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MARINE CORPS ORDER 3900.19

From: Commandant of the Marine Corps
To: Distribution List

Subj: APPLYING ENERGY PERFORMANCE METRICS AND MEASURES IN REQUIREMENTS DEVELOPMENT AND ACQUISITION DECISION-MAKING

Ref: (a) U.S. Marine Corps Expeditionary Energy Strategy and Implementation Plan, 23 Feb 2011
(b) Initial Capabilities Document for United States Marine Corps Expeditionary Energy, Water and Waste, 2 Sep 2011
(c) MCO 5311.6
(d) MCO 3900.15B
(e) Manual for the Operation of the Joint Capabilities Integration and Development System, Jan 2012
(f) SECNAVINST 5000.2E
(g) 2009 National Defense Authorization Act
(h) ASN(RDA) Memo, Energy Evaluation Factors in the Acquisition Process, 20 Jun 2011
(i) U.S. Marine Corps Integrated Test and Evaluation Handbook, 6 May 2010
(j) SECNAV M-5210.1

Encl: (1) U.S. Marine Corps Energy Performance Requirements Guide for Capability Development

1. Situation

a. Seventy percent of the logistics required to sustain Marine Corps expeditionary forces ashore is fuel and water. A Marine infantry company today uses more fuel than an entire infantry battalion did in 2001. This increase in demand for "liquid logistics" constrains operations, places a significant risk and strain on the distribution pipeline, and increases the overall weight of the Marine Air Ground Task Force (MAGTF). The primary factor driving the growing demand for fuel is the dramatic increase in the number, weight and energy requirements of systems deployed to support enhanced company operations and sustained combat operations ashore.

b. As highlighted in reference (a), a Marine infantry battalion has increased the number of assigned radios by 250 percent and the number of data systems by 300 percent since 2001. This increase in electronic systems has driven up the demand for power generation equipment, resulting in an increase from 65 megawatts (MW) to 303 MWs of capacity in the Marine Corps inventory. In 2001, the same battalions had 64 High-Mobility Multi-Wheeled Vehicles. Today, their 173 Mine Resistant Ambush Protected vehicles are 3000 to 5000 pounds heavier and have larger engines, decreasing per-vehicle energy performance by over 30 percent. Vehicle energy performance is further

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strained as both combat and tactical utility vehicles support ever-increasing on-board electrical loads over a growing portion of their mission time.

c. Our ability to harness and employ energy at a time and place of our choosing enables the Marine Corps' formidable lethality. Energy is the only combat enabler that crosses all elements of the MAGTF, from our aircraft to our individual Marines, on every mission and movement. The challenge with capturing energy in our requirements and acquisitions processes is that most energy consumers often are not responsible for the energy they use and those that supply energy have no controls over consumers. This Order is designed to assist our requirements and acquisition professionals with defining energy performance considerations early in the development of new capabilities and upgrades to legacy capabilities. The aim is to increase the efficiency and effectiveness of the MAGTF by lightening the load on our Marines and our combat logistics.

d. On 23 February 2011, the Commandant of the Marine Corps published reference (a), which is a *"bases-to-battlefield"* energy strategy and implementation plan, to communicate his vision, mission, goals, and objectives for expeditionary and installations energy. Reference (b) was approved by the Marine Requirements Oversight Council (MROC) on 2 September 2011 and by the Joint Staff Joint Capabilities Board on 14 September 2012. References (a) and (b) serve as the framework for energy materiel and non-materiel investment across the Marine Corps. This framework focuses on increasing MAGTF energy efficiency and self-sufficiency through the actions of planners, operators, Advocates, Capability Integration Officers (CIOs), and acquisition Program Managers (PMs) along three lines of operation:

(1) Procuring equipment that is more energy efficient and including energy efficiency in upgrades to legacy equipment.

(2) Increasing development of renewable energy systems that harvest energy in place.

(3) Establishing an expeditionary ethos that equates increased combat effectiveness with efficient resource employment.

e. Reference (c) identifies the Director, Marine Corps Expeditionary Energy Office (E2O), as the Marine Corps Proponent for operational energy matters.

f. The implementation plan in reference (a) directs that energy efficiency be made a priority in all analysis supporting Expeditionary Force Development System (reference (d)) capability evolution and materiel development. The term energy efficiency is refined and replaced herein by the term energy performance (EP), which is defined as follows:

> Energy Performance (EP). The rate of energy consumption or energy harvesting required to perform a specific function or task in a specific operational mode, mission profile, and environmental condition. EP applies to any capability or system that converts energy into work or from one form to another, stores energy, transfers energy, or consumes energy.

g. Reference (e), the Joint Capabilities Integration and Development System (JCIDS) Manual, requires that an Energy Key Performance Parameter (KPP) be included in "all documents addressing systems where the provision of energy, including both fuel and electric power, to the system impacts operational reach, or requires protection of energy infrastructure or energy resources in the logistics supply chain."

Reference (e) specifies that the Energy KPP intent is "to optimiz[e] fuel and electric power demand in capability solutions as it directly affects the burden on the force to provide and protect critical energy supplies. The [Energy] KPP includes fuel and electric power demand considerations in systems, including those for operating "off grid" for extended periods when necessary, consistent with future force plans and [Integrated Security Constructs]."

h. Reference (f) establishes Department of the Navy policy regarding JCIDS and Defense Acquisition System implementation.

i. Reference (g) defines Operational Energy as "the energy required for training, moving, and sustaining military forces and weapons platforms for military operations. The term includes energy used by tactical power systems and generators and weapons platforms."

j. Policy in this Order expands on the tasks in reference (a) and applies the scope and intent of the Energy KPP and the Operational Energy definition. This Order is intended to augment, not supersede, JCIDS and Defense or Naval Acquisition policy.

