directly delivering fuel consumed, the contractor has little authority or direction to plan for base energy demand evolutions and little incentive to invest in energy demand reduction technologies. Contractors are typically neither tasked to examine nor rewarded for examining what steps could be taken to reduce power demands, consolidate loads, or to optimize use of equipment. Additionally, as units rotate in and out of semi-permanent bases, they bring their own equipment and behaviors which impact energy usage (outside the control of the operating contractor).

It is important to point out there have been legislative initiatives to promote the use of energy efficient technologies in contingency operations. The *NDAA for FY12*, included such a provision. Title III Sec. 315 "Energy-Efficient Technologies in Contracts for Logistics Support of Contingency Operations," for example, updates the 2007 10 USC 2911 DoD authorization bill requirement for annual energy performance goals and an energy master plan by adding the requirement to "specifically address the application of energy-efficient or energy reduction technologies or processes" in logistics support contracts for contingency operations, and include "goals, metrics, and incentives for achieving energy efficiency in such contracts." These technologies or processes must meet certain criteria: 1) achieve long-term savings by reducing demand for fuel and other sources of energy, 2) not disrupt the mission, and 3) able to "integrate seamlessly into the existing infrastructure." Since its passage in the 2007 budget cycle, this legislative requirement had limited ability to impact energy demand at already established bases in Iraq and Afghanistan. However, the Task Force would expect future iterations of DoD contingency contracts like LOGCAP, AFCAP, and Africa's Multifunctional Peacekeeping Support Program (AFRICAP) to have these requirements fully embedded.

Despite legislation to address the issue, the Task Force found efforts to provide the most efficient methods for power production at the prime-contract level have been hampered by regulations and burdensome processes governing procurement thresholds for larger equipment, military construction, and utility system justification required to support semi-permanent bases.

The Task Force found in one case a smart microgrid was classified as a "Defense Business System" (DBS) because it reports information to a central location. The consequence is a barrier for the Joint Task Force to easily and efficiently adopt the system.[15]

Furthermore, the Task Force learned of major bases requiring large power systems, but these cannot be procured under theater procurement capabilities due to the conflict between use of Operations and Maintenance (O&M) dollars and Other Procurement (OP) dollars in appropriations. Currently, Contingency Construction projects are funded from three sources: the NDAA, which allows limited use of O&M and Army funds for construction over $1 million; regular Military Construction (MILCON) programming; and annual supplemental MILCON appropriations. The requirement for project approval using these types of funds is inconsistent with supporting rapid response to urgent military construction requirements and, as a result, the Military Departments must meet wartime requirements using peacetime rules.[16] Rather than rapidly building an efficient distributed generation system, the needs are met through incrementally increasing the power capabilities and creating a highly inefficient distribution system. The Task Force found the acquisition approach to buying a power system to be one of the largest obstacles to effective, efficient power management.

5.3 Acquisition policy, regulations, and other administrative processes burden contingency contracting effectiveness

The Task Force heard from contractors who have provided power support via contingency contracts, such as the U.S. Army LOGCAP, and found there is significant opportunity to improve energy efficiency with policy and contracting changes. In particular, briefers identified opportunities for contractual incentives for base designs and power grids that reward the operating contractor for innovations and power consumption reduction. Contractor representatives believed, with a well-constructed contract, it is possible to ensure base design requirements include the ability to scale the base up and down while optimizing power production efficiency. Application of microgrid solutions, leveraging advances in facilities construction or materials, and real time collecting and reporting dashboard data on power use are examples of techniques that contingency contractors would leverage to achieve efficiencies in power, loads, and demand. The resulting benefit would not only be cost savings, but would also reduce the exposure of convoys to risks.

[15]The question on a smart system's classification as a DBS, is a barrier to adoption with significant hurdles for current JTF Engineers to overcome. Another example of policy problems would be if units grouped their generators together. Would this action then constitute a "camp utility?" If so, does this make unit equipment personal or real property requiring construction funding to install the generators? ARCENT is having to deal with these unresolved issues today.

[16]See *10 USC 2805*, *10 USC 2803*, *10 USC 2804*, and *10 USC 2808*.

Along with ensuring contingency contracts incentivize improved energy efficiency, there are also policy and potentially other legislative issues that hinder efficiency initiatives. In particular, "colors of money" needed for establishment of power systems appropriately sized for large bases can exceed allowable minor construction thresholds (~$750,000) that can be paid for with O&M appropriations. Without relief or waiver of these thresholds, the only available solution often ends up being far less efficient. Contingency contract planners must include MILCON funding as part of their budget requests and/or develop mechanism to attain the necessary "color money" in timeframes appropriate to contingency operations. Construction projects that exceed $1.5 million in value require specific approval by Congress. However in contingencies, the Secretary of Defense (SECDEF) has the authority and flexibility—in the interest of national security and national interests—to authorize MILCON not otherwise authorized by law[17] but must report on that authorization to Congress in writing a minimum of 14 days before the project can start.

With the evolving nature of military contingency operations and the bases that must support them, the need for MILCON funds may not be known at the early planning and budgeting stages. A base as initially envisaged may evolve to something else with other requirements. Therefore, budget analysts and planners would not have the opportunity to pre-plan either the appropriate color of money or the request for SECDEF authorization. Changes to how contingency contracts and contract task orders and options are developed to support such unknown MILCON requirements are necessary to avoid sub-optimization of energy systems in the interest of expediency.

5.4 Data and information about power demands and production need to be collected by the tactical units in theater

In both Afghanistan and Iraq, power data collection and analysis was not seen as a significant mission and, as a result, power efficiency was not taken as a measure of importance. Due to the diffusion of organizational responsibility for power planning and generator optimization among multiple units and levels, data and information about power demands and production are generally lost, if collected at all by tactical units. Until recent efforts began to reduce operational energy demands, capture and analysis of data by higher level military units or contractors rarely occurred. As more enduring bases are established and responsibility shifts to prime energy producers, the higher level organizations (e.g., the 249th Engineer Battalion, Army Reserve units, Air Force and Navy civil engineering organizations) and contractors, are in a position to develop and analyze data to improve the efficiency of operations and should do so.

[17] 10 USC Subtitle A – General Military Law, Part IV Service, Supply and Procurement, Chapter 169 – Military Construction and Military Family Housing, Subchapter I – Military Construction, Section 2804: Contingency Construction with amendments in effect as of July 7, 2015.

5.5 A joint, integrated approach is needed to drive efficiencies

In the case of both Iraq and Afghanistan, power needs grew with the increase in the number of forces in theater and requirements were satisfied on an ad hoc basis. There was little anticipatory service or joint planning directed at the eventual needs for power and consideration of development of joint service power production in shared bases. Differences in equipment, training, and quality of life requirements among the Military Departments increased the difficulty in developing a more common approach to dealing with energy production at bases above the Army brigade level.

In the Army, responsibility for actual operations and maintenance of generators and power delivery systems is distributed among tactical units, their maintenance support activities, and the Army's 249th Engineer Battalion (Prime Power), which represents the Army's only expertise at this higher level of power supply. Responsibility for power planning is ad hoc and limits activities that can be pursued in the interests of improving efficiency of power generation operations. Whereas in the Air Force, power generation specialists are part of the civil engineering units and are available in initial theater entry units as well as longer-term base operations units. Achievement of energy efficiency will require the development of the proper organizations and the training of effective specialists to realize the potential significant improvements in power generation systems and related infrastructure.

Planning for power generation at the joint and theater level has been limited and taken as a complement of facilities operations. Relevant joint publications (JP) 4-0, 4-05, 4-08, and 4-10,[18] are silent on incorporation of power generation activities in theater operations throughout the multiple phases of engagement (though better designing and managing energy systems is generally consistent with the required future capabilities described in the recent *Joint Concept for Logistics 2.0*,[19] which includes improving forces' ability to include consideration of logistics supportability in force planning, and in operations and contingency planning earlier in the planning process). The inter-service publication guiding such activity, *Joint Operating Procedures Management and Standardization of Mobile Electric Power Generating Sources*,[20] was last published in September 2003 and prescribes policies, assigns responsibilities, and mandates procedures necessary for acquisition program management and standardization of Mobile Electric Power Generating Sources (MEPGS)—and systems—utilized by all Military Departments and the Defense Logistics Agency (DLA) worldwide. It also addresses

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[18] Joint Chiefs of Staff. Joint Publication 4-0, *Joint Logistics*, October 16, 2013; JP 4-05, *Joint Mobilization Planning*, February 21, 2014; JP 4-08, *Logistics in Support of Multinational Operations*, February 21, 2013; JP 4-10, *Operational Contract Support*, October 17, 2008.

[19] Joint Chiefs of Staff, "Joint Concept for Logistics (version 2.0)," September 25, 2015.

[20] *Joint Operating Procedures Management and Standardization of Mobile Electric Power Generating Sources*. Army Regulation 700–101, AFI 63-110(I), NAVFACINST 4120.12, MCO 11310.8C, DLAI 4120.16, HQs Departments of the Army, the Air Force, the Navy, Marine Corp, Defense Logistics Agency Washington, DC, September 2, 2003.

administrative functions in the areas of contracts and production, program management, logistics support, and configuration and data management. *Engineer Prime Power Operations*[21] describes theater level power infrastructure and inter-service responsibilities and, although dated from 2013, has not been significantly updated since 1997. The Air Force issued facilities oriented *Air Force Instruction (AFI) 32-1062*[22] in 2015, but does not address inter-service activities.

5.6 Lack of standards and interoperability causes sustainment challenges

Tactical generator systems and comparable commercial systems and the infrastructure to support them have been developed over time without common standards. As a result, interoperability of tactical and prime power generators within, and among, the Military Departments is difficult to achieve and adds to the considerable additional logistics challenge of operating and maintaining many generator systems at both the tactical and prime levels. Efforts are underway to deal with this problem, but quickly replacing current systems with more standardized systems will be difficult.

Most efforts dealing with standards have focused on in-theater operations, where use of local power has typically not been possible and interoperability considerations have been minimal. However, in future situations and in operation of remote bases in non-combat zones, the opportunity to take advantage of local power systems and a growing number of commercial renewable resources or power storage devices may be much more prevalent and, thus, interoperability becomes more critical and merits attention. Acknowledging that each nation has its own different system, host nation commercial standards and interoperability are critical to this effort which, in turn, is important for civil-military relationships as well as military-to-military partner capability generation efforts.

5.7 Transition planning from contingency to enduring locations is inadequate

As in-theater movement declines and operations become more stable in the latter part of Phase III (dominate) and throughout Phase IV (stabilize), the size and complexity of the bases from which the forces operate increase as does the demand for power to support non-tactical base operations. Where feasible, as power demands increases, a shift is made from tactical power systems to prime power units (i.e., high voltage generation systems requiring transformers operated by the Military Departments or by contractors). Organizations within the Army, the Air Force, and, to limited extent, the Navy have some capability to develop prime power. **Figure 1** depicts the role of prime power units as a provider of continuity between tactical generators and commercial power grid sources. Prime power generating systems have been developed by the Military Departments under DoD Research and Development (R&D)

[21] United States Army. TM 3-34.45 (FM 3-34.480). *Engineer Prime Power Operations*, August 2013.
[22] United States Air Force. AFI 32-1062, *Electrical Systems, Power Plants And Generators*, 15 January 2015.

programs, or are commercially procured as necessary, and can be operated by trained personnel within the Military Departments or contracted companies.

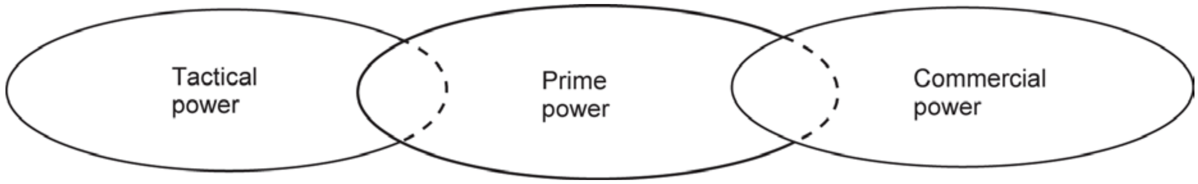

Figure 1. The Power Continuum (Source: U.S. Army Technical Manual No. 3-34.45[23])

Tactical power systems have been optimized for field use based on tactical unit requirements, which include system portability. When operated as a group in a static situation, they tend to be inefficiently utilized, consume significant quantities of fuel, and require trained personnel to ensure their continuous operation. If unit locations (e.g., FOBs) are stabilized, facilities become more enduring, and power demands grow (from air-conditioning, laundry, dining facilities, and Morale Welfare and Recreation (MWR) facilities, etc.); as units typically continue to run off of tactical power, the number of small generators is increased to carry the load, instead of replacing them with more efficient systems. Maintenance demands of tactical and non-standard generators also increase the theater logistics burden. When the tactical units become part of semi-permanent base facilities, prime power is added in increments as the bases grow. Were operations to take place in a region where commercial power was available, at some point, part of the load could be moved to commercial power systems; however, competing military and civilian demands and the unreliability of these systems make this unlikely under many scenarios.

One of the challenges in fully leveraging power management systems in base camps is that a base camp tends to evolve over time. What was intended to support a short-term deployment situation can and often does evolve into a semi-permanent base. In such situations, planning for the longer stay has not been built into the initial laydown of the base design, and reconfiguring has proven to be both time consuming and expensive.

5.8 Behavioral changes impact energy effectiveness

Behavior modification has long been at the core of military training. Education and training are essential to obtain "buy-in" among operators for optimal practices (e.g., number of batteries or munitions to carry). The Task Force heard many examples of behavior-type changes geared toward efficiency, some of which are mainly a function of discretionary individual choices and habits, and others which stem from training (standard operating procedures), infrastructure, and human factors design. Examples of energy efficient changes include: 1) dissuading units from

[23] Department of the Army, "Engineer Prime Power Operations, Technical Manual 3-34.45(FM 3-34.480)" (Army Knowledge Online, August 2013), http://armypubs.army.mil/doctrine/Active_TM.html.

setting up their own individual generators when the base has a designed power distribution grid; 2) shutting doors in air-conditioned spaces; 3) turning lighting and HVAC systems off when spaces are not occupied; and 4) laying out command posts with heat-sensitive computer systems closest to the air conditioning source, rather than in the center of the facility where the cooled air has to travel the farthest.

The Task Force was informed that even the most basic, and seemingly obvious, behavior changes would improve energy performance, such as: establishing reasonable set point temperatures in soft-walled expeditionary shelters (e.g., not cooling to 55° F or heating to 90° F); turning off all equipment when not in use; minimizing use of environmental control units (ECUs) (USMC is headed very much in this direction already, minimizing vehicle idling, particularly "within the wire," and improving driving techniques of tactical vehicle operators.) The Task Force found that in all of the behavior issues associated with energy efficiency in the military, the ability to show energy consumption on some form of dashboard is key to effectively managing the behaviors that impact that consumption. For contract-established bases, contract specifications for power distribution should require the contractor to monitor energy consumption and provide that information via a dashboard or management system back to the government base commander and tenants as the critical means of understanding how to influence change. We must be able to see/measure the outcome of behavior in order to successfully modify it.

5.9 Recommendations

Available energy can be used more efficiently by the Military Departments at remote and forward operating bases and expeditionary bases, reducing the risks and costs of logistics. Therefore,

- The USD(AT&L) should incentivize the Military Departments to collaboratively develop future considerations for remote and forward operating bases and expeditionary forces that address energy demands and the alternative sources to meet demand, reduce risk, and improve efficiency.
- The USD(AT&L) and Military Departments should improve efficiency of current deployable energy and drive efficiencies for future deployable energy through standards and integration, contracting, measuring data, training, and operating behavior. Metrics to evaluate effectiveness should be established and annually assessed.
- Combatant Commanders should report annually on the status of tactical basing for operations. Then, the Secretary of Defense should evaluate after a period of time (recommend 18 months), in a static position, the change from a non-enduring to an enduring base.

6 Alternative Energy Can Offer Some Solutions

For decades and still today, most electrical power for FOBs, ROBs, and expeditionary operations is produced with diesel generators. As stated earlier, the Task Force found the conversion of fuel to electricity—and utilization of this electricity—has been inefficient, and the air and ground delivery of liquid fuel has been at significant cost in both lives and dollars. This observation gives credence to DoD initiatives to evaluate and deploy alternatives to petroleum-based fuel systems. The DoD Energy Policy states that DoD will "diversify and expand energy supplies and sources, including renewable energy sources and alternative fuels."[24] The Task Force discussed a variety of (not necessarily mutually exclusive) categories that could describe energy sources, energy carriers, and power conversion technologies that differ from the standard military tactical power system which include petroleum-based fuels and engine-generator sets.[25]

The Task Force found that renewable sources of energy such as wind and solar can reduce the need for some fuel, but most renewable resources are limited by location, weather, time of year, storage capacity, and constrained by available land area and/or constructability. Several technologies are useful to meet some small unit demands, but are not a comprehensive solution for providing electrical power for the majority of future demands. In recent years, the use of renewable energy[26] sources to replace or displace demand for conventional fossil fuels has increased dramatically, primarily due to improved economics, helped by government subsidies and performance. Military adoption of renewable energy has been seen at large scales on domestic bases and in specific use cases in deployed locations—e.g., where a small source of power (few watts) is needed to power sensors, UAVs, and dismounted warfighter power

[24] DoD Directive, "DoDD 4180.01, DoD Energy Policy."

[25] A common feature of non-standard or "alternative" (for purposes of this document) energy systems being pursued by the DoD for operational use is the potential to reduce the burdens and risks associated with energy resupply. "Energy harvesting" is a term increasingly used to describe the harnessing of energy sources available in the vicinity of the operating environment; this may include renewable energy (e.g., solar, wind, biomass, geothermal), non-renewable energy (e.g., partially depleted batteries), or biomechanical energy (e.g., capturing kinetic energy from a soldier's knee or backpack). "Indigenous energy" has also been used to describe locally available harvestable energy sources, though the term is not commonly used, such that it is debatable whether an existing local utility power grid (or even using fuels commonly sold in local markets) would be considered indigenous. Although wireless power beaming requires an energy source, and may be better described as an alternative energy conveyance system (substituting for transmission lines or fuel trucks), it may be considered an alternative energy source for the military operational purposes. Although electricity is a fungible energy carrier that can be derived from many sources, liquid fuels are critical energy carriers for many military platforms. As with alternative sources of electricity, alternative fuels may be renewable (e.g., biofuels) or not (e.g., aluminum powder, coal-to-liquid fuels), though alternative fuels are typically sourced from industry (and not produced on site). Alternative (energy) conversion devices—such as fuel cells, novel engines, or waste heat recovery/utilization devices—are also being developed to more efficiently convert fuels (petroleum and/or alternative) to electricity.

[26] Renewable energy is defined as energy that comes from readily available resources that are replenished naturally and on a useful timescale. Some have argued that nuclear energy is renewable through breeding and reprocessing nuclear fuel, but it is rarely considered a renewable energy source.

systems. For the immediate future, diesel generators will continue to be the primary source of electrical power for U.S. military units.

