Increasing Capabilities and Reducing Logistics at Contingency Bases

Via Energy-Efficient System-of-Systems Solutions

Base camp for the Balikatan military exercise where TROPEC performed extensive testing of expeditionary energy solutions (Phillipines, 2013).

The Opportunity

Fuel is a lifeline for military expeditionary missions. Fuel adds capability and endurance, critical needs for most missions. Two solutions for more fuel are increasing delivery (and logistics and delivery risk) or extending the reach of existing fuel via efficiency gain. Efficiency gain reduces delivery, logistics, and risk and is therefore a much more desirable option if capabilities are not compromised. There is dramatic potential for capability improvement via fuel efficiency advances at contingency bases. No one solution offers the silver bullet. The most impactful solutions are combinations of proven solutions that additively, yield dramatic improvement in capability and endurance.

Summary

The Transformative Reductions in Operational Energy Consumption (TROPEC) program has conducted extensive evaluations of energy efficient solutions aimed at enabling large reductions in the energy footprint of forward contingency bases with an emphasis on tropical climates. TROPEC has recently looked at combinations of these solutions for enabling greater military capability.

The TROPEC team leveraged data from multiple technology evaluations and modeled them into a system-of-systems (SoS) framework to explore the potential of compounding impacts of layering energy-efficient technologies and strategies in forward locations. This brief highlights the synthesis of system-of-systems approaches toward meeting DoD's expeditionary energy goals. It overviews the challenges, some key technology solutions, and the SoS solutions that were evaluated to demonstrate major, base-wide energy use reductions possible at contingency bases in tropical climates.

Energy Baseline for Measuring Impact

In the FY11 conception of TROPEC, a notional baseline for measuring impact was built upon information gleaned from readily-available sources. The baseline represented systems that were currently "on-the-ground" in existing military deployments. In FY14, the Army released the Technology Enabled Capability Demonstration (TECD-4a) Operationally Relevant Technical Baselines (ORTBs) which have been vetted across military stakeholders. These baselines have been adopted by TROPEC for impact evaluation.

TROPEC analysis indicates the ORTB for "hot" climates is representative of tropical climates. This ORTB, however, uses a modulating capacity environmental control unit (ECU; the HDT F-100[2]) which was used in small quantity at TROPEC's inception (instead fixed-capacity, bypass-type ECUs dominated). TROPEC adjusted the ORTB baseline for this single variance to match TROPEC's inception and corresponding goals basis. Camp metrics for the 300–PAX (person) TECD-4a baseline and the TROPEC adjusted baseline are as follows:

Base Energy Use (Gal JP8, Hot climate, 300 PAX)	
TROPEC Baseline	• 4.3 gal/day per person • 494 kgal/yr
TECD-4a Baseline	• 3.8 gal/day per person • 437 kgal/yr

1. TROPEC is a joint, interagency effort led by U.S. Pacific Command (PACOM) and supported by military and energy experts from Naval Facilities Engineering & Expeditionary Warfare Center and Department of Energy Oak Ridge and Lawrence Berkeley National Laboratories.

2. The Hunter Defense Technologies (HDT) F-100 is currently not a military program of record system.

Key Challenges and Opportunities

Cascading, interactive effects of current ECU-shelter- generator combinations lead to major SoS inefficiencies. Five challenges that dominate contingency base energy use inefficiencies are:

1. Generators artificially loaded to avoid high inrush currents from ECUs and low part loads; newer generators are less sensitive but remain highly vulnerable to these events.
2. Thermally inefficient, unshielded shelters result in excessive space conditioning energy use and larger ECUs; initiatives on shelter design improvements are in progress across DoD.
3. Conventional (hard-start) electric motors in ECUs lead to excessive generator quantities and low load/low efficiency operation; soft-start motors in some current/next generation ECUs will help but better generator utilization is needed.
4. Fixed-capacity ECUs are often oversized in moderate climates and during periods of moderate demand; newer modulating capacity ECUs use less energy and can provide better environmental control but their high power draws during extensive periods of low to no cooling demand represent much more opportunity.
5. Energy management control capabilities from simple, dedicated control systems like occupancy and timing controls to camp-wide control systems are not utilized; technology solutions to address the challenge are under development, primarily for camp-wide solutions.

Shelter Efficiency Solutions

In tropical climates, shelter solutions are enabling technologies – their great value comes from what improving shelters enables, not just from reducing shelter energy use. Improving shelters enables reducing ECU size, which (like soft-start) enables more ECUs to be tandemed on individual generators (reducing the number of generators in operation and overall energy use). Improved shelters also enable two shelters to be served by one ECU (tandem) which in turn can cut generator needs in half. These high-impact scenarios have been examined by TROPEC in collaboration with DoD partners, and can produce dramatic fuel savings at the base level (even with minimal equipment change).