2. Mission. Deputy Commandants; Commander, Marine Corps Systems Command (MCSC), and Program Executive Officers (PEOs), with direct support from the Marine Corps E2O, integrate EP metrics and measures into all applicable materiel capabilities to achieve the objectives set forth in reference (a).

3. Execution

a. Commander's Intent and Concept of Operations

(1) Commander's Intent

(a) Purpose. To increase MAGTF combat effectiveness.

(b) Method. Integrate changes to Marine Corps non-materiel and materiel development processes and documentation that are repeatable and ensure properly-framed EP analysis, EP metrics and measures, and decision-making that balance energy demand with other elements of performance for each MAGTF capability. Requirements and milestone/gate reviews will:

1. Consider EP in tradeoffs with other performance factors when developing capability requirements, considering materiel alternatives, and selecting materiel providers.

2. Employ a systems engineering approach that considers alternatives for reducing both system and overall MAGTF energy demand, lightening the individual and MAGTF combat load, and optimizing energy production, storage, transfer, and consumption for a given capability.

3. Focus on the operational impacts of reducing energy demand and more efficiently supplying energy. These impacts include, but are not limited to, the following:

a. Individual combat load and performance.

b. Volume and frequency of fuel and battery resupply.

c. Exposure to enemy threats created by fuel, battery, and water management and resupply.

d. Energy demand and loss of transportation and human asset availability to manage and resupply fuel, batteries, or water.

e. Tactical and operational maneuver, reach, and endurance limitations created by the individual and MAGTF energy and water combat load and resupply demand.

(c) Endstate. EP metrics and measures are analyzed when building future materiel capabilities or updating legacy materiel to include all weapon systems and platforms; air, ground combat, and tactical/utility vehicles; command, control, communications, computer, intelligence, surveillance, and reconnaissance (C4ISR) equipment; sustainment and shelter, water, and waste life support systems/equipment. EP metrics and measures are used as a component of capability performance tradeoff decisions, are briefed when seeking MROC approval for new or upgraded legacy capabilities, and are used as a critical decision-making factor by milestone decision authorities.

(2) Concept of Operations

(a) New materiel requirements, and changes to legacy requirements, for capabilities that produce (harvest or convert), store, transfer, or consume energy shall include documented EP metrics and measures in the form of one or more key system attributes (KSAs) and/or KPPs. Supporting analysis will include the cost (e.g., break-even point, operations and support cost avoidance, etc.) and operational (e.g., range, endurance, individual or MAGTF logistics burden, etc.) return on investment (ROI) and be documented in the KPP/KSA rationale. CIOs, working with the E2O and requirements integrated product teams (IPTs), will determine the best means to characterize EP ROI based on factors such as the type of capability, its operational modes and mission profiles, available trade space, and the anticipated acquisition strategy. Requirements documents for capabilities that do not produce, store, transfer, or consume energy will include a brief rationale as to the non-applicability of EP requirements. This documentation will be included in the documents identified in paragraph 3a(2)(c).

(b) Initial Capabilities Documents (ICDs) will include EP gaps related to the capability and, where applicable, identify any intent to consider energy in materiel alternatives.

(c) An EP KPP or KSA, with rationale and supporting energy attributes or statement of non-applicability, will be included in all new or modified requirements defined by:

1. Capability Development Documents (CDDs)

2. Capability Production Documents (CPDs)

3. Operational Requirements Documents (ORDs)

4. Operational & Organizational Concepts (O&Os)

5. Statements of Need (SONs)

6. System Requirements Documents (SRDs)

7. Engineering Change Proposals (ECPs)

When applicable, other routine requirements documents (e.g., letters of clarification, lifecycle management letters, etc.) and Urgent Statements of Need will summarize energy considerations and implications as part of the supporting abbreviated Doctrine, Organization, Training, Materiel, Leadership and Education, Personnel, and Facilities assessment. Examples of factors to consider in these assessments include, but are not limited to: use of the most efficient conventional and alternative program of record power sources, opportunities to employ rechargeable batteries while minimizing proliferation of unsupported battery types, and ensuring access to conventional and renewable recharging sources.

(d) The E2O will be included in materiel requirements development from inception in order to guide the EP analysis. Energy attributes, EP KPPs/KSAs, and justifications for non-applicability will be reviewed by the E2O prior to requirements and acquisition decision points and all gates defined in references (e) and (f), when they apply.

(e) EP tradeoffs will be explicitly considered in each applicable Materiel Development Decision (MDD), Analysis of Alternatives (AoA), and Source Selection Decision (SSD) as a value element.

(f) EP cost and operational ROI analysis must consider and document a representative profile of operational modes, theaters, and tempo over the expected materiel lifecycle in approved warfighting scenarios.

(g) While this Order is primarily focused on materiel development, non-materiel solutions may prove to be the most effective way to ensure EP-related combat effectiveness. Non-materiel solutions that foster an ethos of efficient employment of scarce battlefield energy resources as an element of combat effectiveness are force multipliers that may be easier and more cost effective to develop and implement.

b. Tasks

(1) Deputy Commandant for Combat Development and Integration (DC CD&I); Deputy Commandant for Aviation (DC AVN)

(a) Coordinate EP requirements development and supporting ROI analyses with the Director, E2O; Commander, MCSC; and PEOs that manage Marine Corps programs.

(b) Ensure that appropriate E2O, MCSC and PEO subject matter experts (SMEs) are included in requirements IPTs and throughout the Requirements Transition Process to define capability baselines and develop EP KPPs/KSAs.

(c) Include EP metrics and measures in all capabilities based assessments for capabilities that produce, store, transfer, or consume energy and refine them through subsequent JCIDS and program development phases.

(d) In all documents listed in 3a(2)(c), identify the baseline capability and system boundaries to be used for EP and acquisition cost comparisons.

(e) Include EP KPPs/KSAs for capabilities that produce, store, transfer, or consume energy during CDD, CPD, and SON development.