The fully burdened cost concept has been used to justify investments in efficiency and alternative energy sources. To date, renewable energy technologies used by the military have been limited to electrical power production, though research on field production of liquid fuels—from indigenous feedstocks or cultivated algae—have been studied by the Defense Advanced Research Projects Agency (DARPA) and other organizations.

In looking at alternative energy sources that would offset the amount of fuel supply required, several key points frame any solution:

- Alternative energy sources could address some remote and forward base consumption, but fossil fuel supplies would still be required for the high-demand consumers such as aircraft and ground vehicles. In Iraq and Afghanistan, fuel for base support power generation systems is estimated to have required as little as 13% of the total fuel consumption for bases such as Bagram. Clearly, fewer requirements to operate and secure fuel convoys would drive down the non-base camp consumption as well, but selection of alternative power generation methods has to be made with the knowledge that the end state is a reduction—but not elimination—of fuel delivery costs and exposure to enemy interdiction.
- Historically, initial use of tactical generators in a theater of operations has been quickly followed by insertion of non-tactical, largely contractor-supported, power generation systems in support of base camps and other non-tactical situations. This process has created major fuel demands on the logistics system.
- Base camp technologies that continue to evolve include hybrid renewable power sources and power distribution systems which can substantially improve power management.

6.1 Alternative energies are not the comprehensive solution set

The DoD has successfully utilized alternative energy for installations—in particular renewables such as solar, wind, biomass, geothermal—of which such applications are beyond the scope of this report.

Over the last decade, many studies on the feasibility of renewable energy technologies for expeditionary military operations have found most renewable energy sources are advantageous only in a limited set of cases. For example, solar energy has shown the most promise to date, with successful demonstrations in remote Marine Corps outposts, on dismounted soldiers, for sensors, and on UAVs.[27] However, due to the intermittent supply and large footprint required

[27] Michael Bowes and Barry Pifer, "Reducing Energy Footprint on the BattleField [Distribution Limited to DOD Agencies. Specific Authority: N00014-05-D-0500]" (CNA, June 2010); S B Van Broekhoven et al., "(U)

to produce each kWh, solar power does not offer the capability of conventional power production systems when significant amounts of on-demand power are needed.

Table 2 provides an overview of the various alternative energy sources and technologies that the Task Force reviewed, which could offer benefit for military operational use; one drawback of many of these technologies is that power production would be variable and potentially unpredictable over time. Additionally, **Table 3** provides a summary of energy storage devices which would be essential to enable adoption of intermittent energy supplies for a significant fraction of energy demanded at bases (or on the civilian power grid). An explanation of alternative energy technologies is found in *Appendix F*.

Table 2. Alternative Energy Sources and Technologies

Energy Source	Availability	Technical Maturity	Operational Considerations
Solar Power	Available globally; varies with location, season, weather, time	Widely deployed on the civil grid and military installations; limited deployment of tactical units	Small rugged panels can be beneficial; possible visible target; glint/glare concerns; requires cleaning
Wind Power	Available globally; varies with location, season, weather, time	Widely deployed on the civil grid and military installations; small units exist, but are typically not attractive for military use	While potentially beneficial, concerns with small wind turbines include reliability, visibility, and interference with communications
Hydrokinetic Power	Common but not everywhere; varies with location, season, weather, time	Utility-scale hydroelectric dams are mature and common; small portable tidal, wave, and micro-hydro power systems are under development	Requires sophisticated technologies and potentially a large material footprint; variable but more predictable than wind and solar
Geothermal Power	Exists in limited locations worldwide; where present, heat output is often steady	Very mature for civil applications	Requires considerable time and initial capital cost for construction; likely attractive for some enduring locations
Ocean Thermal Power	Exists in the deep sea and near specific islands	Under civil sector development and under evaluation for use on U.S. Kwajalein Army Base	Requires significant initial capital cost and large structures; may be attractive for some enduring locations

Tactical Power Systems Study" (Lincoln Laboratory, May 19, 2014), https://www.dtic.mil/DTICOnline/downloadPdf.search?collectionId=tr&docId=ADB399778; Daniel Carvell and Michael Bowes, "Marine Corps Expeditionary Energy Cost Analysis [Distribution Limited to DOD Agencies. Specific Authority: N00014-11-D-0323]" (CNA, August 2013); ED McGrady, Jessica Stewart, and Kathleen Ward, "Solar and Wind Power as Alternative Sources of Energy in Expeditionary Environments [Distribution Limited to the Sponsor. Specific Authority: N00014-11-D-0323]" (CNA, April 2011); Michael Woodard and Joan Sailor, "Alternative Sources of Energy for U.S. Air Force Bases" (United States Air Force Scientific Advisory Board, August 1, 2009).

Energy Source	Availability	Technical Maturity	Operational Considerations
Waste to Energy Systems	Solid waste, wastewater, and other energy-containing wastes are available wherever humans live and operate.	Mature for large civilian applications; the military has deployed small incinerators, and is evaluating systems capable of extracting heat or power from waste.	Requires dedicated equipment and is operationally complex; the scale of energy generated from waste resources would make up a small fraction of civilian or military needs.
Indigenous or Cultivated Biomass	Available throughout much of the world, but variable by location and time of year.	Common for simple heating and cooking tasks, and mature for industrial use, but mobile reliable systems are under development.	If reliable, could reduce need to deliver fuels to remote locations; biomass logistics and infrastructure must be considered.
Wireless Power Transfer/Beaming	Potential energy inputs (grid or solar panels) are available, but transmission technology is not currently available.	Requires significant implementation costs despite advanced knowledge of the physics; the DoD continues to monitor and make limited investments in R&D.	Likely requires a large structure to receive energy; an accident could have severe consequences; requires evaluation of vulnerabilities before implementation.
Host Nation Grid	Often available but not consistently reliable.	Interconnection of military base power systems with a local transmission network is straightforward and well understood.	Could reduce costs, but may be unreliable, requiring back-up power generation systems (as is the case with intermittent renewables).

Table 3. Electrical Energy Storage Devices

Energy Storage Devices	Attributes
Pumped Hydroelectric Storage	In addition to steadily producing electrical power by directing the flow of water from a river through a turbine generator at lower elevation, hydroelectric dams can serve as energy storage devices, if surplus grid power is used to pump water from the low side to the high side of a dam.
Compressed Air Energy Storage	Surplus grid power can be used to compress and store air in an underground cavern. When electricity is required, the pressurized air is typically heated and expanded in a turbine driving a generator to produce electrical power.
Flywheel Energy Storage	Electrical or rotational energy is stored by accelerating a rotor (flywheel) to a high rotational speed. Extracting energy through a generator will slow the flywheel.
Rechargeable batteries	The most common form of electrical energy storage near the point of use. They contain electrochemical cells that store energy with a mechanism for releasing it on demand.

6.2 Recommendation

Locally available energy sources can alleviate energy demand and risks in some cases. Therefore,

- The USD(AT&L) science and technology (S&T) organizations and Military Departments should continue to invest in research, development, test, and evaluation (RDT&E) of alternative energy technologies with the potential to offer improved capabilities in remote and forward areas. In particular, these technologies should be measured in terms of reduced logistics, reduced signature during operations (i.e., survivability), reduced health and safety risk to warfighters (e.g., force protection) and the local population, and reduced overall cost (not an exhaustive metrics list).

7 The Case for Nuclear Power

7.1 Nuclear energy sources can provide abundant, continuous electrical power

The Task Force evaluated the merits of nuclear power energy systems toward the "what if" goal of providing reliable, abundant, and continuous energy on a continuous basis, shutting down only for maintenance and/or long-term refueling.

In the United States, nuclear plants generally operate as base-load plants, generating electricity around the clock at low marginal operating costs. This source is not subject to weather nor the intermittency associated with wind and sun. The Task Force assessed and found that nuclear energy in the form of certain very small modular reactors—an explicit tasking in this study—for use at FOBs and ROBs, could provide ample/sufficient energy for current and anticipated future energy requirements and demands. Nuclear power sources could offer a compelling alternative for the production of electrical energy to employing either conventional fossil fuels or alternative energy sources for military applications. The Task Force acknowledges there are numerous challenges for making nuclear energy a reality for these purposes. However, these are not insurmountable. This section of the report addresses the benefits and challenges for nuclear energy application to FOBs and ROBs.

7.2 Categories of nuclear power energy systems

For the purposes of this study, the Task Force characterized nuclear power energy systems into three categories—all of which exploit the transformation of mass in the nucleus of an atom into energy: 1) radioisotope thermoelectric generators; 2) large nuclear power plants; and 3) small modular reactors (a subset of this category is very small modular reactors). The Task Force did not review large nuclear reactors because they are not relevant to FOBs and ROBs. A brief discussion of each category follows.

7.2.1 Radioisotope thermoelectric generators

The first category of energy systems is the radioisotope thermoelectric generator (RTG). The nuclear fuel used in RTGs is generally a radioisotope that spontaneously decays, breaking down the original atomic nucleus and releasing energy—proportional to the mass lost—and matter from that nucleus. RTGs work by converting the heat generated from the natural decay of radioactive materials directly into electricity, typically through a series of solid-state thermoelectric couples (though other power conversion technologies have been considered). RTGs have been used to power satellites, spacecraft, and remote unmanned facilities where conventional power systems are impractical or infeasible. The radioactive materials used as a fuel source for RTGs include plutonium-238 and strontium-90.

In general, existing designs of RTGs yield a smaller electrical output than needed in the field by the military, requiring multiple RTGs and compounding the logistics and policy problems.

RTGs are well understood and have been deployed in Russian lighthouses and many of NASA's satellites, for example. A recent DSB study suggested that RTGs be evaluated for dismounted warfighters as a means to eliminate demand for small batteries. RTGs are simple to operate with no chain reaction concerns. However, there are safety and security concerns with the fuel materials, which contributes to the political sensitivity of introducing these materials into foreign countries.

7.2.2 Large nuclear power plants

There are hundreds of large nuclear power plants worldwide with a power output over 300 MWe; most of these facilities have a power capacity of greater than 1,000 MWe. The most common are light water reactors in which the nuclear fuel undergoes a fission reaction to produce thermal energy that is used to boil water into steam in the coolant loop, which in turn drives a turbine generator set to produce electricity. These reactors are sold by commercial vendors globally but, for the purposes of this study, they were not considered due to the fact their power output greatly exceeds the needs of any envisioned forward or remote operating bases.

7.2.3 Small modular reactors

According to the DOE, small modular reactors are nuclear power plants with an output of less than or equal to 300 MWe. Throughout this study, the Task Force reviewed several reactor concepts considered a very small variant of SMRs with output less than 10 MWe. Some terms used for such reactors are special purpose nuclear reactors (SPNRs), very small modular reactors (vSMRs), and micro modular reactors (MMRs). The Task Force chose the term *vSMR* to refer to SMRs which are significantly smaller than commercial SMRs, and could conceivably be transportable and deployable in FOB, ROB, and expeditionary force situations. vSMRs are nuclear reactors consisting of nuclear fuels that undergo a fission reaction to release their energy and matter, and the heat would typically be converted to electricity via a power conversion system. This class of power sources differs in important ways from traditional nuclear reactors. Most of the vSMRs evaluated by the Task Force do not use typical moderator or cooling systems commonly found in traditional light water nuclear reactors; that is, they are a subset of "advanced" non-light water reactors.

The Task Force acknowledges vSMRs may create an opportunity to invert the expeditionary energy supply paradigm from energy scarcity to abundant energy—constrained only by the output capacity of the reactor and not logistics. Not only could a reactor reduce the need for logistics related to power, but now-abundant power could essentially substitute or reduce the need for other infrastructure and logistic needs such as water, munitions, and potentially even fuel or spare parts. This relates back to the Task Force's "what if" approach for this study.

7.3 Recent proposals to evaluate or develop vSMRs for military bases

The Task Force notes that the idea of deploying vSMRs to forward and remote bases is not new. A history of the Army's (terrestrial vSMR) reactor program, which ran from the 1950s through 1970s, has been described in several publications.[28] Although several recent reports address the attractiveness of a small deployable reactor for military or emergency applications,[29] much of the literature discusses the merits of vSMRs for permanent and typically remote military installations.[30] The Air Force, in particular, addressed SMRs in the 2009 Air Force Science Advisory Board report, recommending that the Air Force evaluate nuclear power systems for selected bases and engaging the DOE and industry for a concept demonstration[31] – which was echoed by the Air Force's Chief Scientist as a technology to watch, which holds promise for ground stations in the 2016–2025 time frame.[32] Most recently, Sandia National Laboratories supported a study on Air Force Space Command installations, in which Schriever Air Force Base (AFB) in Colorado and Clear Air Force Station (AFS) in Alaska were identified as the most suitable locations to evaluate the feasibility of siting a light water SMR[33] – using a method developed by Oak Ridge National Laboratory for evaluating the suitability of DOE and DoD properties for siting light water SMRs.[34]

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[28] George E. Robitaille, "Small Modular Reactors: The Army's Secure Source of Energy?" (DTIC Document, 2012), http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA561802; George Griffith, "US Forward Operating Base Applications of Nuclear Power" (Idaho Falls, ID: Idaho National Laboratory (INL), 2015), http://www5vip.inl.gov/technicalpublications/Documents/6468101.pdf; Lawrence H. Suid, *The Army's Nuclear Power Program: The Evolution of a Support Agency* (Greenwood Publishing Group, 1990); Robert A. Pfeffer and William A. Macon Jr, "Nuclear Power: An Option for the Army's Future," *Army Logistician* 33 (2001): 4–8.

[29] Griffith, "US Forward Operating Base Applications of Nuclear Power"; J.R. Powell and J.P. Farrell, "Compact, Deployable Ultra Lightweight Multi-Megawatt Nuclear Power Systems for Very Long Range Electromagnetic Launchers," in *2008 14th Symposium on Electromagnetic Launch Technology*, 2008, 1–5, doi:10.1109/ELT.2008.96; NRC, "Force Multiplying Technologies for Logistics Support to Military Operations" (National Academies Press, 2014).

[30] Marcus King, LaVar Huntzinger, and Thoi Nguyen, "Feasibility of Nuclear Power on US Military Installations (2nd Revision)" (Washington, DC, 2011), http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA550479; Richard B. Andres and Hanna L. Breetz, "Small Nuclear Reactors for Military Installations: Capabilities, Costs, and Technological Implications" (DTIC Document, 2011), http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA545712; William J. Barattino et al., "The Business Case for SMRs on DOD Installations," January 1, 2011, 433–44, doi:10.1115/SMR2011-6552.

[31] Woodard and Sailor, "Alternative Sources of Energy for U.S. Air Force Bases."

[32] USAF Chief Scientist, "United States Air Force Energy S&T Vision 2011-2026 (AF/ST TR 11-01)," January 31, 2012.

[33] Thomas R. Boland et al., "MR1: Assessment of Small Modular Reactor Suitability for Use On or Near Air Force Space Command Installations (SAND2015-8732)" (Sandia National Laboratories, August 2015), SAND2015-8732.

[34] Willis P. Poore III et al., "Evaluation of Suitability of Selected Set of Department of Defense Military Bases and Department of Energy Facilities for Siting a Small Modular Reactor" (Oak Ridge National Laboratory (ORNL), 2013), http://www.osti.gov/scitech/biblio/1073001.

The Defense Advanced Research Projects Agency was the first DoD organization in recent history to budget for vSMR research and development. After issuing a public request for information (RFI) in 2010,[35] DARPA budgeted $10 million in FY12 to develop a rugged deployable reactor program.[36] Overall, DARPA proposed a six-year, $150 million program to develop compact, simple, and safe nuclear reactors with an output of 10 MWe or less and capable of producing fuel and water in addition to electricity; such reactors would be suitable for large (i.e., battalion or larger) forward bases. The proposed program planned to leverage DOE programs for technology innovation and siting/regulatory paths. However, the program was never started and was abandoned due to budget cuts.

7.4 The DoD is not participating in advanced commercial developments in order to tailor them for their unique needs

There are multiple vendors in the United States and internationally who are working on the development and deployment of light water (and other variants of) SMRs for commercial use. In general, these SMRs target power markets in the few hundred megawatt- to gigawatt-scale systems. The Task Force interviewed many of these vendors to understand the state of their technology and their plans for deployment. While all the vendors seemed interested in the DoD market, none offered any assurance they would be willing to divert resources at this time away from their expressed commercial interests. As a result, given the technical, operational, licensing, and economic challenges associated with commercial sized SMRs, these systems as a class appear not to be suitable for our forward contingency locations. Given the need to "ruggedize" these systems for DoD applications, we believe it would require substantial investment to modify these commercial designs for forward and remote operating base applications. Examples of these modifications include extensive concrete fortification, placing the SMRs below grade, and constructing a berm around them to avoid line of sight access.

7.5 State of readiness of vSMR technology

Several of the commercial light water SMR designs the Task Force reviewed are currently under development in the United States and conceivably could be redesigned and properly scaled for remote operating bases (e.g., Fort Greely, Alaska; Sundance, Wyoming; or Camp Century, Greenland), considering appropriate electricity, water purification, and process heat requirements of the base (and potentially the surrounding civilian infrastructure). These are the same bases previously served by the Army's Nuclear Power Program.

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35 DARPA, "Request for Information (RFI) on Deployable Reactor Technologies for Generating Power and Logistic Fuels - Federal Business Opportunities: Opportunities," 2010, https://www.fbo.gov/index?s=opportunity&mode=form&tab=core&id=d0792af88a6a4484b3aa9d0dfeaaf553&_cview=0.

36 Ibid.

The Task Force reviewed a few light water vSMR concepts[37] better suited for ROBs or offshore electricity supply (e.g., the former USS Sturgis, which consisted of a vSMR on a barge) due to physical size and transportability attributes. The light water vSMR designs are in various stages of development and licensing, and could be in commercial operation in the 2023-2025 time frame. There is another class of SMRs entitled "advanced" reactors. These advanced SMRs use more exotic cooling and/or moderating systems in their operation (e.g., liquid metal, molten salt, and high temperature gas). It is widely held that these advanced systems are at least a decade or more behind light water SMRs in development and licensing.

Considering the multifaceted uses of FOB power supplies now (e.g., electricity, process heat, water treatment) and in the future (e.g., incorporating energy weapons) and the stated size requirements (less than 10 MWe), the Task Force found the most likely vSMR technologies that merit consideration would be advanced vSMRs or radioisotope power systems. Below is a list of attributes with a range of suggested characteristics for vSMR systems for use at FOBs and ROBs as informed by Task Force discussions and a recent INL report[38] which summarizes findings from a DARPA request for information.[39] Key required characteristics of vSMRs and other findings from the INL report are reproduced in *Appendix I*.