From an energy efficiency viewpoint, findings indicate it is not so important what type of insulation or radiation barrier (e.g. a shade or reflector) is used. What is important is that both thermal and solar impacts be addressed. When mated with current ECUs that run in bypass mode, improving shelters alone does little to reduce camp fuel use. The substantial impacts come from solution sets mating improved shelters to smaller, shared (fewer), or modulating-capacity ECUs. These options combined with loading as many ECUs on individual generators as possible, enable large base-wide fuel use reductions.

Radiant heat reflector used to enhance the energy performance of a soft-sided structure (from Crimson Viper military exercise; Thailand).

ECU Efficiency Solutions

Two primary improvements to newer, medium-sized ECUs are 1) soft-start to avoid high inrush currents that constrain the number of ECUs put on a single generator and 2) modulating capacity which enables throttling back energy use when cooling loads are low to zero; hours with low- to no-cooling demand dominate the year in tropical climates.

Soft-start is also an enabling technology – while little related to ECU efficiency, it can allow doubling the ECUs on a single generator (potentially halving the generators needed and their corresponding fuel use). Modulating capacity allows an ECU to deliver less cooling during low demand which reduces energy use. Variable speed modulation, a capability not currently integrated into DoD ECUs (but used in commercial markets), is perhaps the most efficient modulating strategy available. ECUs with any of these capabilities offer reduced fuel use, but achieve much greater impact when deployed in concert with shelter and generator solutions.

A modulating capacity ECU that powers down in proportion to cooling demand.

Current modulating capacity ECUs (e.g., the F-100 and IECU - Improved ECU) use less energy that DoD's fixed-capacity ECUs but they maintain high power draw during periods of low to no cooling demand.

ECU energy use is being improved via a variety of technical solutions for next generation systems, but simple cycling control can make current fixed-capacity military ECUs operate almost as seasonally efficient as newer, more complex ECUs. For example, a current modulating capacity ECU reduces power to about 3 kW during non-cooling hours, while duty cycling imposed on a fixed-capacity ECU (the HDT B0008) reduces power draw to less than 1 kW during non-cooling hours (which brings their annual energy use comparable in a tropical climate).

TROPEC testing of a variable-speed, split-system heat pump indicates that greater base fuel use reductions are possible if variable speed could be integrated into ECUs.

Generator Solutions

Military generator improvements center on increased reliability, somewhat higher efficiency, and lower part-load resilience. However, it is the systems downstream of generators and how they are configured and operated that offer the deep impact to expeditionary camp fuel use.

Integrated Solutions for High Impact

Combining improved shelters, ECUs, and ECU controls/load management can offer savings of 50–80% of ECU energy use, which in turn can equal 25–40% of base fuel use. Newer, modulating capacity ECUs are not necessarily required for this level of impact (better ECU control strategies like duty cycling can achieve the lower end of these ranges), but they enable greater impact.

A major opportunity for fuel use reduction lies in reducing ECU power draw during non-cooling hours (these can reach 60% of the annual hours in a tropical climate). To date, this opportunity is only being partly addressed by next-generation ECUs. Cost-effective control solutions could be integrated to achieve this in both current- and next-generation ECUs.

Five solution sets (combinations) that TROPEC has modeled and evaluated are outlined in the table below. Four exceed the program's initial impact goal of reducing base energy use by 25%. Note that each solution set depends on addressing both thermal (via insulation) and solar (via shade or reflector) loads through shelter improvements.

In solution Set 1, two tents are connected (tandemed) to a single 5-ton ECU, enabling generators in use to be nearly halved. Base energy use impact from this approaches 25% without ECU change. In Set 2, multiple ECUs are connected to one generator. This can be achieved by duty cycling ECUs (the simple approach evaluated here) or by using more advanced ECUs with soft start capability.

Solution Sets 3 thru 5 involve ECUs that use different types of capacity modulation. Set 3 uses pulse duty-cycling to modulate capacity (like the IECU and F-100). Set 4 uses two-stage modulation (low and high load; a mature, rugged, and simple design that has not been adopted to date, although a prototype of this design was recently delivered to DoD for evaluation). Set 5 uses one of the most efficient, modulating designs available; a variable-speed, split-system heat pump.

Multiple strategies can achieve 25% and greater base-wide fuel use reduction. Some reflect merely operational change (e.g., tandem arrangements of tents or ECUs to reduce needed generator quantities) while others involve materiel change (equipment upgrades). In combination, these and other solutions offer foundational means for TROPEC to help DoD and other US Government agencies achieve great fuel use reductions across basecamp operations which can lead to dramatic increases in capability, reduced logistics, and lower risks.

Technology Area	Impact Technology	SOS Solution Set*				
		1	2	3	4	5
Shelters	Insulation	X	X	X	X	X
Shelters	Shade/Reflector	X	X	X	X	X
ECUs	Tents (tandem on ECU)	X				
ECUs	ECU's (tandem on generator)		X			
ECUs	Modulating (pulse)			X		
ECUs	Modulating (two stage)				X	
ECUs	Modulating (var. speed; split)					X
300 PAX Base JP8 Reduction (%):		21	26	28	31	36

*X indicates impact technology is part of solution set.