(f) With E2O input and concurrence, ensure AoA study guidance directs that energy performance measures of effectiveness be included and that alternatives with potential for significant EP improvements are considered.

(g) Include lifecycle assumptions that balance garrison and deployed energy demand in AoA study guidance.

(h) Include EP metrics, measures, projected tradeoffs, and potential cost and operational ROI in MROC program briefings.

(i) Via Director, E2O, nominate budget program elements and/or line items that identify investment intended to improve MAGTF EP to the Deputy Commandant for Programs and Resources for coding as Tactical Energy Investment using the Delta Multi-Use Field in the Program Budget Development Database.

(2) Commander, MCSC and PEOs

(a) Apply the guidance contained in reference (h).

(b) Provide appropriate SMEs to requirements IPTs and throughout the Requirements Transition Process, to support EP KPP/KSA development.

(c) Coordinate EP technology development and ROI analyses with DC CD&I and Director, E2O.

(d) Inform EP requirements development with market research and ongoing science and technology activities to improve MAGTF energy performance.

(e) Include both garrison and deployed energy demand in AoA and business case analysis (BCA) lifecycle assumptions.

(f) State energy lifecycle cost assumptions and conditions explicitly in all AoA and BCA results/reports.

(g) Consider EP with other performance factors and document, in MDDs and SSDs, the rationale for decisions that increase energy consumption from the baseline capability. If no adequate baseline capability exists, document the energy tradeoffs considered and their relevance to the SSD.

(h) Document EP analysis in SRDs and ECPs affecting system energy performance attributes.

(i) In coordination with DC CD&I, Director, E2O; and Director, MCOTEA, establish standard EP metrics and measurement procedures. Measure energy performance for new capabilities and upgrades to legacy capabilities. Document metrics, measurement conditions, and EP data in the Total Force

Structure Management System in order to inform engineering through campaign level models, system requirements, SSDs, and ECPs.

(3) Director, Marine Corps Operational Test and Evaluation Activity (MCOTEA). In accordance with reference (i), provide operational test SME support to EP KSA/KPP development.

(4) Director, E2O

(a) As the Marine Corps SME for operational energy, work closely with the requirements, acquisition, and technology development communities to construct EP considerations into all MAGTF materiel and non-materiel solutions.

(b) Maintain a comprehensive knowledge database of all EP KPP/KSAs and key underlying assumptions.

(c) In coordination with DC CD&I, Commander, MCSC; and Director, MCOTEA, develop an energy modeling strategy that spans from engineering- to campaign-level models, and establish an authoritative model that informs MROC decisions and EP investments across all warfighting functions.

(d) In coordination with DC CD&I, identify business rules and metrics for assessing the completeness and sufficiency of documented EP requirements and ROI analyses.

(e) Validate sufficiency of EP KSAs and KPPs or identify necessary changes prior to endorsing any capability requirements document.

(f) Validate EP non-applicability for requirements documents that do not include an EP KSA or KPP.

(g) Document validated EP sufficiency or non-applicability in a written memorandum to DC CD&I.

(h) In collaboration with DC CD&I, Commander, MCSC; PEOs, and Director, MCOTEA, maintain an energy performance requirements guide for capability development.

(5) Deputy Commandant for Plans, Policies, and Operations (DC PP&O); Deputy Commandant for Installations and Logistics (DC I&L); Director, Command, Control, Communication and Computers Department (Dir C4); and Director, Intelligence Department (Dir Int)

(a) Provide SME support to EP analyses, as required.

(b) Consider energy demand in MAGTF Table of Equipment (T/E) reviews and highlight gaps, shortfalls, excesses, and redundancies. Once established, apply authoritative energy model capabilities to assess T/E and equipment density list energy demand and MAGTF logistics impact.

(c) Include energy supply and demand factors in wargame scenarios and mission analysis; include relevant energy excursions in wargames.

(d) Identify energy performance gaps and opportunities to DC CD&I and Director, E2O; include energy gaps in Advocate Gap Lists.

c. Coordinating Instructions

(1) A systems design/engineering approach is required to develop effective EP metrics and measures. In most cases, this development will require multiple iterations to converge on appropriate metrics and measures as the understanding of a capability's baseline EP and the technological feasibility of improvement evolves. Modeling and simulation tools should be used to the maximum extent practical to refine measures, define operational effects, and consider energy lifecycle costs.

(2) CIOs and PMs must ensure that solutions design efficient use into the system-human interface and provide technical information and new equipment training that clearly communicates the desired EP behavior and its combat effect.

4. Administration and Logistics

a. Administration. The E2O will facilitate review and revisions to this Order, as necessary.

(1) Enclosure (1) provides a standardized framework for defining EP requirements. It is intended to serve as a stand-alone desktop reference for CIOs and PMs to use when developing or updating EP KPPs/KSAs, and during requirements and acquisition indoctrination and refresher training. This guidance is also intended to minimize the need for analytic support to non-system-of-systems (SoS) EP requirements. It should be noted that enclosure (1) repeats some references used in this Order; however, the sequencing differs and is defined in the reference list therein.

(2) Records created as a result of this Order shall be managed according to the National Archives and Records Administration approved dispositions per reference (j) to ensure proper maintenance, use, accessibility and preservation, regardless of format or medium.

b. Logistics

(1) The quantity and character of analytic support necessary to develop EP KPPs/KSAs and supporting attributes is expected to vary based on the cost and complexity of each requirement. In some instances, organic analytic capabilities may need to be augmented. This additional support may come from one or more of several sources:

(a) Marine Corps Studies System.

(b) DC CD&I, Operations Analysis Division models.

(c) MCSC and PEO engineering and cost models.

(d) MCSC Systems Engineering, Interoperability, Architectures and Technology systems engineers.

(e) E2O operational energy analysts.

(2) Additional resources to support EP analysis for SoSs or other complex capabilities are available via request through the Director, E2O.