- *Outputs:* Modular and scalable units capable of producing 2–10 MWe and potentially useful heat (which could facilitate water or fuel production)
- *Size and transportability:* 25–40 tons; transportable by truck or C-17 aircraft
- *Ultimate heat sink:* Ambient air (in contrast to conventional water-cooled reactors); capable of passive cooling
- *Time to install:* 12–72 hours
- *Refueling:* Refueling should not be required more than annually; fresh and used fuel should be transportable by air, sea, and ground
- *Time for planned shutdown, cool down, disconnect, and removal:* 6 hours to 7 days
- *Operation:* Autonomous or semiautonomous operations with minimal manning to monitor overall health of the vSMR

[37]It is also technically feasible for all of the commercial light water SMR designs currently under development in the United States to be used to supply electricity to DoD bases within the continental United States under specific requirements. These requirements would include conditions such as near-base siting, utility-owned and operated, Nuclear Regulatory Commission (NRC) licensed, dedicated transmission line and electricity supply to the base, excess electricity supplied to the local grid. Consideration would also be appropriate for other outputs from the reactor such as water purification and process heat for the base and surrounding community.
[38] Gougar et al., "Innovative Deployable Energy System Concepts."
[39] DARPA, "Request for Information (RFI) on Deployable Reactor Technologies for Generating Power and Logistic Fuels - Federal Business Opportunities: Opportunities."

- *Response to emergency:* Capable of immediate shutdown and passive cooling
- *Health and safety risks:* No net increase in risk to public, military personnel, environment; no net increase in consequences of adversary attack
- *Proliferation risk:* No net significant increase in proliferation risk

The designs examined are in varying degrees of conceptual design and development. Some of the concepts examined involve teaming with industry, laboratories, and universities, which will help to ensure manufacturability, quality, innovation, and market factors are considered in design. The Task Force found two of the concepts more technically mature than the others. The first is LANL's MegaPower Reactor System and the other is Filippone & Associates LLC's "Holos" Gas-cooled Hardened Micro Modular Reactor. The vSMR concept descriptions below were informed by the technology developers; the Task Force did not assess the accuracy of the data.

MegaPower. One vSMR concept being developed by Los Alamos National Laboratory (LANL), which the Task Force reviewed, is the "MegaPower" reactor [Patent No. US 20160027536 A1]. In this concept, the nuclear fuel is uranium oxide enriched up to 19.5% in uranium 235. This level of low enrichment is considered "non-weapons grade" from a proliferation standpoint. The large mass of fuel is encapsulated in a solid steel monolith to form a sub-critical nuclear core which is surrounded by a material that reflects decay neutrons emanating from the uranium metal core back into the core, in a controlled way, causing a sustained nuclear reaction (a "critical reaction"). The thermal energy created by the fission reactions is removed from the uranium metal core by heat pipes, which in turn produce electrical energy via open-air Brayton or supercritical carbon dioxide Stirling engines. This concept is designed to provide 2 MW of electricity and another 2 MW of process heat for 12 years of continuous operation, weighs about 35 metric tons, and is transportable by air and highway. Funding from NASA and Laboratory Directed Research and Development programs is being leveraged to mature MegaPower. The system could be connected to the generators and operated within 72 hours upon arrival. The reactor system can be shut down, cooled, disconnected, and "wheeled out" in less than seven days. The reactor core and all other critical equipment are housed in special armor, which protects the reactor systems from beyond the design basis attack, and also shields personnel and environment from the core radiation during operation and transport. The design is mature, but would require additional investment for demonstration. Every component has technology readiness level (TRL) of six [40] or better, with integration of the components into system prototypes the major remaining work to be done. A projection has been made that a unit could be available for concept demonstration in five years.

[40] TRL 6 is defined as a system/subsystem model or prototype demonstration in a relevant environment. Examples include testing a prototype in a high-fidelity laboratory environment or in a simulated operational environment.

Other technical features include proven uranium dioxide fuel (19% enriched), solid steel monolith core, and passive heat pipe coupling with no moving parts in the core. Connection to generators requires thermal-hydraulic coupling (balance of plant) for transport of the turbine fluid to the turbine-generator system outside of the containment/shield vessel housing the core.

Holos. This concept features a "plug-and-play" system with effective full-power days (EFPDs) capability corresponding to approximately 13 years with 8% core enrichment as determined by an independent study[41] and a privately funded study.[42] The core sub-assemblies and shields can be transported with current FOB and ROB lifting capabilities. Only when all sub-assemblies are coupled via exoskeleton structure in an armored and shielded ISO transport container, the core becomes whole and coupled neutronics enables electricity production. The core sub-assemblies fit in storage canisters commercially utilized for waste/spent fuel temporary and permanent disposal to minimize decommissioning cost. If required, each sub-assembly may be loaded with different fissile and fertile isotopic compositions. Holos integrates modular power conversion systems within each sealed core-sub-assemblies and does not require balance of plant or equipment outside the armored ISO transport container. The Holos core is formed by universal cartridges which can be loaded by various types of fuels and moderators, including ceramic melt-resistant fuels, and other advanced fuels proposed by various national laboratories.

Safety features are included in both of these designs to address the concern of breaching in hostile or accidental environments. For Holos, to address the reactor core breach risk due to attack or sabotage, the vSMR concepts sustain damage only if the sub-assemblies are involved in a direct hit. This assumes penetration of the armored transport container, shielding, and sub-assembly pressure vessels. Sub-assemblies not directly hit become displaced from optimal geometry and inherently induce the "whole" core shutdown. The use of TRISO fuel ensures volatile dispersion would be minimal. Each sub-assembly, if stolen, could not become supercritical. The core composition makes it nearly impossible to utilize maliciously, other than as base for ineffective dirty bombs. Holos could be built and tested at full-scale with an electrically-driven mockup core in less than three years. Holos does not require on-site working fluid charging (no balance of plant) and can remotely execute start-up, load following, and shut-down operations under cybersecurity protocol currently applied to drones. As it can be factory-tested and certified, it is deployed ready for electric connection to the grid or represent an electric island at sites with no grid. One hour after shutdown, assuming 10 years of uninterrupted 10 MWe production the Holos whole core (all sub-assemblies) will dissipate 250 kW of decay heat. Decay power further decreases to 100 kW in less than 30 hours for the whole

[41] Holos neutronic analysis executed and published by the Department of Physics and Nuclear Engineering United States Military Academy, West Point, NY.

[42] Holos core neutronics and shielding analysis executed by the Department of Material Sciences & Engineering at the University of Florida.

core representing approximately 3.3 kW thermal per sub-assembly, thus enabling rapid air-transport after shutdown.

7.6 Transportability of vSMRs

A representative from the Air Force's Rapid Engineer Deployable Heavy Operational Repair Squadron Engineer (RED HORSE) contingency construction organization briefed the Task Force on how a vSMR concept could be incorporated into FOB or ROB operations. The comparable construction battalion within the Navy is the Seabees and within the Army is the Corps of Engineers; it was clear that constructability of vSMRs fall within these entities' capabilities.

The perceived risks of transporting nuclear fuel—whether unirradiated or used (aka "spent" fuel with high radioactivity) have been considered and a plan of transport operations conceived, **Figure 2** illustrates how a vSMR might be transported to the forward operating area.

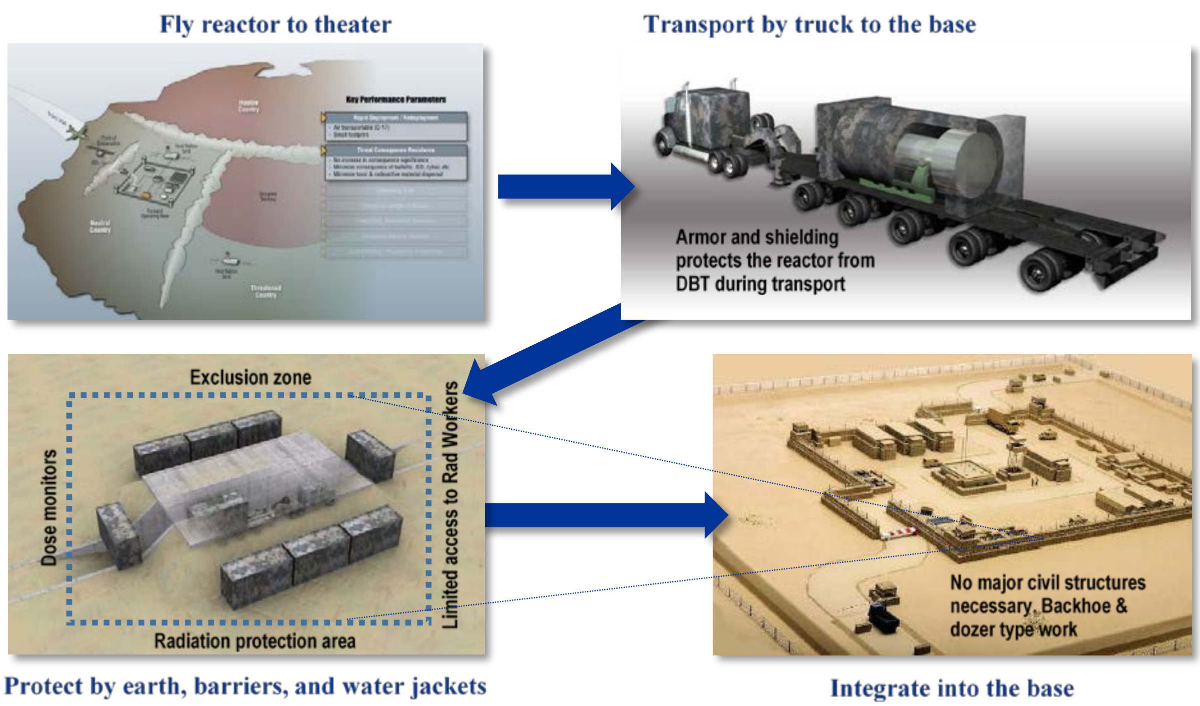

Figure 2. Concept of Operations: Transport to Theater and FOB

7.7 Some challenges of vSMRs

Although the Task Force did not consider the technical challenges of designing and building vSMRs to be insurmountable, we fully appreciate the other challenges facing deployment—from the proliferation threats, to deployment on foreign soil, to the regulatory process. The Task Force reviewed these challenges and understands these must be worked in parallel with vSMR technical concept development. This section provides a summary of the challenges the Task Force examined.

7.7.1 Threat risk and consequence management

A risk associated with placing a nuclear reactor at a remote or forward operating base, or to support Expeditionary Forces on foreign soil, is that adversaries may potentially target the reactor as 1) a lucrative target to become a dirty bomb if breached, or 2) as a source of fissile material that could be extracted and repurposed for nuclear weapons, should that reactor contain highly enriched uranium (HEU). Thus, the Task Force did not consider designs calling for HEU. In fact, the reactors proposed for military use assessed by the Task Force focus on low-enriched uranium (LEU) (i.e., less than 20% enrichment) or other fuel types that may have an even lower proliferation risk.

Key system attributes of a vSMR would include that the reactor poses no significant increase in FOB threat consequence effects (e.g., unacceptable radiological consequences), and that the reactor would be capable of immediate shutdown and passive cooling. The concepts the Task Force considered had threat risk and mitigation technology incorporated into their designs. A consequence management plan should be part of any operational plan or humanitarian relief plan in which vSMRs are a part. Such planning should include technical, political, radiological health, and environmental aspects. Furthermore, the Task Force believes the proliferation concern associated with vSMRs is likely no greater than that associated with commercial reactors.

7.7.2 International deployment considerations

Overcoming the current stigma associated from fear and distrust of radioactive materials could be achievable in the lead time horizon of vSMR fielded capability. It would be prudent to pursue international transportation, policy, and liability agreements prior to deployment.

The Task Force examined the policies that support entry of U.S. nuclear powered warships into foreign ports to determine if these policies might be helpful in shaping policies for land based reactors on foreign soil. As with all naval vessels, nuclear powered ships and submarines enter foreign ports around the globe. Nuclear powered ships and submarines make more than 150 ports of call each year in over 50 foreign countries. The DoD would need to work with the Department of State, the DOE, the Nuclear Regulatory Commission (perhaps), and the host nation to develop policy for use of vSMRs in a foreign country, leveraging what may be applicable from the Navy's experience.

Deploying a vSMR terrestrially in a foreign country may require the United States to hold a bilateral agreement covering privileges and immunities of the reactor and its operating personnel, military or civilian, as well as liability issues with the host country prior to the desired time of deployment. This guidance likely holds for both Humanitarian Assistance Disaster Relief (HADR) and conflict scenarios—utilizing rugged military vSMRs for humanitarian scenarios has been proposed since the early days of the Army's reactor program. Some of the international considerations the Task Force surfaced are presented in the table below. The Task Force did not explore whether these are all applicable to vSMR deployment abroad, but we present these to the DoD to legally review and resolve prior to deployment.

- Should the USG seek diplomatic clearance for transport on or over foreign territorial sea (12 miles limit) or exclusive economic zone (200 mile limit)? Or, should doing so be considered an exercise of freedom of the seas?
- Should the vSMRs and physical protection systems be designed to meet standards for non-military/peaceful applications, as described in the *Convention for the Physical Protection of Nuclear Material*, article 2, paragraph 1, and the IAEA INFCIRC 225, paragraph 1.18?
- If deployed at a ROB during peacetime, should the host nation's regulatory organization have oversight authority over the U.S. military vSMR? (If contractor owned and/or operated, we suspect it is more likely that the host nation's authority would have jurisdiction if available.)
- *Nuclear Non-Proliferation Treaty*, IAEA safeguards, and bilateral Nuclear Cooperation Agreements with host states would not apply, as these generally apply only to peaceful nuclear activities.
- Introducing a military vSMR in a hostile environment may be considered dangerous to civilians and neutral nations. Although the United States is not a party, 174 nations are party to *Article 56, Additional Protocol I to the 1949 Geneva Conventions*, which prohibits attacks on reactors that might release dangerous forces.
- *The Convention on Early Notification of a Nuclear Accident* requires "any accident involving facilities or activities of a State Party" involving a release or a likely release of radioactive material that could be of radiological safety significance for another State" information on the accident is to be given, either directly or through the IAEA, to any countries which "are or may be physically affected." The United States is a party, and the DoD would need procedures to make the necessary notifications through the State Department.
- Under these treaties, operators are not liable for damage resulting from armed conflict, civil war, or insurrection (*Convention on Supplementary Compensation, Annex Article 3, paragraph 5; Vienna Convention, article IV, paragraph 3(a)*). Although the United States is not a party to these treaties, it could become party to the *Convention on Supplementary Compensation*.
- What International Traffic in Arms Regulations (ITAR) requirements must be considered?

7.7.3 Regulations and licensing

While the Military Departments successfully operated nuclear reactors in remote sites for nearly a quarter century from 1954 to 1977, the regulatory apparatus that has been subsequently imposed on the nuclear industry since 1977 makes the time required to field the capability—even at TRL 6 for the subsystems—to be 10 to 15 years. The Task Force believes the long-pole in fielding the capability would be dominated by the licensing process, financing, and siting considerations—not engineering considerations—if innovative thinking is not applied in these areas. A successful example of a U.S. Government organization responsible for military reactors exempt from civilian licensing under Section 91 of the *Atomic Energy Act* is the Naval Reactors program. *Appendix J* is a primer on the Naval Reactors organization.

Authors of the Center for Naval Analyses (CNA) report stated that it "seems unlikely that DoD would pursue exemption under [*The Atomic Energy Act*] Section 91b[43] in the future" if seeking to site a nuclear power system at a military installation, such that the Nuclear Regulatory Commission (NRC) would serve as the primary regulator; however, the authors of the CNA report acknowledged that DoD may deem it worthwhile to exercise this authority if a vSMR were incorporated into tactical power systems[44] (which may include HADR). Although the NRC is currently unprepared to review an application for a license for an advanced reactor, the NRC has stated it could ramp up the required expertise through contractors from industry, academia, national laboratories, and within the U.S. Government. The Task Force understands that the DOE Office of Nuclear Energy provides nuclear power systems for national security applications via transfer under *Atomic Energy Act* Section 91b under DOE safety authorities.

Particularly, the DoD should explore exemption under Section 91b in the future. Regulating nuclear power plants is not a current DoD core mission, but if the DoD could assemble and invest in the personnel with sufficient expertise to act as regulators for nuclear power plants, this could be a path. The Task Force believes the DoD should investigate alternative approaches (other than through the NRC, to include DOE's regulatory approach for non-commercial applications) to license vSMRs (e.g., demonstrations, DoD exceptions, self-regulating), which may not be as constraining as the NRC process but could still ensure an equal level of safety assurance.

7.7.4 Costs

The Task Force found little interest in the commercial sector for developing SMRs with a power output comparable to the energy demand at FOBs and even ROBs. Vendors are focused on the

[43] Section 91b. The President from time to time may direct the Commission (1) to deliver such quantities of special nuclear material or atomic weapons to the Department of Defense for such use as he deems necessary in the interest of national defense, or (2) to authorize the Department of Defense to manufacture, produce, or acquire any atomic weapon or utilization facility for military purposes…"

[44] King, Huntzinger, and Nguyen, "Feasibility of Nuclear Power on US Military Installations (2nd Revision)."

much larger international markets and have not seen a demand signal to explore design variants aimed at DoD applications. For these vendors to consider DoD vSMR applications, the DoD needs to step up with an investment strategy for at least prototyping such a capability.

Development costs

The Task Force does not have high-confidence estimates of vSMR development costs.[45] The Task Force was presented engineering estimates based on the current states of design, engineering development, prototype testing, and component/material supply chain and procurement specification maturity.

There may be benefit in extrapolating from current light water SMR design development, albeit these are not suitable for FOBs. For example, the current DOE-SMR program[46] has provided qualitative development cost estimates of approximately $1 billion for engineering, design development, testing, NRC design certification, and the detail design to be able to procure components for each first-of-a-kind (FOAK) SMR. Recently, a detailed cost estimate was performed by NuScale with their owner and engineering partner, Fluor, for a 12 reactor SMR system with approximately 570 MWe in net power output. NuScale believes this effort would require greater than $1 billion for FOAK development costs and roughly $3 billion overnight capital cost for the site specific engineering, procurement, and construction (EPC) of the FOAK plant. Costs are expected to decline due to learning, factory manufacturing, and repetitive use of the standard plant design such that the "nth–of-a-kind" EPC cost might be approximately $2.5 billion. Added to that would be the owner's initial SMR costs, estimated at about $300 million and financing costs for the period of any loans or financing. For an SMR suitable for a FOB, testing, experimentation, and prototype demonstrations could likely be more rigorous and extensive than planned for the commercial NuScale SMR, thus adding to development costs. Additional prototype demonstrations of a vSMR power unit, generator units, and other potential process units (e.g., process heat, water purification, and/or desalinization) would likely be required before military procurement, due to the unique reliability, protection, operational, and transportability requirements for FOB or ROB vSMRs.

The development costs for more advanced reactor concepts are even less firm. For example, presenters from the LANL[47] cited a FOAK range of $140 million to $325 million for their reactor heat pipe system, MegaPower, with an expectation that the power conversion system would be provided on a loan basis for the initial vSMR development and testing. Considering a $25 million to $50 million range for the power conversion and other process system design

[45] Previous reports on the feasibility and challenges associated with constructing the first SMR have ranged from $800 million to $2 billion.

[46] NuScale Testimony before the House of Representatives Energy Subcommittee Committee on Science, Space and Technology, Michael McGough, December 11, 2014.

[47] LANL Brief - "Special Purpose Reactor for Powering DOD Operations", P. McClure, January 14, 2015

development, then advanced reactor FOAK development costs could range from $150 million to $375 million. The large cost uncertainties reflect the impact of interagency agreements that could potentially be worked out between DoD and DOE/NNSA entities. The recently enacted Gateway for Accelerated Innovation in Nuclear Energy (GAIN) program offers an effective method for public-private partnership to mature technologies that may include MegaPower. Los Alamos is teaming with Idaho National Laboratory to exploring potential pathways for demonstrating and ultimately commercializing this technology. Costs associated with the MegaPower concept, which the Task Force found to be the most technically mature advanced vSMR, are listed below.

MegaPower cost estimates include:

- Reactor technology development: $85 million to $125 million
- LEU fuel (16 to 19% enriched) depending on DOE fuel supply: $5 million to $45 million
- Development and test facility modifications: $50 million to $100 million
- Transport Security Armor development: $0 to $25 million
- NRC Licensing: $0 to $30 million
- Total estimated costs: $140 to $340 million

As a second example, the Holos concept cited FOAK range of $51 million inclusive of integral core and power conversion system (all comprised in its sealed sub-assemblies) with a projected NRC licensing cost of $114 million based on large light water reactor licensing cost estimation models. As a full-scale electrically driven reactor prototype, Holos can support and accelerate licensing procedures and processes, and the estimated licensing cost may be reduced. Costs associated with the Holos concept are listed below.

Holos cost estimates include:

- Reactor technology development: $51 million
- LEU fuel (<10% enriched): $4.5 million (no refueling)
- Development and test facility modifications: $5 million to $8 million
- Transport Security Armor development: $0 to $10 million
- NRC Licensing: $0 to $114 million
- Total estimated cost: $60.5 to $187 million

Expected life-cycle costs

The cost of ownership of vSMR technologies is not just the cost to develop and acquire; it includes all of the life-cycle costs and liability through operation, operational support (i.e., fuel movement and costs if refueling is required), and ultimate disposal of the system and any waste generated. Category comparison with current SMRs can be assessed, but for vSMR there is no data. The life-cycle costs may be less than current SMRs, although the assessment has not been done.

Decommissioning and disposal costs

In addition to acquisition, deployment, and operating costs, the DoD needs to plan for the end of deployment and/or end-of-life phase.

The activities associated with either decommissioning after deployment or ultimate disposal of the SMR or its fuel is likely to be highly regulated, whether the activities were to take place in the United States after a deployment or in a host country where the vSMR has been operating.

Factors that need to be considered in decommissioning and disposal include:[48]

- physical plant aspects (i.e., configuration, condition, and amount of contaminated materials)
- reactor location, type, and operating history
- amount of spent fuel that must be handled
- decommissioning program plans and project team experience
- time available for decommissioning work
- waste disposal infrastructure availability
- distance from disposal facilities and the effect on waste transportation costs
- unique requirements of countries (that the vSMR was deployed to/operated in)

In the case of deployable vSMRs, a power generation location (or plant) may be taken out of service for the purpose of redeployment but may not in fact be the "decommissioning" of the vSMR. Additional procedures and guidance should be developed for the safe deactivation or defueling, movement, and/or storage for reuse of the vSMR.

7.8 Bottom line—The Task Force finds there is room for nuclear power

The Task Force identified a series of challenges to nuclear power for FOBs and ROBs as reflected in the previous sections. However, we did not consider any as "show-stoppers" to pursue engineering development and prototyping of vSMR capability. Rather, the Task Force

[48] Small Modular Reactor Report 2013 – "Delving Deeper to Get Better Control Over Decommissioning Costs" Ritesh Gupta, Nuclear Energy Insider December 11, 2013.

sees the need and benefit outweighing the difficulty in achieving nearly limitless energy on the battlefield. The Task Force did not find the technology to be unachievable nor are the deployment issues impossible; the U.S. military has overcome comparable challenges before. The needs of missions and regulatory policy will have to be balanced. Achievement will take leadership with vision to ride out the unavoidable bumps along the way. Patience and perseverance is needed in several key areas to enable vSMR development and deployment.

- Technology development and prototyping.
- Analysis and quantification of the operational and logistical benefits.
- Communication campaign to highlight the benefits of a vSMR as an enabler of future capabilities.
- Safety demonstration and licensing.
- Training of personnel or creating a government-owned, contractor-operated (GOCO) or contractor-owned, contractor-operated (COCO) arrangement.
- Development of agreements with other countries.

Regardless of the challenges confronting nuclear power options for FOBs and ROBs, the Task Force holds that while perhaps prohibitive for commercially motivated organizations, these should not be used as excuses and rationale for the DoD—a mission-driven organization—not to pursue game-changing technologies and capabilities.

The Task Force looked at the energy needs for tomorrow and found a void in enabling those needs to come to fruition. Energy will be the limiting enabler. While pursuing alternative energy sources and greater energy efficiency, the DoD must figure out a way to entice industry into a vSMR-niche market and provide an efficient path to pursue (e.g., regulatory relief). By implementing the Task Force's recommendations, we can further explore the approach of vSMR application to future military and humanitarian relief operations.

7.9 Recommendations

Some forward and remote bases may be suitable for vSMRs, where the challenges and risks associated with energy supply are significant. Therefore,

- The Secretary of Defense should designate the Army as the Executive Agent for all of the nuclear energy applications recommended in this study and provide adequate resources to accomplish the mission.
- The Secretary of the Army should direct the appropriate entity within the Army to investigate and invest in vSMR technology maturation and develop a demonstration program for application to forward and remote operating bases and expeditionary forces.

- The first deployment of a vSMR prototype should be to a remote site (e.g., Alaska or Guam) to develop personnel needs and concepts of operations (CONOPs).
- The Defense Threat Reduction Agency (DTRA) with the DOE should conduct a study to assess vSMR consequence management scenarios.
- The Joint Staff should incorporate vSMRs into scenario planning models and future wargames.

Appendix A: Task Force Terms of Reference

ACQUISITION, TECHNOLOGY AND LOGISTICS

THE UNDER SECRETARY OF DEFENSE
3010 DEFENSE PENTAGON
WASHINGTON, DC 20301-3010

FEB 18 2014

MEMORANDUM FOR CHAIRMAN, DEFENSE SCIENCE BOARD

SUBJECT: Terms of Reference – Defense Science Board Ad Hoc Committee on Energy Systems for Forward/Remote Operating Bases

Operations at forward/remote operating bases require a significant amount of energy. By its nature, a forward, remote operating base lacks the surrounding infrastructure to easily transport the large quantities of energy required to support operations. Therefore, supplying energy at forward, remote operating bases incurs significant costs (e.g. personnel, monetary, force structure, etc.) and risks (e.g. security, scarcity, etc.) at both the endpoint as well as the logistical operations used to supply the energy.

The study should assess the different mechanisms to provide energy to forward, remote operating bases. In addition, the assessment should identify the relevant factors (e.g. survivability, sustainability of logistics services, force protection requirements, etc.) of the energy sources. At a minimum the study should address these factors in a qualitative manner. Whenever possible, the study should provide quantitative analysis.

The study is not constrained to address any one mechanism to support the energy needs of a forward operating base. However, to address Senate Armed Services Committee National Defense Authorization Act for Fiscal Year 2014 language, it should examine the feasibility of deployable, cost-effective, regulated, and secure small modular reactors with a modest output electrical power (less than 10 megawatts) to improve combat capability and improve deployed conditions for the Department of Defense (DoD). The study must address: technical feasibility, policy oversight and regulation, robust safety and secure design features, logistics and resources, proliferation concerns, life-cycle costs, deployment policies and transportability, personnel costs, and lessons learned from recent combat operations.

I will sponsor the study. General Paul Kern, USA (retired) and Dr. Michael Anastasio will serve as Co-chairmen of the Task Force. Dr. Bret Strogen, from the Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, will serve as Executive Secretary, and Lt Col Michael Harvey will serve as the Defense Science Board Secretariat Representative.

The study will operate in accordance with the provisions of P.L. 92-463, the "Federal Advisory Committee Act," and DoD Directive 5105.04, the "DoD Federal Advisory Committee Management Program." It is not anticipated that this study will need to go into any "particular matters" within the meaning of title 18, U.S.C., section 208, nor will it cause any member to be placed in the position of action as a procurement official.

Frank Kendall

Appendix B: Task Force Membership

Co-Chairmen

Dr. Michael Anastasio

General Paul Kern, U.S. Army (Retired)

Members

Admiral Frank "Skip" Bowman, U.S. Navy (Retired)

Major General Jan Edmunds, U.S. Army (Retired)

Dr. Gerry Galloway

Dr. William Madia

The Honorable William Schneider

Government Advisors

Colonel Thomas Bongiovi	Joint Chiefs of Staff
Mr. Nathan Cornell	U.S. Army
Dr. Juan A. Vitali (supporting)	U.S. Army
Mr. Michael Richards (supporting)	U.S. Army
Mr. John Roros	U.S. Navy
Captain Kevin Gallagher (supporting)	U.S. Navy
Mr. Burrus Carnahan	Department of State
Mr. Thomas Miller	Department of Energy

Executive Secretary

Dr. Bret Strogen	Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics

Defense Science Board Secretariat

Ms. Karen D. H. Saunders	Executive Director
Colonel Rob Freeland, USMC	Executive Director *(prior)*
Mr. Robert Ramsey III	Executive Director *(prior)*
Mr. David Jakubek	Executive Director *(prior)*

Lieutenant Colonel Victor Osweiler, USAF	Deputy for Operations *(beginning Dec 2015)*
Lieutenant Colonel Michael Harvey, USAF	Deputy for Operations *(through Dec 2015)*

Study Support

Ms. Sarah Gamberini	SAIC
Ms. Brenda Poole	SAIC

Appendix C: Briefings Received

13 – 14 January 2015

Overview of the Historical "Army Nuclear Power Program" and Current Responsibilities of the Army Reactor Office
Army G3

Regulation of Commercial and Military SMRs
Nuclear Regulatory Commission

Policy and Regulatory Considerations for "Micro" Reactors for Domestic and International Use
Law Firm of Morgan, Lewis & Bockius, LLP

SMR-160 Overview and Nuclear Component Fabrication
Holtec International

Overview of UPower Technologies Concept Reactor
UPower Technologies, Inc.

Applying the B&W mPower Reactor Technology to Forward Operating Bases, Generation mPower
B&W

ORNL's Salt-Cooled Reactor Development – Status and Related SMR Experience
Oak Ridge National Laboratory

Fully Burdened Cost (FBC) Tool – Support to Tradeoff Analysis
Army G4

Previous Assessments of SMRs for Military Use
Creative Erg, LLC

4S Reactor
Toshiba

Special Purpose Reactors for Powering DoD Operations
Los Alamos National Laboratory

Innovative Deployable Energy System Concepts - Summary of Results of a DARPA Project
Idaho National Laboratory

Sodium-Cooled Fast Reactor Concepts and AFR-100
Argonne National Laboratory

NuScale SMR and Potential Adaptation to Forward/Remote Operating Bases
NuScale

Westinghouse Small Modular Reactor Technology Overview
Westinghouse

Compact Fusion Reactor
Lockheed Martin Skunk Works

Next Generation sUAS…Doing More with Less, Reducing Energy Demand
(Stalker XE Fuel Cell Technology)
Lockheed Martin Skunk Works

23 – 24 February 2015

Cluster Basing – A Joint Solution to the A2 Challenge
RAND

US Army PM E2S2: An Overview of PM E2S2 and Contingency Basing Camps
U.S. Army, Project Manager Expeditionary Energy & Sustainment Systems (PM E2S2)

Future Capabilities Wargame FG15: Basing Seminar
U.S. Air Force

Fuel from Seawater
U.S. Naval Research Laboratory

Teleconference with President and Chief Technologist
Flibe Energy

Small Modular and Advanced Reactor Technology: Industry Perspective
Nuclear Energy Institute

Red Horse Capabilities and Considerations for Supporting an SMR
U.S. Air Force

Navy's Nuclear Fleet Training & Management Program
U.S. Navy: Nuclear Reactors

Threat Analysis
Defense Intelligence Agency

An Overview of Issues, Opportunities, and Risks Associated with Forward Deployment of Small Modular Reactors
Independent Consultant

SMR Advanced Concept
Filippone & Associates LLC

Boeing Defense: Electrical Power Generation for Forward Operating Bases
Boeing

9 – 10 April 2015

TRADOC Capabilities for Base Camps: Army Operating Concept
Maneuver Support Center of Excellence, Capability and Integration Directorate

Wireless Electric Power Transfer for Vehicular Applications
U.S. Army TARDEC

Solar and Wind Power in Expeditionary Environments: Summary for DSB
Energy and Environmental Research Group, Center for Naval Analyses

USMC Expeditionary Energy Cost Analysis: Summary for DSB
Energy and Environmental Research Group, Center for Naval Analyses

Supporting Energy Needs for Forward/Remote Operating bases
Fluor

Overview and Outcomes from Defense Operational Energy Projects for Forward Operating Bases and More
Sandia National Laboratory

PACOM Basing, Oil Supply, and Other Ideas Related to Renewable Energy
PACOM

MegaPower: Mobile Reactor to Power DoD Operations at Remote Sites
Los Alamos National Laboratory and Y-12 Plant

Feasibility of Transportable & Retrievable Hardened Modular Reactors for the DoD
Filippone & Associates LLC

Forward Base Defense
Air Force Research Laboratory

Appendix D: Primer on Energy and Power Terminology

This appendix contains terminology the Task Force used to inform their study deliberations.

Energy and power

Energy is a measure of a system's ability to perform work. Energy can take many forms, including: kinetic energy (e.g., moving objects), radiant energy (e.g., sunlight), thermal energy (e.g., hot steam), gravitational potential energy (e.g., water at the top of a dam), elastic potential energy (e.g., tension on a spring), chemical potential energy (e.g., combustible fuels), or electrical potential energy (e.g., energy stored in a circuit as a result of an electrostatic field).

Common units of energy include megajoules (MJ), British thermal units (BTU), kilowatt-hours (kWh), calories, and gallons of gasoline equivalent (gge). The amount of energy stored per unit mass or volume of a material, or a material system, is its ***energy density***.

Power is expressed in units of energy per unit time, and common units of power include watts (W, defined as one joule per second) and horsepower (hp).[49] Power input characterizes the rate at which a system consumes energy, and power output characterizes the rate at which a system performs work (including the production of electrical energy). ***Power density*** refers to the rate at which a system can perform work or produce a useful form of energy (such as electricity) per unit mass or volume (often expressed in units of W/kg or hp/liter), without regard to the endurance of the system. Power density is also sometimes used to refer to power per unit area (e.g., W/m^2) of an antenna, solar panel, or cross-section of a wind turbine.

A Ragone Plot of various energy systems is shown in **Figure D-**, highlighting the vast range of energy density and power density found in common energy storage and conversion systems that are used for a variety of applications.

[49] For context, U.S. households consume approximately 1.2 kW on average over the course of the year (EIA, 2013), while a small passenger vehicle that gets 40 miles per gallon on the highway would consume approximately 50 kW in fuel (1.5 gallons per hour), and a typical American's diet amounts to approximately 100 watts (or 0.1 horsepower) in energy.

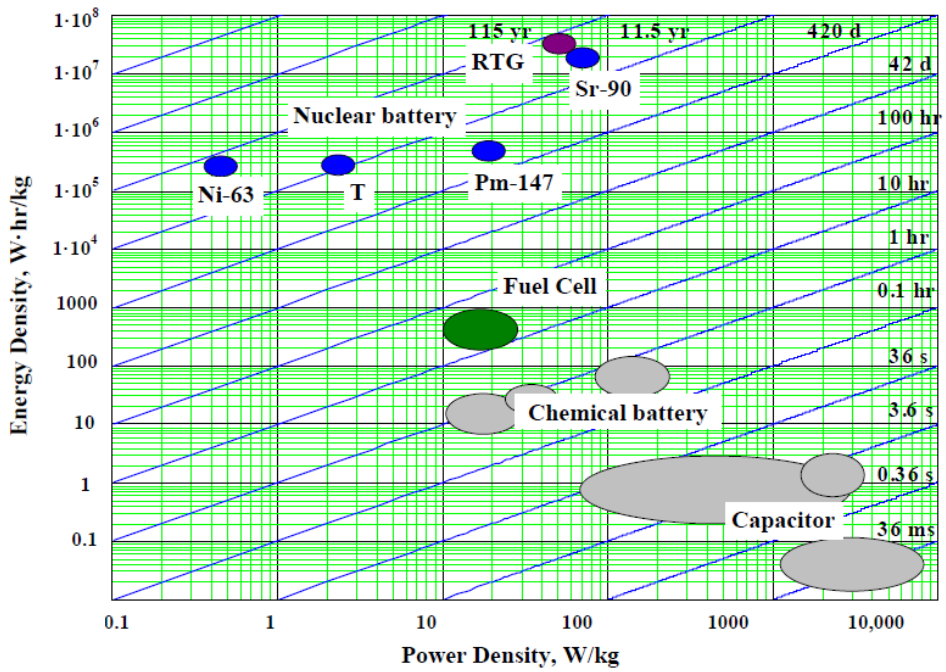

Figure D-1. Ragone Plot for Nuclear Batteries and Various Electrochemical Devices (from Yakubova, 2010)[50]

Energy efficiency is the portion of input energy into a device that is converted to—or maintained in the form of—a useful energy carrier (e.g., MJ of electricity or fuel) and/or a useful form of work (e.g., increased potential energy of a lifted object, or increased velocity of a vehicle); the remaining portion of output energy not considered "useful" is often manifested as waste heat. Electrical power conversion devices, such as diesel engines and power plants, often have an energy efficiency of 20% to 50% —that is, less than half of the energy contained in the input fuel is converted to electrical energy, and the rest is discarded to the atmosphere as thermal energy in the form of hot exhaust. Conventional thermal power plants (e.g., nuclear or coal) tend to be approximately 33% efficient, meaning that 1 MW of electrical power (MWe) is produced by a generator for every 3 MW of thermal energy (MWt) provided by the fuel. Electrical motors (e.g., in electric vehicles or oil pumps) can have efficiency close to 90%, as electrical energy can easily be converted to mechanical work.