5. Command and Signal

a. Command

(1) This Order is applicable to the Marine Corps Total Force.

(2) DC CD&I is the supported command for all EP requirements matters; E2O, MCSC, PEOs, Advocates and Proponents are the supporting commands/organizations.

b. Signal. This Order is effective on the date signed.

J. M. PAXTON, JR.
Assistant Commandant
of the Marine Corps

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# U.S. Marine Corps Energy Performance Requirements Guide for Capability Development

# Challenge

The ability to harness and employ energy at a time and place of our choosing enables the Marine Corps' formidable lethality. Energy is the only combat enabler that crosses all elements of the MAGTF, from our aircraft to our individual Marines, on every mission and movement. The challenge with capturing energy in our requirements and acquisitions processes is the fact that most energy consumers are often not responsible for the energy they use and those that supply energy have no controls over the consumers. This guide is designed to assist our requirements and acquisition professionals with defining energy performance considerations early in the development of new capabilities and upgrades to current capabilities. The aim is to bring energy supply and demand into balance. Finding the most energy efficient solutions at a reasonable cost ultimately enables us to retain our lethality and increase our combat effectiveness while reducing operational risks.

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**REFERENCES**

(a) United States Marine Corps Expeditionary Energy Strategy and Implementation Plan, 23 Feb 11
(b) Initial Capabilities Document for United States Marine Corps Expeditionary Energy, Water & Waste, 2 Sep 11
(c) Manual for the Operation of the Joint Capabilities Integration and Development System, Jan 2012
(d) 2009 National Defense Authorization Act
(e) MCO 3900.19
(f) MCO 5311.6
(g) MAGTF Power and Energy Model (MPEM) Users Manual

## 1. BACKGROUND

On 23 February 2011, the Commandant of the Marine Corps published reference (a) to communicate his vision, mission, goals, and objectives for expeditionary and installations energy. In September 2011, the MROC approved reference (b). These documents serve as the foundational guidance for energy investment across the Marine Corps and focus on increasing battlefield energy performance and increasing energy and water self-sufficiency through the actions of planners, advocates, combat developers, operators, and every Marine along three lines of operation:

- Procuring equipment that is more energy efficient and including energy efficiency in upgrades to legacy equipment.
- Increasing development of renewable energy systems that harvest energy in place.
- Establishing an Expeditionary Ethos that equates increased combat effectiveness with efficient resource employment.

The Implementation Planning Guidance (IPG) in reference (a) directs that energy efficiency be made a priority in all analysis supporting [Marine Corps] Force Development System (MCFDS) capability evolution and materiel development. The term energy efficiency is refined and replaced herein by the term energy performance (EP).

Reference (c) requires that an Energy Key Performance Parameter (KPP) be included in "*all documents addressing systems where the provision of energy, including both fuel and electric power, to the system impacts operational reach, or requires protection of energy infrastructure or energy resources in the logistics supply chain.*"

The specified intent of the Energy KPP is "*to optimiz[e] fuel and electric power demand in capability solutions as it directly affects the burden on the force to provide and protect critical energy supplies. The [Energy] KPP includes fuel and electric power demand considerations in systems, including those for operating "off grid" for extended periods when necessary, consistent with future force plans and [Integrated Security Constructs].*"

Reference (d) defines *Operational Energy* as "*the energy required for training, moving, and sustaining military forces and weapons platforms for military operations. The term includes energy used by tactical power systems and generators and weapons platforms.*"

Reference (e) further develops reference (c) and (d) guidance, integrates that guidance into Marine Corps processes, and establishes policy regarding the application of operational energy performance in capability requirements and acquisition program specifications.

## 2. PURPOSE

Reference (f) assigns the Director, Expeditionary Energy Office (E2O) as the Proponent for Marine Air-Ground Task Force (MAGTF) Operational Energy. This guide is provided by the E2O, in coordination with Capabilities Development Directorate, to assist Proponents, Advocates, Capabilities Integration Officers (CIOs), Program Managers (PMs), and requirements integrated product teams (IPTs) in defining and applying operational energy performance metrics and measures to capability requirements, analyses of alternatives (AoAs) and materiel specifications. This guide is an extension of the policy set forth in reference (e) and provides a framework and user reference for writing energy performance requirements that achieve the intent expressed in references (a) and (e), and closing capability gaps in reference (b).

## 3. TERMS

**Energy Performance (EP):** The rate of energy consumption or energy harvesting required to perform a specific function or task in a specific operational mode, mission profile, and environmental condition. EP applies to any capability or system that converts energy into work or from one form to another, stores energy, transfers energy, or consumes energy.

**Energy Consumer:** Systems or sub-systems that require electrical, mechanical, or thermal energy to perform their intended function.

**Energy Producer:** Systems or sub-systems that harvest or convert energy for storage, transfer, or use by consuming systems.

**EP Key Performance Parameter (EP KPP):** A metric, with measures, for a system or system of systems (SoS) EP attribute that is deemed critical or essential to the development of an effective military capability, or for which energy performance improvements would enhance individual, unit, or MAGTF combat effectiveness. EP attributes apply to any system whose primary mission includes energy harvesting, conversion, storage, transfer, or consumption. The EP KPP may require supporting attributes or Key System Attributes (KSAs) and must be technically feasible and quantifiable for test purposes.

**EP Key System Attribute (EP KSA):** A metric, with measures, for an EP attribute considered critical or essential to the development of an effective military capability, or for which energy performance improvements would enhance individual, unit, or MAGTF combat effectiveness, and that is selected to provide an additional level of capability prioritization below the KPP but with senior sponsor leadership control. The EP KSA must be technically feasible and quantifiable for test purposes.

## 4. ENERGY PERFORMANCE (EP) REQUIREMENTS PLANNING CONSIDERATIONS

An effective EP KPP/KSA has several important qualities:

1) Defines testable attributes that can be validated during developmental and operational test plans and programs, in accordance with specified test criteria.