Energy intensity is a metric of the energy input required per unit of functional activity (e.g., gallons of fuel per mile driven, kWh per lumen-hour of light, or MJ of fuel to heat a given volume of shelter space). In addition to improving the efficiency of energy conversion devices, energy efficiency initiatives broadly strive to reduce the energy intensity of well-understood and well-defined activities. The 2008 DSB report recommended the United States military strongly pursue energy efficiency initiatives,[51] though it is challenging to quantitatively establish energy efficiency

[50] Yakubova, "Nuclear Batteries with Tritium and Promethium-147 Radioactive Sources."
[51] DSB, "Report of the Defense Science Board Task Force on DoD Energy Strategy, 'More Fight - Less Fuel.'"

goals and report on progress for military operations that cannot be defined against a clear and standardized baseline.

Power generation

Although in physics, power connotes the rate of energy per unit time, power is used throughout this report to specifically denote the rate of electrical energy produced per unit time. Electrical power can be obtained from small or large engine-generator sets, fuel cells, small self-contained chemical batteries, and many other devices. Below are descriptions of a few power-generating devices relevant to this report.

Engine-generator sets ("gen-sets" or sometimes referred to simply as "generators") entail the use of an engine (typically an internal combustion engine which converts fuel's chemical potential energy into thermal and kinetic energy) and an electric generator (which converts the kinetic energy from the engine into electrical energy). Gen-sets are the dominant technology used for producing electrical power in places where central grid power is either not available or when power is needed only temporarily. These gen-sets require a fuel source that must be regularly resupplied, and power output of military gen-sets ranges from a few kWs to several hundred kWs. Although they may use a variety of fuels (e.g., gasoline, diesel, natural gas) and engine types, military gen-sets typically consume jet fuel in diesel (i.e., compression ignition) engines to produce electricity. For large stationary applications, turbine engines have also been used to convert liquid or gaseous fuels into electrical power.

A ***fuel cell*** is a device that converts the chemical energy from a fuel directly into electricity through a chemical reaction. Fuel cells differ from batteries in that they require a continual source of fuel and oxygen to sustain the chemical reaction. Fuel cells can produce electricity continuously for as long as these inputs are supplied. There are many types of fuel cells for different applications using different types of anodes, cathodes, and fuels. They also range in power output from watts to MWs.

The Military Departments are evaluating fuel cells for both dismounted soldiers and unmanned vehicles (to serve the function similar to rechargeable batteries) and for small bases (to serve the function of diesel gen-sets). Most commercial fuel cells are designed to operate with fuels that would be considered exotic for military operations (e.g., hydrogen, propane). One major challenge associated with fuel cells for military use is that tactical fuels (primarily JP-8) typically contain sulfur, which is problematic for materials used in most existing fuel cells.

Nuclear power energy systems provide reliable, abundant energy on a continuous basis, shutting down only for maintenance and/or long-term refueling. In the United States, nuclear plants are generally known as base-load plants, generating low-cost electricity around the clock. This source is neither subject to weather nor the intermittency associated with wind and sun, but existing commercial reactors all rely on a large supply of water for cooling purposes (though advanced concepts may not require a local source of water).

Microgrids, minigrids, and distributed resource island systems

When operating in remote and forward areas, the military often brings its own power generation equipment and electrical grid, but occasionally integrates with power production, distribution, or consumption components supplied by the local host nation or other nations' militaries. By interconnecting many loads onto a single grid, and powering them using multiple generation sources (including host nation power grids), energy resources can be used more efficiently.[52] While the upfront investment in more interoperable and controllable power systems is not appropriate for many small and temporary operations, the Departments of Defense and Energy are putting significant effort into standards and technologies to enable these capabilities. Standards for interoperability of distributed energy resources are being developed, but translation to acquisition requirements has been slow.

The ***microgrid*** has not been officially defined by a U.S. standards organization, becoming a colloquial term interpreted to suit the goals of the writer or user of the term. Some of the more prominent descriptions of microgrids have common themes.

- The microgrid does not denote the size of the grid in power output or physical size.
- The microgrid is an electrical configuration of a power system, with its own power source(s), which is able to operate connected or disconnected (islanded) from a (larger) grid.

The U.S. DOE Microgrid Exchange Group (DOE MEG) defined a microgrid as follows:

> A microgrid is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island-mode.

The Institute of Electrical and Electronics Engineers (IEEE), in order to avoid the colloquial use of the microgrid term, created the term "distributed resources island system," defined as follows:

> Distributed resources (DR) island systems are parts of electric power systems (EPSs) that have DR and load, have the ability to disconnect from and parallel with the EPS,

[52] Van Broekhoven et al., "(U) Tactical Power Systems Study."

include the local EPS and may include portions of the area EPS, and are intentional and planned.[53]

The following definitions are added for clarity.

- *Distributed resources:* Sources of electric power that are not directly connected to a bulk power transmission system. DR includes both generators and energy storage technologies.[53]
- *Electric power system (EPS):* Facilities that deliver electric power to a load.[54]
- *Island:* A condition in which a portion of an area electric power system is energized solely by one or more local electric power systems through the associated point of common couplings while that portion of the area electric power system is electrically separated from the rest of the area electric power system.[54]
- *Point of common coupling:* The point at which a local electric power system is connected with an area electric power system.[54]

Electrical energy storage devices

Technologies for storing and releasing electrical energy are becoming more efficient, smaller, and cheaper. A thorough review of electrical energy storage technologies, with a focus on economics, energy density, power density, and durability, was completed by Ferreira et al.[55]

To date, ***chemical batteries*** ("batteries") are the most common form of storing electrical energy near the point of use (though pumped hydroelectric power, compressed air, flywheels, and other storage devices have been evaluated at the utility scale and smaller scales). Batteries are self-contained electrical energy storage and production devices containing electrochemical cells that store energy with a mechanism for releasing the energy on demand. Batteries come in two main forms.

- *Disposable* (or "primary") batteries are typically discarded after their internal chemical has been released for various purposes, but many disposable batteries have a longer shelf life (i.e., lower self-discharge rate) and higher energy density than rechargeable batteries.
- *Rechargeable* (or "secondary") batteries can endure multiple cycles of charging and discharging; consist of a wide variety of anode, cathode, and electrolytic materials; and range in power output from consumer electronic uses to MW-scale batteries that stabilize electric power grids.

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[53] IEEE Std 1547.4 – "2011 IEEE Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems."
[54] IEEE Std 1547.3 – "2007 IEEE Guide for Monitoring, Information Exchange, and Control of Distributed Resources Interconnected with Electric Power Systems."
[55] Ferreira et al., "Characterisation of Electrical Energy Storage Technologies."

Appendix E: Future Military Requirements Expected to Increase Demand for Energy

This appendix provides additional information on some of the potential future weapons and capabilities that will require more energy demand that were highlighted in *Section 3, Future Capabilities Will Require More Energy*.

Directed-energy systems

Directed-energy (DE) systems refer to a class of weapon systems that convert electrical energy into radio frequency energy for high-power microwave applications, lasers for the disruption of sensors of the destruction of adversary weapon systems or other targets, and particle beams to accelerate sub-atomic particles to disrupt or destroy a target.[56]

The High Energy Laser Mobile Demonstrator (HEL MD) is a tactical weapon system developed by Boeing that is mounted on a vehicle and used on the battlefield as an offensive or defensive weapon system. The design power requirement for that system is limited by the size of the truck and the ability to carry the fuel required to use the HEL effectively. The current HEL objective power requirement is 100 kW. It is designed to execute force protection missions, intelligence, surveillance, and reconnaissance (ISR), and offensive operations. These systems will be mounted on a customized Heavy Expanded Mobility Tactical Truck (HEMTT). As technology matures, higher power lasers will be integrated with improved pointing and tracking capabilities to extend range and increase system effectiveness.

These systems require high levels of prime power to support their operation at the megawatt scale for some applications. For example, a megawatt-class ballistic missile defense (BMD) high-energy laser system will require approximately 3 MW of prime power. In fall 2015, Lockheed Martin began production of a new generation of modular high-power (60 kW) lasers for a U.S. Army vehicle, and the company intends to develop laser weapon systems tailored to address missions across sea, air, and ground platforms. If electricity is produced from a gen-set with an efficiency of 33%, every 10 kW in laser power would require approximately 1 kg of fuel every 250 seconds (4.7 gal/hour) while operating.

Railguns

An Electromagnetic Railgun (EMRG) is a weapon system that fires projectiles using electricity instead of chemical propellants by applying high electrical currents to create electromagnetic fields that accelerate a sliding metal conductor (armature) between two rails. Railguns are made up of

[56] For example: High Energy Lasers (HEL) for possible BMD application: http://www.ga-asi.com/hellads; tactical laser:https://lasers.llnl.gov/science/photon-science/directed-energy; high-power microwave: https://engineering.llnl.gov/technologies/core-competencies/applied-electromagnetics.

three basic parts: a power supply, a pair of parallel rails, and a moving armature, and are capable of launching a projectile at up to 4,500 mph.

In 2005, the Navy started investing in the development of railguns for shipboard applications. Phase I of the Navy's efforts completed in 2012 with two vendors building and demonstrating a proof of concept 32 MJ muzzle energy railgun. The Navy is currently working on Phase II, which will concentrate on demonstration of repetitive-rate fire capacity. Railguns provide several advantages over conventional guns and missiles; for example, railguns are multi-mission and eliminate the safety hazards of handling explosives material (gunpowder, missile fuels)—simplifying transportation, handling, and storage; the projectiles used in railguns cost significantly less than conventional rounds and missiles; and projectiles travel faster and further than conventional rounds. Technical challenges can be grouped into three basic areas: thermal, materials, and electrical.

In test firings, the EMRG launched a projectile with an initial kinetic energy of 32 MJ. The repetition rate for firing the weapon is projected to be 10 rounds per minute. Assuming the transfer efficiency from stored energy (fuel) to kinetic energy for the EMRG is 33%, 97 MJ of stored energy (fuel) are required to accelerate the projectile to achieve the specified muzzle velocity (equating to 32 MJ of kinetic energy). The general mode of charging and discharging the capacitors (energy storage devices) is to charge the capacitors for five seconds and allow one second for discharge. This causes a gap in the power draw that is unfavorable to most sources, so resistive loads will typically be switched in to smooth out the power draw. To deliver 97 MJ in five seconds requires 19.4 MW. Taking power conversion efficiency into consideration, this results in a power draw of approximately 24 MW; if the primary fuel for electricity generation is diesel or jet fuel, this translates to approximately 2 kg (2/3 of a gallon) of fuel per shot.

Additive manufacturing

Additive manufacturing is the manufacturing process used to build a three-dimensional (3D) object by compiling (often thousands of) successive, ultrathin layers of material one on top of the other. Additive manufacturing is performed by an industrial robot or "printer" and can be used to create objects of almost any shape, using a wide variety of input materials. Innovators are exploring new opportunities to use titanium, aluminum, and nickel-chromium alloys, or others made specifically for 3D printers. 3D printers have been used in a number of applications – to create medical implants and prosthetics, to build parts to be used in thousands of jet engines, and to produce weapons and firearms. Energy producers are exploring opportunities to exploit additive manufacturing technology to increase their processes as well; GE Power & Water plans to implement additive manufacturing to create parts used in gas and wind turbines.

Additive manufacturing techniques have the capacity of accelerating innovation, condensing supply chains, minimalizing required input materials, and reducing waste and energy usage.

Additive manufacturing techniques can save energy by eliminating steps in the production cycle. Building objects in an additive way, layering materials rather than employing traditional manufacturing processes that require cutting material away, substantially reduces initial material inputs. Additive manufacturing techniques also allow for re-use of byproducts and production of lighter objects, which reduces material costs. According to the DOE Advanced Manufacturing Office, material savings can reduce costs by up to 90%. In addition, additive manufacturing can be used to reinvigorate parts, restoring end-of-life products to their original condition, requiring only 2% to 25% of the energy needed to create new parts. Installing additive manufacturing capabilities (with sufficient raw materials and energy) at a military base could bring the capability of producing equipment and spare parts without the delay, risk, and cost associated with conventional logistics resupply. (For similar reasons, NASA is continuing to develop additive manufacturing techniques for use in space.)

Water treatment and production

As previously mentioned, demand for water results in a major logistics burden for forward locations—often exceeded only by fuel in terms of mass transported. The DoD is considering innovative approaches for on-site, sustainable water production, water treatment, and wastewater treatment at FOBs. Water could be produced on site by dehumidifying ambient air[57] or condensing water vapor found in fuel-burning engine exhaust. Deployable water treatment technologies[58] can reduce the need for water resupply logistics, by enabling conversion of locally available nonpotable water sources (e.g., river, well, or sea water, or even greywater from showers and laundry facilities) into potable water that is safe for drinking and use in dining facilities, showers, etc. Wastewater treatment technologies (e.g., membrane bioreactors, anaerobic digesters, microbial fuel cells) can also reduce the need for waste removal logistics, as wastewater at forward and expeditionary locations is often hauled off-site in trucks. In addition to reducing the volume of waste material to transport off-site, such wastewater treatment systems may be partially energy self-sufficient, as energy contained in wastewater sludge can be converted to useful methane or electrical currents. The DoD is investigating technologies that would be deployable, easy-to-use, and minimize energy usage. As all of these technology systems require energy to operate, the DoD would not wish to exacerbate the energy supply problem through solving water supply and treatment problems.

Fuels production

Other than a few niche applications (e.g., unmanned systems), all of the fuel used in DoD operations are considered hydrocarbons, which comprise a carbon chain with hydrogen atoms attached to it. As a result, producing tactical hydrocarbon fuels without a source of petroleum requires a source of carbon, in addition to energy to drive chemical reactions and processes. At

[57] Dusenbury, "Water from Air."
[58] Dusenbury and Shalewitz, "The Army Water Supply Program."

varying degrees of scale and technical maturity, industrial facilities have produced hydrocarbon fuels from coal, natural gas, biomass (including biological oils), and even the organic contents of municipal solid waste. As it may not be feasible for the DoD to access, collect, and manage sufficient carbon-containing feedstocks, a group at the Naval Research Laboratory (NRL) has been developing techniques to synthesize liquid hydrocarbon fuel in remote locations using electricity as the primary energy source and carbon dioxide (CO_2) as the primary carbon source. NRL has conducted (on a small prototypic scale) the sustained basic and applied research necessary to develop and demonstrate potential processes to produce alternative liquid fuel from feedstocks found in seawater, which requires approximately 20,000 gallons of seawater to produce a gallon of fuel. Other researchers have been focusing on extracting CO_2 from the atmosphere. In either case, the capture or isolation of CO_2 is a very energy-intensive process.

NRL has a process that addresses the conversion of CO_2 and hydrogen to olefins (short chain carbon molecules). The second step consists of conversion of olefins to a fuel-like fraction of C9–C16 molecules by transforming a simple carbon chain to a complex one using zeolite catalysts. For every kWh of electricity consumed in converting (already captured) CO_2 and hydrogen into final liquid hydrocarbon fuel, approximately 0.60 kilowatt hours of power is stored in the liquid hydrocarbon fuel.

Data centers, computing, intelligence, surveillance, and reconnaissance (ISR)

Recent experience has demonstrated that surveillance and computing systems—which collect and process data to inform decision-making at bases, on mobile platforms, and on dismounted warfighters—are increasingly capable but also increasing in total power requirements. The Military Services continue to pursue analyses and demonstrations to guide efforts to balance computing performance, reliability, and energy use to support operations. For the Army, a data center is often defined as a structure of more than 300 square feet with multiple servers. In addition to providing electrical power directly to the computing and server systems that process data from multiple ISR sources, air conditioning (or some form of cooling) is often required to maintain a reasonable temperature range to operate electronic systems—further driving up power requirements. Even with a long-term trend of stripped-down computing and reduced number of servers, enabled by advanced technologies and innovative energy operational concepts, the desire for more and better ISR means more data to process and more energy demand.

Autonomous and unmanned systems

Automation is the implementation of a process to be executed according to a fixed set of rules with little or no human interaction. The automation can be fixed, whereby specific rules are defined for all situations (e.g., an airplane autopilot), or flexible, where different situations (e.g., different manufactured products) are guided by different rules. However, the key idea is that whatever the process is, the rules are defined and fixed in advance to achieve a predetermined outcome under all anticipated inputs. In most cases, the system can effectively be tested against all (or at least a representative set of) inputs to guarantee the desired output.

While the exploitation of the technologies of autonomous military operations may lead to more rapid and capable military campaigns, the energy requirements at the extremities of U.S. military power will almost certainly increase. While such systems will inevitably be deployed from bases and most will require electrical power, it remains unclear if their energy needs will be drawn directly from base electrical power to charge batteries vice carrying their own fuel, or harvesting energy during operations. Most “energetically autonomous” systems utilize solar energy, though other forms of energy (e.g., thermal lifts) are being researched, and DARPA previously supported research on an Energetically Autonomous Tactical Robot (EATR) that could forage for plant biomass. As these energy-harvesting techniques develop, mission lengths may be extended such that maintenance becomes a more significant constraint than energy.

An illustration of the direction future U.S. requirements may take is suggested in a recent paper by General Paul F. Gorman (USA, ret.) which builds on the growing recognition of the tactical and operational value of man-machine collaboration to rapidly improve the combat capability of small units. Gorman’s concept couples modern UAVs (e.g., the U.S. Air Force’s Reaper and the U.S. Army’s Gray Eagle) with low-signature/detectability unmanned Remotely Commanded Ground Vehicles (RCGV) employing modern ISR and advanced weapon systems. The aim of the concept (for 2025) is to introduce novel technological interventions that significantly improve combat power of small units, yet reduce casualties by depopulating the zone of close combat. The DoD research and development (R&D) is aiming at new manned/unmanned teams that amplify the cognitive awareness, prowess, and survivability of combatants in small units. Sustaining unmanned systems, and utilizing the data they supply, requires significant energy.

Appendix F: Alternative Energy Technologies

This appendix provides a brief and non-exhaustive overview of various alternative energy technologies that the Task Force reviewed for military operational use.

Solar power

Solar energy (sunlight) radiated from the sun can be converted to useful energy by introducing a device that converts the light directly into electrical energy via a photovoltaic (PV) device, or the sunlight can be absorbed and converted into heat—which can be used for heating purposes, or could be further converted to electrical energy through another device. "Solar energy" or "solar power" most commonly refers to PV devices, especially for military applications, though it is not uncommon for commercial and residential buildings to utilize solar water-heating devices.

Availability: Solar energy is available throughout the world, though solar incidence varies by more than a factor of 10 from Arctic regions to deserts in Africa. Even in a given region, minute-to-minute variability and uncertainty[59] requires users to have backup sources of power (e.g., batteries, grid power, or other power conversion systems).

Technical maturity: Solar power systems are well understood and are widely deployed for civilian applications. Although commercial and residential solar panels are prevalent, small-scale, and modular, ruggedized panels for military use have only recently been used in deployed locations. A recent study found that PVs are more often attractive for small austere bases than larger (MW-scale) bases, unless the FBCF is less than $10 per gallon, as payback time is likely to exceed four years.[60]

Operational considerations: Tactical PV systems have been successfully deployed on the roof of shelters (including tents), mounted on the ground, and draped over individual warfighters. While such systems provide valuable electrical power, they do require maintenance to keep the panels clean and free of dust. To produce a large portion of base power, panels require significant land area, and glint and glare from panels can impact pilots if not properly mitigated.

Wind power

A fraction of the kinetic energy of wind can be converted to useful mechanical energy by introducing turbine blades (a type of airfoil) that absorb energy from the wind while increasing their rotational energy. Early windmills were used entirely for mechanical work, but modern wind turbines use a generator to convert the turbine's rotational energy into electrical energy.

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[59] Ela et al., "Impacts of Variability and Uncertainty in Solar Photovoltaic Generation at Multiple Timescales."
[60] McGrady, Stewart, and Ward, "Solar and Wind Power as Alternative Sources of Energy in Expeditionary Environments [Distribution Limited to the Sponsor. Specific Authority: N00014-11-D-0323]."

Availability: As with solar energy, wind resources vary significantly by location, season, and time of day. Additionally, as wind speed increases with altitude, tall structures enable the most significant capture of energy (per unit of land area), which introduces a tension between power output, constructability, and visibility.

Technical maturity: Wind power systems are well understood and are widely deployed for civilian applications. Although commercial wind turbines are very large, small units have also been developed for individual homes, boats, and even military use.

Operational considerations: Installing wind turbines is technically feasible, maintenance is typically anticipated to be minimal, and regulatory processes are unlikely to deter the military from deploying wind power units. Even in areas with strong wind resources, the speed of wind varies significantly over time, such that wind (without being integrated with significant electrical energy storage systems) cannot be depended on as a sole source of power. The visibility of wind turbines from afar is a potential public relations issue and a vulnerability—due to the potential for turbines to interrupt communication signals, provide adversaries with a visible target, and potentially interfere with aircraft routing. In a study of alternative energy systems for expeditionary use in Afghanistan, wind power was not found to be a viable way to replace existing power systems.[61]

Hydrokinetic power

Hydrokinetic power is a broad term that entails utilization of the energy contained in moving water.

Hydropower is extremely common throughout the world, and entails the capture of potential energy of water at high elevations (originating from rain) by passing the water through a turbine at lower elevations. Hydroelectric dams are large infrastructure projects that take years to construct, though small versions deemed "micro-hydropower" are increasingly being deployed to take advantage of relatively low flow rates of water across minor elevation changes (e.g., rivers and streams).

Tidal power entails the capturing of kinetic energy of moving water that occurs as the ocean's tides go in or out. This type of power source is most promising in areas with large volumes of water passing through a restricted inlet. This energy originates from the shifting gravitational pull of the moon against the earth's interconnected ocean bodies.

Wave power entails the capturing of kinetic energy from moving water in the form of waves. The energy of waves can typically be attributed to wind, though other large disturbances to water will

[61] Ibid.

result in waves. A typical wave power device will force an incoming rolling wave to lift a buoyant device to pull against an anchored device under the water surface.

Availability: Hydrokinetic resources exist throughout the world, but also vary by time and location. Hydropower resources tend to be reliable over long time periods (in the absence of droughts), while tidal and wave power are more variable.

Technical maturity: Hydropower is very mature for civil applications, but not military/mobile applications. The technology associated with tidal and wave power, while technologically simple, have been demonstrated in relatively limited cases to prove their long-term reliability under corrosive and aggressive ocean conditions.

Operational considerations: While some hydrokinetic power resources are predictable, all of these power sources require sophisticated and rugged technologies for potential use in deployed locations.

Geothermal power

Geothermal energy systems entail the extraction of heat from the earth's subsurface, in order to heat a working fluid (e.g., steam) to pass through an engine (e.g., turbine) which is connected to a generator to generate power—in a similar manner to how conventional (fuel-burning) thermal power production technologies work. Geothermal energy systems require heat exchangers with relatively large surface area to be buried under ground (as heat moves slowly through most types of soil and rock), and may be configured with very deep geothermal wells (small areal footprint, but requiring significant drilling) or with large ~trenches (large areal footprint, but requiring significant excavation).

Availability: Geothermal energy resources exist in relatively small patches throughout the world.

Technical maturity: Geothermal power production is mature for civil applications, but not for temporary military-type operations.

Operational considerations: The time and initial capital cost required to construct a geothermal energy system is considerable, and may be only feasible in locations where the military expects to operate for long periods of time. Their complexity, especially if deep excavation is required and regulated, render such systems unattractive for scenarios in which the military would only be operating for a short time period.

Ocean thermal power

Ocean thermal energy systems entail the exploitation of temperature gradients with depth under the ocean's surface. Warm water at the ocean's surface may be used to heat a working fluid that expands through a turbine, with cold water pumped from a deeper section of the ocean to be used as the heat sink. An advantage of these systems (especially for islands) is that most of the infrastructure can be placed at sea, without taking up much land area.

Availability: Ocean thermal resources are best in tropical regions where the temperature gradient is greatest between the surface water and deeper water, but would be attractive in providing a consistent and reliable supply of power.

Technical maturity: Ocean thermal power systems are under development for the industrial sector by companies, such as Lockheed Martin, and are being evaluated for the remote base of Kwajalein.

Operational considerations: As with geothermal energy systems, an ocean thermal energy system would likely require significant initial capital cost and time to construct, and ecological impacts would need to be considered.

Waste to energy systems

Often viewed as a nuisance, liability, and cost, the collection and management of waste can be done in a way that enables waste to become a resource for beneficial uses. In particular, plastic waste and organic waste (e.g., wood, food) contain energy that can be captured through direct incineration, biological conversion to fuels (e.g., anaerobic digestion of organic wastes such as food scraps or wastewater to methane-containing biogas), or thermochemical conversion to fuels (e.g., gasification of the wastes to synthesis gas which can be combusted in an engine directly, or converted to liquid fuels through Fischer-Tropsch synthesis; waste fats, oils, and greases can also be converted to petroleum fuel substitutes such as biodiesel).

Availability: Waste is produced wherever humans live and operate, and is a relatively steady feedstock source; however, the scale of energy that may be produced from waste resources is a fraction of the energy needs of most civilian populations, and would likely be a small fraction of the energy needed for deployed military personnel.

Technical maturity: Waste-to-energy systems are relatively well known and deployed for large civilian applications. The military has deployed several incinerators; however, no deployed incinerators capture or utilize the heat produced, as the Military Departments have not yet created a requirement for energy-capturing waste systems. The Joint Deployable Waste-to-Energy (JDW2E) community of interest has been identifying gaps and coordinating research efforts in this space.

Operational considerations: Waste-to-energy systems remain attractive largely as a means to use beneficially a ~free resource, while reducing the cost and public health liabilities associated with accumulating or treating waste in other ways (e.g., via burn pits). Systems vary in complexity and the output of energy, if any (e.g., heat for hot water or syngas for electricity), but such outputs may be highly valued in remote and non-permissive scenarios.

Indigenous or cultivated biomass

Indigenous biomass, such as grass, trees, algae, or agricultural and forest debris is essentially sunlight stored in chemical form. Renewable biomass is increasingly being used as a source of fuel to produce electricity and/or heat (for applications that may otherwise utilize coal or natural gas), and as a feedstock for making fuels such as synthetic gas or liquid fuels such as biodiesel.

Availability: Biomass is available throughout the world, but is significantly more abundant in tropical areas than desert areas.

Technical maturity: Biomass combustion systems have been used throughout human history for heating and cooking, and industrial systems for producing heat and electricity from biomass are relatively mature. A few commercial-scale systems are being constructed to convert biomass into gaseous or liquid fuels (e.g., synthesis gas and/or liquid Fischer-Tropsch fuels), but small-scale systems are not mature enough to deploy.

Operational considerations: Before deploying a biomass energy system in a remote military environment, one must ensure a sufficient supply of biomass is available, and that the integrated technology system for producing power, heat, or liquid fuels is reliable. Beyond these considerations, the resources required for collecting, transporting, and storing biomass also must be considered.

Wireless energy transfer (or power beaming)

Long-distance[62] wireless energy transfer entails the use of electromagnetic radiation, ranging from microwaves to lasers, for the conveyance of energy from one location to another without the use of cables or wires. Typically, electrical energy is converted into focused waves for wireless transmission, which is then converted back into electrical energy near the point of use through a receiver (e.g., rectenna for radiofrequency energy or photovoltaic cell for laser energy).

Although not a source of energy itself, such technologies could eliminate the need to install power lines and wires to move electrical energy from the point of production to consumption, and/or could eliminate the need to physically move fuel from one point to another in cases where fuel would be moved for the purpose of producing electricity. This concept has been evaluated for beaming power from space back to earth (i.e., space-based solar power), from land to the sky (e.g., powering UAVs), and medium-range beaming of power within households or camps.

[62] Energy can also be transferred wirelessly via electrostatic or electromagnetic coupling, which are non-radiative. Such technologies would be attractive for military applications when the energy source and receiver can nearly touch, but are not relevant in discussing potential means of supplying energy to an entire remote base.

Availability: Long-distance power beaming systems are not yet available or approved for use at military bases.

Technical maturity: While the physics of these systems is understood, the associated costs are anticipated to be significant. These technologies have been under development since the 1970s, and were addressed in the recently released DARPA/INL study on deployable energy systems.[63] The DoD is actively involved in the Interagency Working Group on Wireless Power Transfer, and DARPA may be initiating a program to evaluate these technologies over the coming years.

Operational considerations: Power beaming could be attractive for sending energy from a location with abundant energy to locations that are difficult to access with wires or conventional logistics; however, transmission losses can be significant, and the surface area required to receive energy from the sky can also be significant. Additionally, the vulnerability of components of such a system to attack would need to be evaluated, and the safety consequences of accidents, intentional misuse, or attacks on these systems could be severe.

Host nation (or local utility) grid

When deploying to new locations, the military often brings its own power production systems that require a reliable and consistent system for delivery of fuel. In some cases, when operating in host nations that can offer electricity to the military, it would often be less costly for the military to enter into contracts for the purchase of electricity from local utilities, especially if a base will be operating for several years.[64]

Availability: An oft-cited problem with host nation power is that reliability is low, such that this source of power may be treated similarly to renewable sources, meaning that the military would still need to host significant fuel reserves and power generation systems on base.

Technical maturity: The interconnection of military base power systems with a local transmission network is straightforward and well understood.

Operational considerations: While host nation power could reduce the costs, and improve diplomatic relations associated with operating a military base, such an arrangement could lead to diplomatic tension without the use of reasonable contract mechanisms.

[63] Gougar et al., "Innovative Deployable Energy System Concepts."
[64] MIT Lincoln Labs, "Guidance for DoD Utilization of Host Nation Power."

Appendix G: Nuclear Powered Energy Systems

This appendix provides illustrations of the two very small nuclear reactor (vSMR) technologies the Task Force determined that were most mature. **Figure G-1** depicts the MegaPower reactor concept that was briefed by Los Alamos National Laboratory. **Figure G-2** shows the key design and safety features of Filippone & Associates' "Holos" gas-cooled hardened micro modular reactor. The Task Force reviewed other interesting concepts; the two highlighted below are most mature—technologically and in operational thinking.

LANL MegaPower Reactor

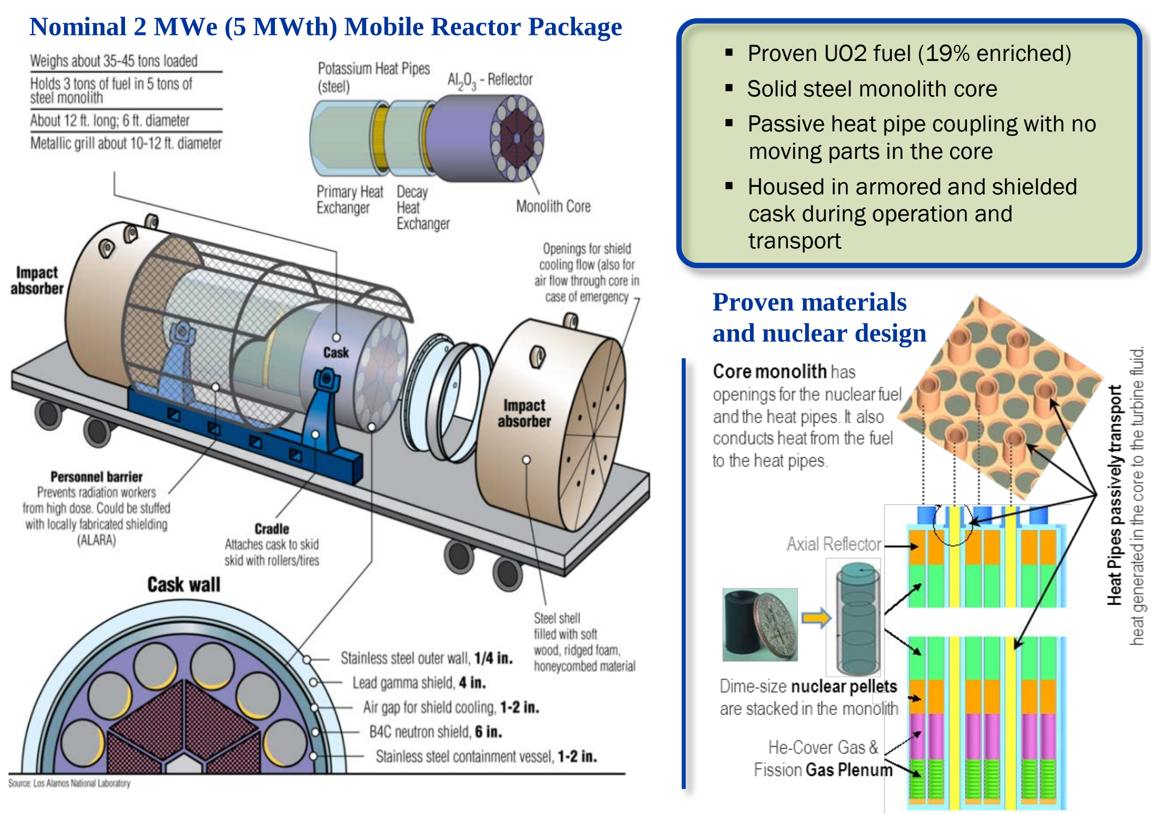

Figure G-1. MegaPower Reactor Systems

F&A Holos Reactor

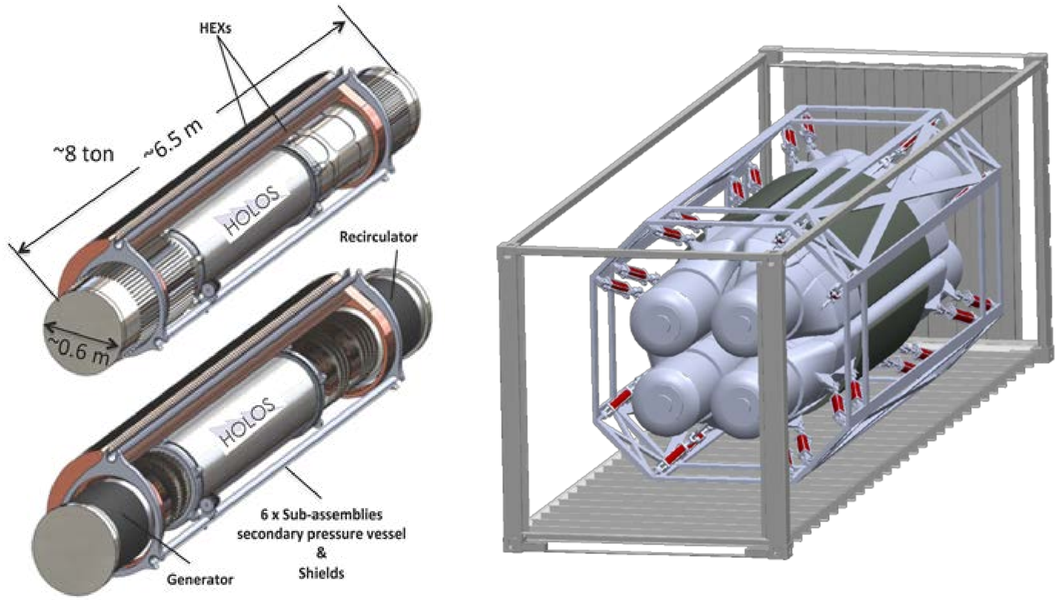

Figure G-2. F&A's "Holos" Gas-cooled Hardened Micro Modular Reactor (H-MMR)

Key design features of the Holos Reactor

- 10 MWe of output with 45% efficiency air-cooled Brayton cycle engine.
- 13 year operation without refueling with 8% enriched uranium.
- Each sub-assembly integrates a fully sealed power conversion unit, thus eliminating need for balance of plant (extra piping, valves, fittings, heat exchangers, pumps).
- Core sub-assemblies and shields can be transported with current FOB and ROB lifting capabilities.
- Only when all sub-assemblies are coupled via exoskeleton structure in an ISO container, core becomes whole and combined neutronics enables electricity production.
- Sub-assemblies fit in storage canisters commercially utilized for waste/spent fuel temporary and permanent disposal.
- Each sub-assembly may be loaded with different fissile and fertile isotopic compositions.
- Plug-and-play capabilities; deployment and connection via any power grid sub-station (jump-start configuration); high-resolution load-following.
- Voltage and frequency synchronization/conditioning.
- Holos design could be built and tested at full-scale via electrically driven mockup in less than three years.

- Projected cost for a 10 MWe Holos reactor with the exclusion of the core and licensing costs remains in the $50 million range, as proposed.

Key safety features of the Holos Reactor

- Core breach (attack/sabotage): only the sub-assemblies directly hit would sustain damage. Sub-assemblies not directly hit become displaced from optimal geometry through exoskeleton structure (all contained within ISO container).
- TRISO fuel ensures volatile dispersion would be minimal.
- Each sub-assembly, if stolen, cannot become supercritical; core composition makes it nearly impossible to utilize maliciously, other than as base for ineffective dirty bombs.

Appendix H: Review and Status of 2008 DSB Task Force Energy Report

Many of the findings and recommendations of the DSB Report of February 2008[65] remain relevant today. Questions that came up during Task Force discussions that relate to the 2008 study include the following.

- Has the DoD re-engineered its business processes to make energy a factor in key requirements decisions?
- Does the DoD have in place the strategy, policies, metrics, information, and structure to manage properly its energy risks?
- Has the DoD and the Military Departments been effectively and consistently evaluating and implementing energy efficiency opportunities?
- Has the DoD developed meaningful energy efficiency KPPs that are used in evaluating new projects?
- Have we added bottoming cycles to current diesel generators to remove some 40 tankers per year (as recommended by an INL report from February 2013)?
- Will the military's Joint Requirements Oversight Council (JROC), chaired by the Vice Chairman of the Joint Chiefs of Staff, make energy efficiency a "requirement" or even a desired outcome?

2008 DSB Energy Task Force findings

The 2008 DSB Energy Task Force reviewed the outcome of a 2001 DSB report, "More Capable Warfighting through Reduced Fuel Burden,"[66] on military energy management, and presented additional findings that are presented below.