2) Increases MAGTF capability by minimizing the energy required to produce the desired combat effect.

3) Drives consideration of both demand- and production-side energy efficiency tradeoffs and opportunities.

4) Considers system employment variability and EP across a range of operating modes and mission profiles.

5) Ensures that threshold metrics and measures produce a solution of equal or greater capability with better energy performance than that of the baseline capability.

This section provides considerations and a recommended approach to developing EP KPPs/KSAs.

### a. EP Analysis

EP analysis is used to guide decisions regarding the inclusion of EP KPPs, KSAs or other energy attributes, and to define the associated metrics and measures. This analysis is led and guided by the CIO and conducted jointly by requirements IPT members. Analysis may range from a desktop assessment and market research for simple requirements to modeling and/or data collection for more complex systems or platforms. Once the requirements IPT determines that EP metrics are applicable to the capability of interest, they will identify the relevant EP characteristics, define the EP baseline capability and the metrics that will be used to define energy performance, and then use available resources (e.g., Expeditionary Energy Office, PM market research, ongoing government technology development, modeling) to determine the feasible range of energy performance. Given this information, AoAs or business case analyses, as appropriate, will characterize lifecycle costs, operational impacts, and return on investment to support requirements IPT recommendations regarding EP measures. **Figure 1** depicts a general methodology for developing EP KPPs/KSAs. Note that defining measures is likely to require iteration iterations.

<u>*Example:*</u> *The Combat Operations Center (COC) V(1) EP KSA for fuel demand (gallons per day) was developed by applying an "inside-out" approach (**Figure 2**) that used threshold and objective EP benchmarks for component technologies. Using multiple specification, test and evaluation sources, achievable electronics and lighting EP and improvements in shelter thermal efficiency were first determined. Next, environmental control units (ECUs) with achievable efficiency were right-sized and power sources, in turn, were right-sized for each COC segment. Threshold and objective power source EP was then applied. ECUs and power production was modeled in scenario-based environmental conditions to examine the range of daily fuel demand given different*

*combinations of component EP. Finally, a KSA was defined to ensure the ability to efficiently meet peak load requirements.*

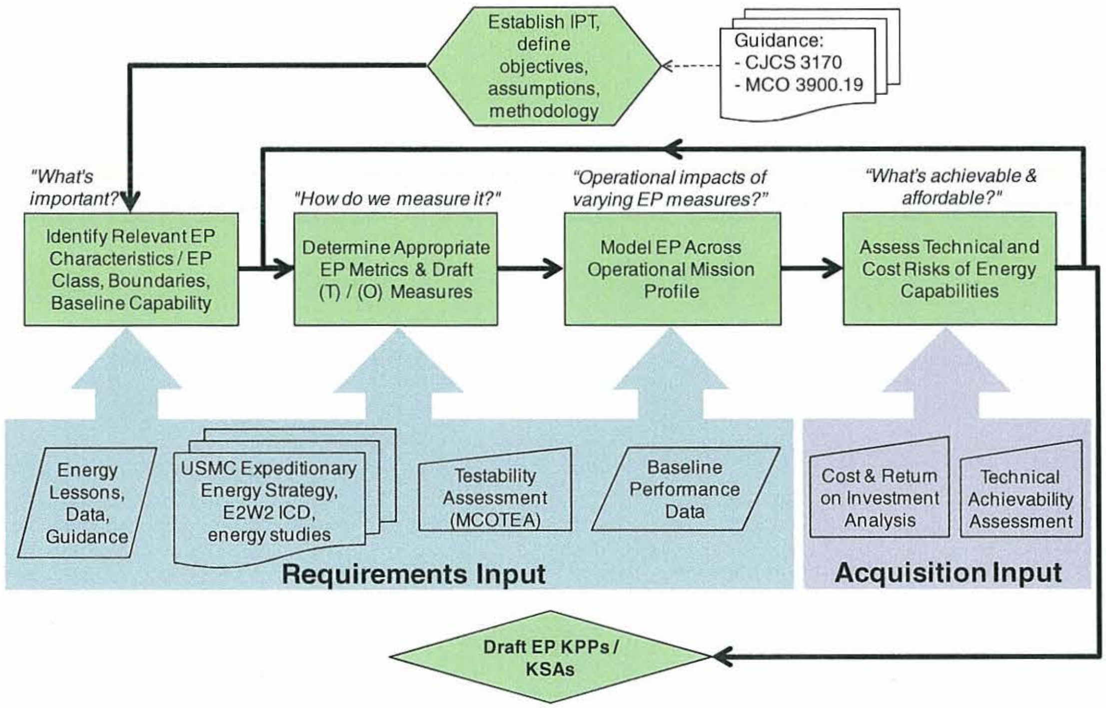


**Figure 1. EP Analysis Methodology**

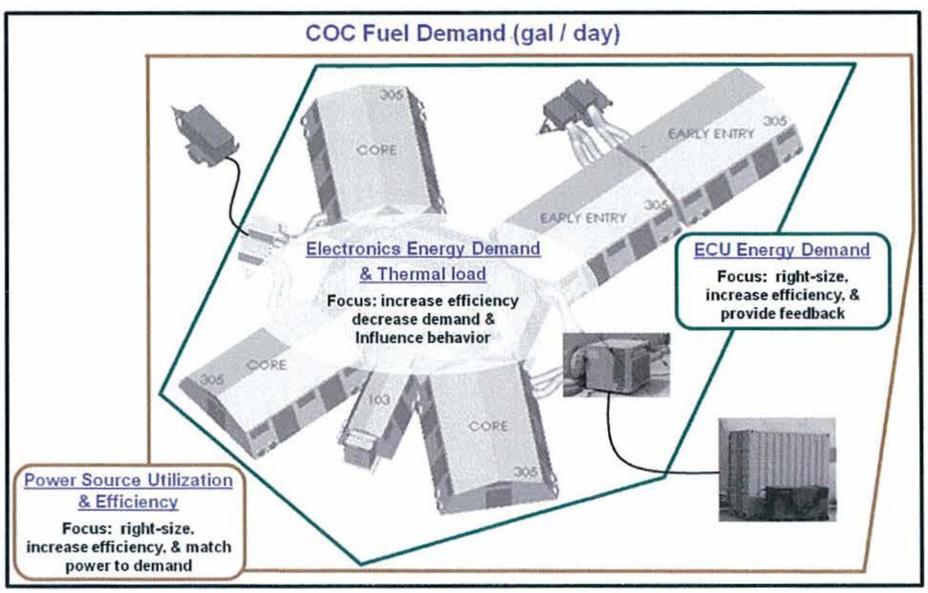


**Figure 2. COC V(1) Energy Performance KSA Model**

### b. EP Classification

With respect to energy, materiel capabilities generally fall into one of four classes: ***Production, Storage, Transfer,*** and ***Consumption***. Energy ***Production*** categories include *energy conversion* and *energy harvesting*. ***Consumption*** categories include *air platforms*, *ground mobility platforms*, and *non-mobility systems* (**Figure** 3). Within these categories, materiel capabilities share similar architectural considerations and energy performance attributes and may be addressed with similar metrics.

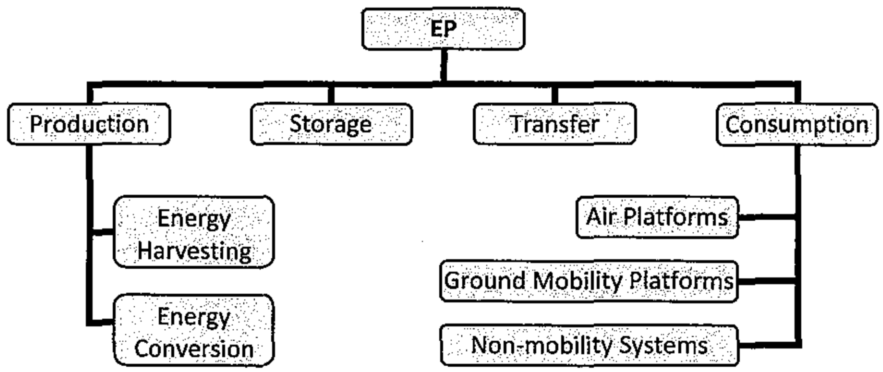


**Figure 3. Energy Performance Classification**

### c. EP Baseline

Once the applicable EP category is determined, an EP baseline is established in order to understand the capability of interest and what EP attributes and metrics are operationally relevant before defining EP KPPs/KSAs. There are 4 essential steps to defining the *EP Baseline*:

1) **Baseline Capability Identification**. Identify the baseline capability to be used for EP, lifecycle cost, and return on investment comparisons. This baseline will generally be the capability that is being replaced, but may be an aggregate of multiple capabilities. For example, the mobility, maneuverability, payload, and protection of a tactical vehicle would define the baseline capability for an upgrade or one-for-one replacement of the legacy vehicle, but consolidating vehicle missions (e.g., tactical mobility with data, communications, and surveillance) may require a composite of multiple platforms, or a suitable surrogate, that provide an equivalent capability. Establishing a baseline capability requires either test data under specified operating modes and conditions or calculation/modeling using validated tools.

2) **System Boundary Definition**. After determining the baseline capability, define the systems and any subsystems whose EP will be used to establish the EP baseline. For example, a legacy vehicle replacement could simply use the EP of the legacy vehicle or vehicles that it replaces as a baseline. On the other hand, command and control (C2), data and communications, or intelligence, surveillance, and reconnaissance (ISR) capabilities that require external power support may include the consuming system(s) and power production and storage components as part of the system. System boundary decisions should be driven primarily by the planned concept

of employment to ensure that *whole* capabilities provide the EP intended by the KPP/KSA and the desired effect on MAGTF energy demand.

3) **Metrics Determination.** Determine appropriate metrics that will be used in the new requirement to define KPPs/KSAs. Considerations for selecting appropriate metrics are discussed at length later in this guide.

4) **EP Baseline Definition.** Given a defined baseline capability, system boundary, and selected metrics define the energy performance characteristics of the system or systems that provide the capability, within stated "system" boundaries.

Every attempt should be made to identify the baseline capability and to define the associated *EP Baseline* early in capability development (e.g., ICD, AoAs, etc.). Baseline definition will typically require iterative development and close coordination between requirements IPT members (i.e., CIOs, PMs, and engineers). In some instances, this baseline will change as a requirement matures and more specific materiel solutions become known. As a result, EP metrics and measures must be updated in each JCIDS document and confirmed at milestone decision points.

## d. EP Modeling

Computer-based modeling may be required to explore metrics and determine measures for the more complex system, platform, and SoS requirements and when empirical baseline data is not available. Relevant models will span the analytic hierarchy from engineering to campaign level models (**Figure 4**). Though EP KPP/KSA threshold and objective measures will typically be determined using an engagement level model, these models require engineering data and/or modeling input/calibration. Engagement level data, in turn, informs mission and campaign level models that enable MAGTF impacts and operational return on investment to be characterized for different measures and, eventually, different materiel alternatives.