- Recommendations from the 2001 DSB Task Force Report "More Capable Warfighting through Reduced Fuel Burden" have not been implemented.
- Critical national security and homeland defense missions are at an unacceptably high risk of extended outage from failure of the grid and other critical national infrastructure.
- The DoD lacks the strategy, policies, metrics, information, and governance structure necessary to manage its energy risks properly.
- Technologies are available to make DoD systems more energy efficient, but they are undervalued, slowing their implementation and resulting in inadequate S&T investments.

[65] DSB, "Report of the Defense Science Board Task Force on DoD Energy Strategy, 'More Fight - Less Fuel.'"
[66] Truly and Alm, "More Capable Warfighting through Reduced Fuel Burden."

- Many opportunities are available that can reduce energy demand by changing wasteful operational practices and procedures.
- Operational risks from fuel disruption require demand-side remedies; mission risks from electricity disruption to installations require both demand- and supply-side remedies.

2008 DSB Energy Task Force recommendations and status

The Task Force made five broad recommendations with specific subordinate tasks. **Table H-** lists recommendations relevant to operational energy, with notes on their implementation status.

Table H-1. Status of Recommendations from 2008 DSB Task Force Report, "More Fight, Less Fuel"

Task	Status
Recommendation #1: Accelerate efforts to implement energy efficiency Key Performance Parameters (KPPs) and use of the Fully Burdened Cost of Fuel (FBCF) to inform all acquisition trades and analyses about their energy consequences, as recommended by the 2001 DSB Task Force.	
Task 1.1: By July 2008, the DEPSECDEF requires the Defense Acquisition Board to apply milestone exit criteria to all programs to determine whether an energy related KPP has been appropriately applied, and whether FBCF has been appropriately used as a factor for acquisition trade studies and systems engineering activities. "Black" programs should not be exempt from this requirement.	***Partially Complete*** • JCIDS Manual[67] includes Energy KPP as a mandatory KPP. • FBCF (now FBCE) is regarded by many as not as beneficial as originally expected for acquisition decisions. • DoDI 5000.02[68] requires consideration of FBCE and mandatory KPPs during analysis of alternatives (AoA). • While "black" programs have not been specifically excluded from this requirement, the ability to assess this issue is extremely limited or nonexistent.
Task 1.2: By May 2008, establish a policy requiring all force-on-force campaign analyses and other models and simulations used to support AoA or EoAs to incorporate energy, energy related logistics, and energy protection requirements.	***Complete*** • DoDD 4180.01[69] establishes policy for this task.
Task 1.3: By May 2008, VCJCS establish a policy requiring: • All wargames, major unit field training, and joint exercises include fuel and fuel logistics. • Establish a fuel battle-lab to experimentally find ways to achieve successful battlespace outcomes with reduced energy inputs.	***Partially Complete*** • It is unclear if such a CJCS policy has been established. • Defense Operational Energy Board (DOEB) Guidance Memo #1 directs Services to provide: 1) a pre-game brief outlining how energy will be played and 2) a post-game brief describing what they learned and how they will utilize that knowledge with regard to energy. • No specific fuel battle lab has been established, but Service experimentation centers (e.g., Expeditionary Energy Concepts (E2C), Base Camp Integration Lab (BCIL)) serve similar purposes.

[67] JCIDS Manual series, "Manual for the Operation of the Joint Capabilities Integration and Development System," (December 18, 2015). https://www.intelink.gov/wiki/JCIDS_Manual.
[68] DoD Instruction, "DoDI 5000.02, Operation of the Defense Acquisition System" (Defense Acquisition Portal, January 7, 2015), https://acc.dau.mil/adl/en-US/716926/file/78952/Instruction%20-%20USD%20(AT_L),%20DoDI%205000.02,%20Operation%20of%20DAS,%207%20Jan%202015.pdf .
[69] DoD Directive, "DoDD 4180.01, DoD Energy Policy."

Task	Status
Task 1.4: By June 2008, USD(AT&L) establish a policy requiring application of FBCF and efficiency related capability improvements to engineering decisions affecting modifications made to legacy systems during reset programs. The Task Force recommends these also apply to non-developmental systems used at forward operating locations, since these create large demand for fuel in theater.	***Partially Complete*** • The Services often use resets to add or restore capabilities to legacy platforms, so a strict "energy efficiency" approach will not take this into consideration. • A goal for the Services is to conduct Energy Supportability Analysis to better inform leaders of the operational effects of energy related decisions.
Task 1.5: By April 2008, USD(AT&L) publish initial official values for FBCF to be used in all acquisition trade analyses, and establish a schedule and process for their periodic updating.	***Complete*** • The calculation of FBCE is scenario, situation, and time dependent so there is no single FBCE for any platform.
Recommendation #2: **Reduce the risk to critical missions at fixed installations from loss of commercial power and other critical national infrastructure.**	
Task 2.1: By June 2008, Assistant Secretary of Defense for Homeland Defense and Americas' Security Affairs (ASD(HD&ASA)), in coordination with the JS and Office of the Deputy Under Secretary of Defense for Installations and Environment (ODUSD(I&E)), develop a program plan to assess the risks to mission from power failure, identify mitigation options, assess their efficacy and develop a phased investment plan to bring the risks to within acceptable limits at CONUS and OCONUS installations.	***Unavailable***
Task 2.2: By June 2008, ASD(HD&ASA), in coordination with the JS and ODUSD(I&E), establish metrics for acceptable risks to installation missions from failure of energy supplies, with priority given to critical C4, ISR, strategic deterrence and Homeland defense missions.	***Unavailable***
Task 2.3: By August 2009, ASD(HD&ASA), in coordination with the JS and ODUSD(I&E), complete risk assessments for critical C4, ISR, and strategic deterrence missions and identify the most cost effective risk mitigation options to assure mission resilience, to include efficiency to reduce the demand for on-site power, enhanced backup capability via greater on-site generator capacity, and provision of on-site alternative sources of power.	***Unavailable***
Task 2.4: By June 2008, ODUSD(I&E) develop a plan to "island" critical missions from the grid by December 2009. A preliminary list of Joint Staff identified assets is contained in *Appendix G*.	***Unavailable***
Task 2.5: By June 2008, the Under Secretary of Defense for Policy (USD(P)) develop a legislative proposal to make grid reliability a factor in future Base Realignment and Closure (BRAC) decisions.	***Unavailable***

Task	Status
Task 2.6: By June 2008, ODUSD(I&E) update its 2004 Renewable Energy Assessment by adding biomass, waste-to-power, geothermal power generation systems, and biobased ground transportation fuels; and by October 2009 develop a comprehensive efficiency and renewables investment roadmap to exploit the resources identified in the assessment. The results should be incorporated into the net-zero-energy installations plan.	***Unavailable***
Task 2.7: By October 2008, ODUSD(I&E) require all new Military Construction (MILCON), Operation and Maintenance (O&M), privatized construction and all facility renovations that exceed 50% of replacement cost to meet energy efficiency standards that are at least 50% better than ASHRAE 90.1.2004.	***Unavailable***
Task 2.8: By April 2008, ODUSD(I&E) issue a policy requiring all installation maintenance, whether by contract or in-house, to install only Energy Star and FEMP designated products, and maintain equipment to at least that standard of efficiency.	***Unavailable***
Task 2.9: By April 2008, USD(AT&L) issue a policy requiring the DLA to carry only Energy Star and FEMP designated products, as established by the *Energy Policy Act of 2005, Section 104*; requiring GSA to offer only those products to DoD customers, and prohibiting DoD personnel or contractors from using Government credit cards to circumvent this policy.	***Unavailable***
Task 2.10: By October 2009, ODUSD(I&E) require that electricity and fuel/gas meters be installed on all DoD buildings and facilities in order to more effectively manage energy consumption.	***Unavailable***
Task 2.11: By October 2008, ODUSD(I&E) require that all new MILCON, O&M and privatized construction started in FY 2020 and later meet a "net zero" energy consumption specification.	***Unavailable***
Task 2.12: By October 2008, ODUSD(I&E) require that all DoD installations meet a "net zero energy standard by 2025.	***Unavailable***
Recommendation #3: **Establish a Department-wide strategic plan that establishes measurable goals, achieves the business process changes recommended by the 2001 DSB report and establishes clear responsibility and accountability.**	
Task 3.1: By June 2008, establish a senior energy official responsible for development of policies and procedures and oversight of their implementation. This official should have a voice at the key decision bodies throughout the requirements, acquisition, and funding processes to ensure energy considerations have been accurately factored into key decisions that affect DoD's energy demand patterns and risks from disruptions in commercial energy supplies.	***Complete*** • Initially, the Assistant Secretary of Defense for Operational Energy Plans and Programs (ASD(OEPP)) performed these duties. This role is now filled by Assistant Secretary of Defense for Energy, Installations, and Environment (ASD(EI&E)).

Task	Status
Task 3.2: By June 2008, USD(P) incorporate the concepts of resilience of critical missions at installations and endurance of combat forces as tactically and strategically important metrics to be included in future strategy and planning documents. While the names of these documents change frequently (e.g., Quadrennial Defense Review (QDR), National Military Strategy, Strategic Planning Guidance (being renamed Guidance for Development of the Force / Guidance for Employment of the Force)) these concepts should guide the formulation of Department goals and strategy for managing energy.	***Complete*** • DoDD 4180.01 directs USD(P) to "facilitate development of energy analysis and integration of insights from the analysis into defense planning and programming considerations" • OE considerations are incorporated into the QDR and other classified planning guidance.
Task 3.3: By July 2008, USD(AT&L) direct the establishment of partnerships with: • ODUSD(I&E) and the DOE Office of Energy Efficiency and Renewable Energy (DOE/EERE) to identify technologies related to renewable and distributed energy supplies for installations that have the potential to contribute to resilience metrics for installations. • DDR&E and DOE/EERE to identify technologies with the potential to contribute to endurance metrics by reducing battlespace fuel demand by deployed forces and at forward operating bases.	***Complete*** • The 2010 DoD-DOE Memorandum of Understanding[70] has set up a framework for cooperation with DOE and is led by ASD(EI&E).
Task 3.4: By July 2008, DEPSECDEF establish an interagency oversight group in cooperation with the National Security Council, the Homeland Security Council, the DOE, and the Federal Energy Regulatory Commission to: • ascertain the risks to DoD missions from commercial grid outages; • determine the adequacy of actions being taken under current legislative authority to establish and enforce grid reliability standards; and • propose case specific remedies, as needed, to achieve grid reliability standards needed to support the level of mission resilience considered necessary by the DoD and the Department of Homeland Security (DHS).	***Unavailable***
Task 3.5: By October 2008, develop and implement a Department-wide plan to integrate energy into appropriate education and training programs, to include professional military education, to include Senior Service Schools, Capstone and Apex; and specialty-specific education, such as acquisition corps and engineering. Curricula should include risk to mission, cost and force structure aspects of energy as addressed in this report and appropriate to the course.	***Partially Complete*** • While the OE Strategy and DoDD 4180.01[71] addresses OE in education and training, there has been limited success in implanting this task.

[70] US DoD and US DOE, "Memorandum of Understanding Between the U.S Department of Energy and the U.S Department of Defense."
[71] DoD Directive, "DoDD 4180.01, DoD Energy Policy."

Task	Status
Recommendation #4: Invest in energy efficient and alternative energy technologies to a level commensurate with their operational and financial value.	
Task 4.2: By July 2008, USD(AT&L) issue a policy re-establishing early competitive prototyping for major ACAT I programs. These programs have been all but abandoned by the Department due to cost, but their ability to accelerate technology maturation to a readiness level appropriate for program adoption, overcome reluctance by operators to consider and adopt new technologies, and to guide multi-billion dollar development and acquisition investments, suggests to the Task Force that their value far exceeds their cost. The Task Force recommends dedicating on the order of $500M a year in order to better leverage the billions dedicated to major acquisition programs.	***Partially Complete*** • DoDI 5000.02 calls for competitive prototyping during the technology maturation and risk reduction in the Technology Development Phase; however, no specified funding source has been provided.
Task 4.3: By July 2008, DDR&E initiate a research program to identify the characteristics of synthetic fuels likely to be producible at deployed locations, and identify, or develop as needed, materials for use in propulsion systems compatible with that range of fuel types. Technologies to produce synthetic fuels on a small scale using indigenous feedstocks are under development, and the ability of deployed systems to use those fuels would be operationally advantageous. Locally available feedstocks could include kitchen and human waste, other biological materials or used motor oil.	***Incomplete*** • Generally, the Department has limited its investments in specific fuels and liquid fuel production technology, particularly in an expeditionary environment. • DARPA evaluated concepts for producing fuels from algae and other biomass in remote locations, but to our knowledge, DARPA nor the Services are currently funding such efforts. • Alternative fuel testing and certification activities have continued, but these activities focus on drop-in alternative (or synthetic) fuels likely to be widely available in the commercial markets, not necessarily deployed locations.
Task 4.5: The Task Force recommends the Department continue to invest in basic research to develop new alternative fuels technologies that are too risky for private investments, and to partner with private sector fuel users to leverage efforts and share burdens. The Task Force also recommends the Department work with commercial partners to conduct full "well-to-wheel" life cycle assessments of each synthetic fuel technology to assess environmental, cost, material flow and scalability issues. The life cycle carbon footprint of alternative fuels should be less than petroleum. The Task Force recommends DoD give priority to synfuel production adaptable to forward deployed locations using local materials. Such technologies could reduce the amount of fuel needed to be moved and protected in theater gallon for gallon.	***Incomplete*** • The Department has limited its investments in specific fuels and liquid fuel production technology, particularly in an expeditionary environment. • The Department and the DOE have co-invested with the private sector in the construction of commercial-scale drop-in biofuel production facilities through *Defense Production Act Title III*.[72] • Limited studies supported by USAF, DLA, and OSD, in partnership with DOE, address life cycle environmental, cost, and scalability issues associated with synthetic fuels for military use.[73]

[72] Defense Production Act Title III, "Advanced Drop-in Biofuels Production Project." http://www.dpatitle3.com/dpa_db/project.php?id=190

[73] Allen et al., "Propulsion and Power Rapid Response Research and Development (R&D) Support. Delivery Order 0011"; Strogen et al., "Feasibility of Technologies to Produce Coal-Based Fuels with Equal or Lower Greenhouse Gas Emissions than Petroleum Fuels"; Alcorn et al., "DLA Energy Biofuel Feedstock Metrics Study."

Task	Status
Task 4.7: By July 2008, ODUSD(I&E) establish a policy requiring all buildings to incorporate renewable energy (e.g., solar, wind and ground geothermal) into their design, as appropriate to the location and function of the building in order to reduce the requirement for power from the commercial grid.	***Unavailable***
Task 4.8: By April 2009, ODUSD(I&E) identify five installations for strategic islanding demonstration projects, with a roadmap for implementation within 18 months.	***Unavailable***
Task 4.9: By budget year FY10, DDR&E increase investments in energy storage technologies to improve the performance of electrically powered vehicles, and enable storage of electricity generated by renewable sources at forward operating bases.	***Incomplete*** • Comprehensive data on funding or performance is not available. • DoD is funding a significant energy storage problem together with DOE—the Hybrid Energy Storage Module program (HESM). HESM is working on energy storage devices for DoD field generation, aircraft, and ships.
Task 5.1: By April 2008, DEPSECDEF and VCJCS direct the Services to initiate a comprehensive review of how the Services currently employ simulators, emulators and task trainers, the extent to which their use could be increased while maintaining mission qualification, and to identify technical improvements that could permit increased use. The review should include authoritative experts in the field of cognitive responses to ensure the results and recommendations will lead to a better trained and more capable force.	***Incomplete*** • OSD has not carried out any unified initiatives related to simulators.
Recommendation #5: **Identify and exploit near-term opportunities to reduce energy use through policies and incentives that change operational procedures.**	
Task 5.3: By July 2008, DEPSECDEF and VCJCS issue a joint directive prohibiting unnecessary operational practices that increase fuel usage and costs, such as use of afterburner on takeoff when conditions allow safe operations with military power, multiengine taxi operations, sprint and drift steaming operations; and requiring annual reviews to determine the completeness of the list, effectiveness of the policy, and recommended changes to further reduce unnecessary fuel use.	***Incomplete*** • No related directive or order has been issued by the Department. • However, certain practices—taxing, optimum speeds, center of gravity, optimizing cargos—have been reviewed and implemented by the Services.

Appendix I: Key Findings in INL Report on DARPA's Study of vSMRs for FOBs

The following information includes excerpts[74] from a recent Idaho National Lab study, "Innovative Deployable Energy System Concepts,"[75] which summarized the findings of the previously described DARPA initiative to evaluate vSMRs for FOBs.

Table I-1. Key Performance Parameters and Challenges

KPP	Challenge
Transport fresh and used fuel by air, sea, rail, and highway.	Need a nuclear energy system capable of air transportation, while addressing highly radioactive source terms and large residual heat loads.
No significant increase in FOB threat consequence effects, e.g., avoid unacceptable radiological consequences.	Need a nuclear energy system design that mitigates toxic and radioactive dispersal and related consequences from credible transport or operation accidents or design basis attacks, e.g., ballistic, IED, direct fires that breach the system.
Transportable by C-17 aircraft.	Need a nuclear energy system that can be transported to FOBs worldwide by military transport.
Installed and operating within 72 hours.	Need a nuclear energy system that is agile, quickly set-up and operating.
Shutdown, cool down, disconnect and transport to another location in less than seven days.	Need a nuclear energy system that is agile and able to move with the FOB, i.e., it is not the "long pole in the FOB tent."
Capable of immediate shutdown and passive cooling.	Need a nuclear energy system that is inherently safe, with no negative outcome if all active systems and controls are lost, e.g., due to attack.
No significant increase in risk to the health and safety of the public, military personnel or to the environment.	Need a nuclear energy system that does not result in a significant increase in risk to the health and safety of the public, military personnel nor to the environment, relative to the risk associated with normal human activity.
Greater than one year refueling cycle.	Need a self-contained nuclear energy system that dramatically reduces the number of energy related convoys.
No proliferation risk.	Need a nuclear energy system that is designed to minimize proliferation risk by reducing fuel access opportunity, reducing fuel attractiveness and avoiding production of attractive fuel.
Scalable power; 2–10 MWe	Need to adjust to FOB size and load demand.

[74] The formatting and caption numbering systems were adjusted for consistency with the rest of this report.
[75] Gougar et al., "Innovative Deployable Energy System Concepts."