One example of a model, under development, that applies engineering data and spans the engagement and mission modeling levels to feed campaign level

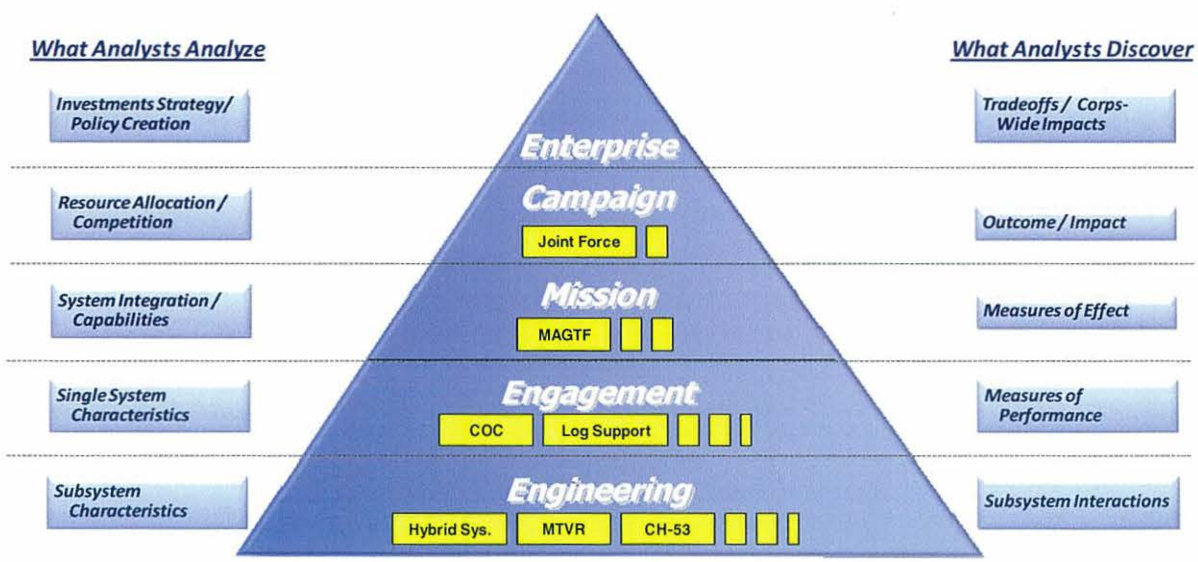


**Figure 4. Energy Modeling Analytic Hierarchy**

analysis is the MAGTF Power and Energy Model, reference (g). This model is an equipment energy-/fuel-demand-based model that captures the complex interrelationships between liquid fuel and its conversion into electricity, and enables comparison of MAGTF energy demand given different equipment sets and/or different levels of efficiency within specific equipment portfolios or individual end-items (**Figure 5**).

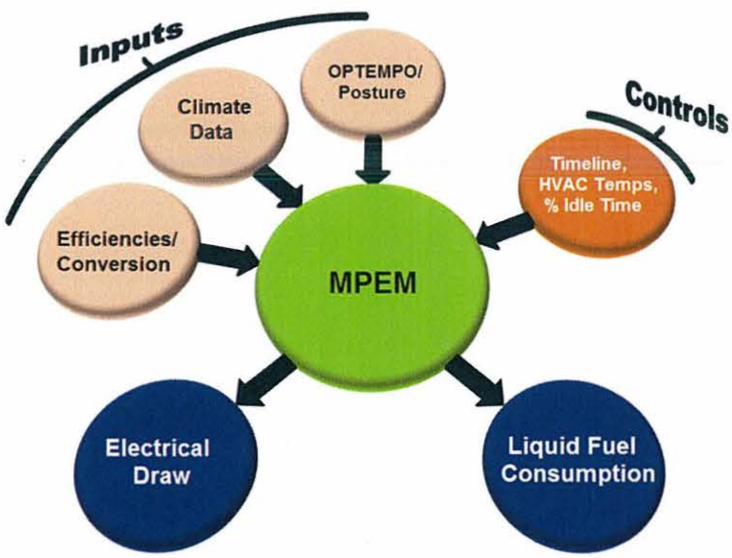


**Figure 5. MAGTF Power and Energy Model (MPEM)**

As of this publication, energy-related models continue to evolve in capability and increase in availability. CIOs and PMs should consult the Operations Analysis Division (OAD) of Headquarters, Marine Corps, Department of Combat Development and Integration, and the E2O for an introduction to the latest available tools and recommendations on appropriate models to use for specific requirements.

### e. Family/System of Systems (FoS/SoS) EP Metrics

In cases where there is not a one for one system replacement for a capability, or when a capability is provided by a SoS or family of systems (FoS), it may be appropriate to include a separate KPP/KSA (or separate threshold/objective) for the entire SoS (i.e., all components) or FoS (i.e., all variants) in addition to those for individual systems, subsystems, or variants. This provides flexibility and trade space as the understanding of the capability and potential materiel solutions matures, and avoids sub-optimizing overall MAGTF EP for the sake of an individual SoS/FoS component.

*Example: A COC EP metric of gallons of fuel consumed per day enables tradeoffs across all relevant system components (e.g. electronics, lighting, shelter, heating/cooling, power production) to achieve a desired maximum fuel consumption. By applying market research, to include current technology development efforts, EP "state of the art" for each component can be used to define the available EP trade space and set target threshold and objective measures for each component/ subsystem, which are then combined to define the KPP measure.*

### f. EP Key Performance Parameter (KPP) / Key System Attribute (KSA) Relationship

An EP KPP may require one or more supporting KSAs or additional attributes. For example, a system or SoS requirement that includes both power production (and/or harvesting) and power consumption components, may use a KPP to define system/SoS EP and a supporting KSA for sources of power to drive architecture, or other expeditionary logistics considerations (e.g., flexibility, adaptability, etc.). The relationship between KPPs and supporting KSAs should be well-explained in the KPP/KSA rationale.