Table I-2. Performance Attributes of Top Candidates

Performance Attributes	High Temperature Gas-Cooled Reactor	LANL Heat Pipe Reactor*	Radioisotope Thermal Power System
Power output (MW_e)	5	2	0.2 or 0.57
Shutdown cooling (MW_t)	<2 (decay heat)	<0.8	0.2 or 0.57
Operating temp (°C)	850 (outlet)	675 (outlet)	700 (outlet)
Fuel type (TRL)	UCO TRISO (TRL 5–6)	UO_2 (TRL 9)	SrF_2 (TRL 9)
Fuel clad failure temp(°C)	>1650	~1450	~1450
LOCA peak reactor temp. (°C)	~1250	~1200	NA
Emergency cooling	Passive	Passive	Passive
Operating pressure (MPa)	7.4	0	2.6
Fuel (fissile) quantity	~ 800 kg U-235 (<20% enrichment)	~880 kg U-235 (19.75% enrichment)	NA
Release potential if breached	TRISO should retain fission products	Minimal release (atm press; fuel in SS block)	Minimal release (fuel in SS pebbles)
Cladding/encapsulation	Silicon carbide	SS-316L	SS-304
Refueling approach and interval	Refuel by replacement of reactor module every 2 yrs	Refuel by replacement of reactor module every 5 yrs	Refuel by replacement of heat source every 10 yrs

All concepts are assumed to be surrounded by a berm or other hardened structures designed to protect the plant from natural and human assaults. Nonetheless, there is a risk of a breach of these barriers (possibly aided by sabotage) with a subsequent release of radiation and radiological material. The StarCore HTGR and the LANL HPR contain fissile material that would require specialized equipment and personnel trained in criticality to contain and remove in the unlikely event of a catastrophic breach. Transporting fissile material requires an agreement with the host country and specialized transport casks. The RPS does not contain fissile material but the Sr-90 fuel is toxic and its dispersal would also pose a significant exposure risk to site personnel.

Based upon input from the designers, the approximate footprint (square feet) of a 10 MWe power supply capable of serving a 10-year mission was estimated for each concept and compared to that of the current diesel generator technology (not counting the fuel during transportation.) In some cases, more than one power plant is needed to achieve the total power output and the footprint is the value of the ensemble including the power conversion and heat rejection hardware.

Table I-3. Approximate Site Footprint and Refueling Interval

10 MWe Power Plant Concept (No. of units)	**Footprint at the FOB (ft^2)**	**Equivalent No. of refueling trucks and refueling interval**
Diesel Generator (50)	~ 4000	Many thousands
High Temperature Reactor (2)	~ 1400	12 (2 years)
Heat Pipe Reactor (5)	~ 2000	15 (5 year)
Radioisotope Power Supply (18)	~ 7200	23 (5 year)

The performance attributes of the nuclear heat systems listed in **Table I-2** are important but there are other considerations that factor into the overall feasibility including: overall footprint including fuel supplies and deliveries, resilience against attack, availability of fuel supply, transportability, and the technical maturity of the system. These are listed in **Table I-4**.

Table I-4. Other Performance Measures and Considerations

Metric	**StarCore HTGR**	**LANL HPR**	**RPS**
Reduction in fuel shipments	1287 tankers per each 5 MWe unit per year	515 tankers per each 2 MWe unit per year	~50 tankers per each 200KWe unit per year
Fuel safety	Extended temperature range and containment of fission products	Extended temperature range; containment in SS block	Containment in SS pebbles
Footprint vs. diesel generator	35%	50%	180%
Time to transport after operations	>7 days	~4 days	<1 day
Treaties and policies required	Yes	Yes	No fissile material treaty/transport
Cost of power (% of diesel power)	35%	32%	42%
Level of protection required	High	High	Moderate
Upfront investment cost	Large	Large	Moderate-Large

Upfront development and qualification costs of all systems are considered very significant but somewhat less so for the Radioisotope Power System (RPS) as it is technologically less complex than the fission-based systems. The key technical challenges and developmental needs are listed in **Table I-5**.

Table I-5. Key Technical Challenges and Needs

StarCore HTGR	• Complete final design and qualification • Cycle length and structural performance of a transportable core • Transport criticality safety and mobility (may require unloading of the fuel)
LANL HPR	• Manufacturing, testing, and qualification of the stainless steel monolithic core design • Characterization of failure modes (heat pipe failure and cascading, passive decay heat removal)
RPS	• Complete final design and qualification • Quantity and disposition of Sr-90 supply • Development of process and procedures for prototype using known domestic supplies (Hanford)

Finally, it was noted that these technologies lend themselves to phased deployment. One can add advanced power conversion technologies to existing systems in the near future while designing and qualifying the RPS and eventually the critical nuclear plant systems. One can also deploy prototype systems in less hostile locations to work out the bugs and optimize the systems before deploying under combat conditions. There are a number of domestic military bases which might benefit from clean nuclear energy technologies. **Figure I-1** illustrates one possible phased deployment scenario.

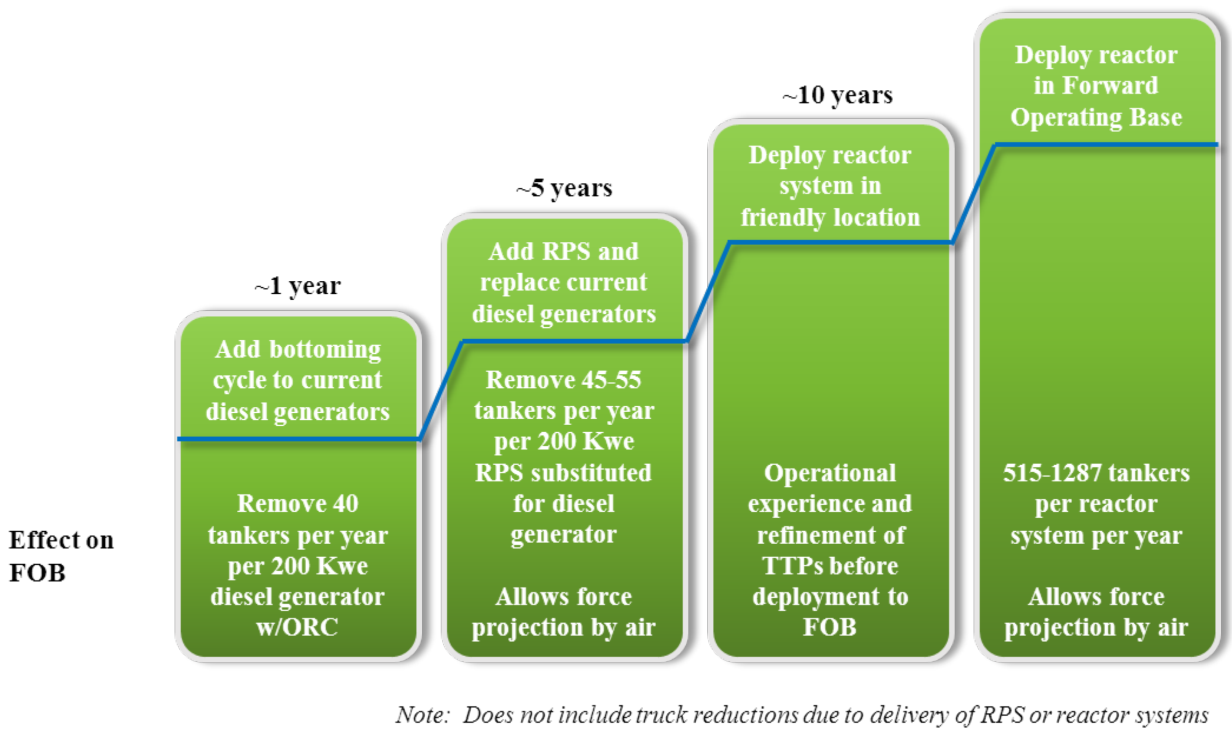

Figure I-1. Progressive Deployment of Technologies Can Bridge the Gap

Conclusions (from the INL Report)

A number of innovative, conceptual, small, energy power systems (most nuclear-driven) were evaluated against performance metrics appropriate for deployment by the military at forward operating bases. One system, the radioisotope power system, could potentially be pursued for near-term (~5 years) deployment. None of the nuclear reactor systems were deemed suitable for near-term deployment but two were considered promising enough for further consideration and investment.

A Radioisotope Power System would rely on the decay heat emitted from the unstable isotope strontium-90 (Sr-90) as a steady but slowly declining heat source. An RPS of this output and purposes has yet to be designed and qualified but the technology is relatively mature and scalable. The known or projected supplies of Sr-90 limit the extent to which this energy source can be deployed.

A heat pipe-cooled fast reactor designed by LANL is small enough to be shipped in a shielded configuration to and from the FOB. The core would be a stainless steel monolith containing fuel rods and heat pipes for simple heat extraction. Such a core concept has not been built (with either heat pipes or other coolant systems) and thus this system would need to undergo significant testing and qualification.

A high temperature gas-cooled reactor designed by StarCore would rely upon demonstrated inherent safety characteristics. The large reactor structure poses a real challenge for transport to and (especially) from the FOB. Analyses are needed to determine the duration of the fuel cycle for such a small core and the integrated final design needs to be completed and tested.

Advanced (gas or supercritical fluid) thermal power conversion systems were also evaluated because of their small footprints compared to traditional steam turbine systems. Preliminary studies indicated that none stood out in terms of cycle efficiency but that an open-cycle air Brayton system was technically most advanced and could reject waste heat directly to the atmosphere without a separate heat rejection loop.

From an operational perspective the study also noted that each of the power source/power conversion system concepts operated most efficiently under continuous power/heat conditions (e.g., RPS heat source is continuous decay heat, reactors operate most efficiently under constant power conditions). Using a control system with each of these systems the primary objective, electricity generation, could be met after which the control system would direct the heat source to multiple secondary and tertiary uses such as desalinization, water purification, sewage treatment, battery charging, hot water for FOB, and heating for occupied space on the FOB.

As shown in **Figure I-1**, the technologies described in this report have the potential for incremental deployment that can begin reducing diesel fuel consumption almost immediately.

Appendix J: Primer on Naval Reactor Program

A successful example of a U.S. Government organization responsible for military reactors exempt from civilian licensing through the Nuclear Regulatory Commission (NRC), under Section 91 of the *Atomic Energy Act* is the Naval Reactors (NR) program. Any effort to reconstitute an organization within the DoD capable of regulating small modular reactors for military purposes should look to the NR program as a model. The Task Force notes that the management philosophy, structure, and culture that is responsible for the success of the NR is well documented.

The mission of the NR organization is to provide militarily effective nuclear propulsion plants and ensure their safe, reliable, and long-lived operation. Naval Reactors organic statute, *50 U.S.C 2406, 2511*, codifying *Presidential Executive Order 12344* sets forth the total responsibility of NR for all aspects of the Navy's nuclear propulsion, including research, design, construction, testing, operation, maintenance, and ultimate disposition of naval nuclear propulsion plants within both the Departments of Navy and Energy. The NR responsibilities include all related facilities, radiological controls, environmental safety and health matters, as well as selection, training, and assignment of personnel. A lean network of research laboratories, nuclear-capable shipyards, equipment contractors and civilians, suppliers, and training facilities are centrally managed by a relatively small headquarters staff.

The NR program, since inception in 1948, has been responsible for maintaining an exemplary track record of safety and reliability in the design and operation of naval nuclear propulsion plants. NR maintains a record of over 157 million miles safely steamed on nuclear power. NR currently operates 96 reactors and has accumulated over 6,700 reactor-years of operation. Because of this demonstrated reliability, U.S. nuclear-powered ships are welcomed in more than 150 ports of call in over 50 foreign countries and dependencies. While naval reactors are exempt from NRC licensing under Section 91 of the *Atomic Energy Act*, NR obtains NRC peer reviews of each of its naval reactor plant designs. These reviews provide additional assurance, domestically and abroad, that U.S. naval reactor plans do not present an undue risk to the health and safety of the public.

The NR program employs approximately 680 technical staff to oversee over 40,000 federal, military, and contractor personnel. NR is responsible for all aspects of the design, operation, testing, and disposal of naval propulsion plants; management and oversight of two DOE laboratories for R&D and new reactor concepts (Bettis Atomic Power and Knolls Atomic Power Laboratories); training all new accessions (officer and enlisted) for one full year of schoolhouse and hands-on prototype education and training; monitoring and inspection of all operating reactors on a near-continuous basis; and oversight of all associated radiological work at the nation's nuclear capable shipyards.

The NRC employs some 4,000 plus staff to license and oversee all operational aspects of 100 commercial reactors operated by 30 power companies, roughly the same number of reactors as the Naval Reactors organization oversees (albeit of different sizes, locations, and purpose).

Appendix K: Acronyms and Abbreviated Terms

ACAT	acquisition category
AEPI	Army Environmental Policy Institute
AFB	Air Force Base
AFCAP	Air Force Contract Augmentation Program
AFI	Air Force Instruction
AFR	advanced fast reactor
AFRICAP	Africa's Multifunctional Peacekeeping Support Program
AFS	Air Force Station
AoA	analysis of alternatives
AOC	Army Operating Concept
ARCENT	United States Army Central
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
ASD(EI&E)	Assistant Secretary of Defense for Energy, Installations, and Environment
ASD(OEPP)	Assistant Secretary of Defense for Operational Energy Plans and Programs *[merged with DUSD(I&E) in 2015 to create the ASD(EI&E)]*

BEAR	Basic Expeditionary Airfield Resources
BCIL	Base Camp Integration Laboratory
BMD	Ballistic Missile Defense
BTU	British thermal units

C4	command, control, communications, and computers
CAES	Compressed Air Energy Storage
CCMD	Combatant Command
CJCS	Chairman of the Joint Chiefs of Staff
CNA	Center for Naval Analysis
CO_2	carbon dioxide
COCO	contractor-owned, contractor-operated
CONOPS	concept of operations
CONUS	continental/contiguous United States
CS&CSS	Combat Support and Combat Service Support

DAB	Defense Acquisition Board

DARPA	Defense Advanced Research Projects Agency
DBS	Defense Business System
DCSLOG	Deputy Chief of Staff for Logistics
DDR&E	Director Defense for Research and Engineering *(now Assistant Secretary of Defense for Research and Engineering)*
DE	directed-energy
DEPSECDEF	Deputy Secretary of Defense
DHS	Department of Homeland Security
DLA	Defense Logistics Agency
DLAI	Defense Logistics Agency Instruction
DoD	Department of Defense
DoDD	Department of Defense Directive
DoDI	Department of Defense Instruction
DOE	Department of Energy
DR	distributed resources
DSB	Defense Science Board
DTIC	Defense Technical Information Center
DTRA	Defense Threat Reduction Agency

E2C	expeditionary energy concepts
E2E	energy to the edge
E2S2	expeditionary energy and sustainment systems
EATR	energetically autonomous tactical robot
ECU	environmental control unit
EERE	Energy Efficiency and Renewable Energy
EFPD	effective full-power days
EIA	U.S. Energy Information Administration
EM	electromagnetic
EMP	electromagnetic pulse
EMRG	electromagnetic railgun
EoA	evaluation of alternatives
EPC	engineering, procurement, and construction
EPS	electric power systems
EV	electric vehicles

F&A	Filippone & Associates LLC
FBC	fully burdened cost

FBCE	fully burdened cost of energy
FBCF	fully burdened cost of fuel
FG15	flood gun
FM	Field Manual
FOAK	first-of-a-kind
FOB	forward operating base
FY	fiscal year

GAIN	Gateway for Accelerated Innovation in Nuclear
GAO	Government Accountability Office
gge	gallons of gasoline equivalent
GOCO	government-owned, contractor-operated

HADR	Humanitarian Assistance and Disaster Relief
HEL	high energy lasers
HEL MD	high energy lasers mobile demonstration
HEMTT	heavy expanded mobility tactical truck
HESM	hybrid energy storage module
HEU	highly enriched uranium
hp	horsepower
HPR	high-powered railgun
HQ	headquarters
HTGR	high temperature gas reactor
HVAC	heating, ventilation, and air conditioning

IAEA	International Atomic Energy Agency
ICD	Initial Capabilities Document
ICT	information and communication technology
IED	improvised explosive device
IEEE	Institute of Electrical and Electronics Engineers
INFCIRC	International Atomic Energy Agency Information Circular
INL	Idaho National Laboratory
ISO	International Organization for Standardization (standards)
ISR	intelligence, surveillance, and reconnaissance
ITAR	International Traffic in Arms Regulations

JCIDS	Joint Capability Integration and Development System
JDW2E	Joint Deployable Waste-to-Energy
JP	joint publication
JROC	Joint Requirements Oversight Council
JS	Joint Staff
JSC	Joint Sustainment Command
JTF	Joint Task Force

KPP	key performance parameter
kW	kilowatt(s)
kWh	kilowatt-hour(s)

LANL	Los Alamos National Laboratory
LED	light emitting diodes
LEU	low-enriched uranium
LOGCAP	Logistics Civil Augmentation Program

MEG	Microgrid Exchange Group
MEPGS	Mobile Electric Power Generating Sources
MILCON	Military Construction
MIT	Massachusetts Institute of Technology
MJ	megajoule(s)
MMR	micro modular reactor
MW	megawatt(s)
MWe	megawatt(s) of electric energy
MWR	Morale Welfare and Recreation
MWt	megawatt(s) of thermal energy

NASA	National Aeronautics and Space Administration
NAVFACINST	Naval Facility Command Instruction
NDAA	National Defense Authorization Act
NNSA	National Nuclear Security Administration
NR	Naval Reactors
NRC	Nuclear Regulatory Commission

NRL	Naval Research Laboratory

OCONUS	outside continental/contiguous United States
ODUSD(I&E)	Office of the Deputy Under Secretary of Defense for Installations and Environment *[merged into the Office of the ASD(EI&E) in 2015]*
OE	operational energy
O&M	Operations and Maintenance
OP	Other Procurement
ORC	Organic Rankine cycle (technology)
ORNL	Oak Ridge National Laboratory
OSD	Office of the Secretary of Defense

PACOM	United States Pacific Command
P.L.	Public Law
PM	project manager
PNNL	Pacific Northwest National Laboratory
PV	photovoltaic

QDR	Quadrennial Defense Review

R&D	Research and Development
RCGV	remotely commanded ground vehicles
RDT&E	Research, Development, Test, and Evaluation
RED HORSE	Rapid Engineer Deployable Heavy Operational Repair Squadron Engineer
RFI	request for information
ROB	remote operating base
RPS	radioisotope power system
RTG	radioisotope thermoelectric generator

S&T	science and technology
SAGE	Smart and Green Energy
SECDEF	Secretary of Defense
SERDP	Strategic Environmental Research and Development
SMR	small modular reactor

SPNR	special purpose nuclear reactor
Sr-90	strotium-90
sUAS	small unmanned aerial/aircraft system

TARDEC	United States Army Tank Automotive Research, Development, and Engineering Center
TFMD	Tactical Fuels Manager Defense
TM	Technical Manual
TOR	terms of reference
TRADOC	United States Army Training and Doctrine Command
TRISO	tristructural-isotropic
TRL	technology readiness level

UAV	unmanned aerial/aircraft vehicle
UOX	uranium oxide
USA	United States Army
USAF	United States Air Force
USC	United States Code
USD(AT&L)	Under Secretary of Defense for Acquisition, Technology, and Logistics
USD(P)	Under Secretary of Defense for Policy
USG	United States Government
USMC	United States Marine Corps
USRA	Universities Space Research Association

VCJCS	Vice Chairman of the Joint Chiefs of Staff
vSMR	very small modular reactor