*Example: The COC V(1) EP KSA for fuel demand (gallons per day) is supported by multiple additional attributes; specifically, additional attributes with metrics were established for thermally efficient shelters, energy efficient lighting, sources of power, energy monitoring and measuring.*

### g. EP KPP/KSA Context

EP requirements must provide PMs with an understanding of the employment context that is expected to produce EP improvements. This context is typically conveyed in the EP KPP/KSA rationale and in a written concept of employment (COE). Requirements rationale and COEs must consider fuel, battery, and water logistics and the security impacts associated with supporting a capability. They must also communicate the role of the materiel solution within the MAGTF energy and SoS architecture and the tactics, techniques, and procedures that are expected to achieve the desired EP. The COE should be used, in turn, to refine EP metrics and measures to achieve the desired operational effect.

*Example: The impact of the COC V(1) EP KSA can be projected in terms of a reduction in bulk tactical refueler truckloads per fielded COC per year [18 (Threshold)/ 28 (Objective )], which equates to one less truckload for every 20 (T) / 13 (O) days of operation.*

### h. EP Training

It is equally important to provide employment context to the Operating Forces in the form of tactics, techniques, and procedures and to convey the value of system/platform EP characteristics to the MAGTF. Without an understanding of the value of energy on the battlefield and how to efficiently employ specific materiel solutions, even the best materiel solution will not produce the desired energy effectiveness.

*Training Example 1: In winter 2009, one unit commander in Afghanistan recognized that inefficiently run generators at his combat operation post put Marines and the mission at risk. He tasked his ordnance officer, "to take as many generators off the grid as [he] could, and still provide support at full capacity." During the next month, two young corporals "made it happen." They reconfigured the camp generators and optimized them for electricity production. The post went from running on 20 generators to running on five or six. This and other efforts increased efficiency at the post by 25 percent and decreased the overall fuel requirement from 1,200 to 900 gal/day.*

*Training Example 2: In 2011, insulating radiant barrier liners for medium soft shelters were fielded to Marine units throughout the Regional Command Southwest area of operations in Afghanistan. These liners had an immediate impact on shelter thermal efficiency in both cold and hot environmental conditions; however, at more than one patrol base (PB) Marines were observed wearing cold weather gear inside* *insulated shelters while the outside temperatures were above 120°F. Less cooling was needed, but Marines continued to operate the ECU continuously at its coldest setting! In a word, they did not appreciate the intent to employ the radiant barrier to reduce PB energy demand and resupply.*

Requirements for new equipment training and sustainment training should include awareness of the specific system/platform energy performance, its impact on the MAGTF, and how to employ the system/platform efficiently. Expeditionary Energy, Water, and Waste Ethos training material is incorporated in the Marine Corps Common Skills Volume I Training and Readiness (T&R) Manual and will be included in Chapter 1 of every military occupational specialty T&R manual. This material is designed to foster an ethos of efficient employment of scarce battlefield energy resources as an element of combat effectiveness and is currently being incorporated into entry level training and professional military education. This resource may be used to define awareness training requirements appropriate for inclusion in, and tailoring to, system/platform-specific training.

## 5. EP METRICS DETERMINATION

### a. Production Systems

**Energy Conversion.** Capabilities include solutions that convert energy (e.g., mechanical, thermal, solar) into electrical power from renewable and non-renewable sources for energy consumer applications.

**Architecture.** Desired attributes include scalability, adaptability to energy consumer systems and interoperability with Service and Joint power systems. Design considerations focus on providing power by the most fuel-, energy-, space-, and weight-efficient means and most effectively for the mission profiles. The means may include energy storage, power management electronics, and load-following/load-matching approaches.

**Performance.** Focus on right-sizing capacity, reducing operating time (i.e., duty cycle), increasing conversion efficiency, and eliminating waste. Right-sizing capacity requires demand factors such as average and peak power (*watts*) required, and the optimum load factor (%) and duty cycle (system active time divided by total time period of interest) to be considered. Efficiency may be addressed by energy density metrics focused on specific energy using one or a combination of multiple parameters: energy-to-weight ratio (*kW·h/weight*), surface energy density (*kW·h/area*), energy density (*kW·h/volume*), etc.

In some cases, a conversion efficiency in terms of kW·h/gallon of liquid fuel may be appropriate to drive power source optimization. This metric may be useful for requirements that include both producer and consumer systems by creating trade space between increases in power source efficiency and reductions in the consuming system power demand. Integration with renewable energy sources or energy storage may enable overall power efficiency increases without actual increases in combustion source efficiency. In general, this approach enables the requirement to drive reduced fuel demand without artificially limiting potential capability; in other words, it avoids building a requirement to achieve efficiency for its own sake.

In almost all cases, a *metric* to address fuel demand in terms of consumption rate (e.g., *GPH, GPD*) is required to make the connection to the desired combat effect of reducing the fuel burden. A fuel demand *measure* is likely to be determined through an understanding of the aforementioned energy demand and efficiency *measures* and some combination of data and modeling.

**Energy Harvesting.** Capabilities include solutions that harvest solar, thermal, and mechanical energy from available sources (e.g., sun, battlefield waste, vehicles, and personnel).

**Architecture.** Desired attributes include scalability and interoperability with other harvesting, production, and storage capabilities. Design considerations:

- Common interfaces;
- Reducing or eliminating DC/AC and AC/DC conversions;
- Power electronics required to support employment of solar harvesting solutions;
- Opportunities to employ DC power directly;
- The potential to enable renewable harvesting solutions by applying a systems engineering approach that integrates demand-reducing solutions;
- The potential to augment or replace fuel combustion power sources with hybrid systems that couple combustion sources with renewable energy sources, energy storage, and power electronics to inherently match loads;
- Form factor for integrated solutions that is consistent with operational modes and mission profiles.

**Performance.** Focus metrics on harvesting efficiency ($kW_{harvested}/ kW_{available}$) in terms of specific energy and enabling renewable energy sources. Metrics may include one or more of several parameters: energy-to-weight ratio (*kW·h/weight*), surface energy density (*kW·h/area*), or energy density (*kW·h/volume*) and may be defined in terms of continuous (or average) and peak energy demands of the supported system(s).

To be effective, harvesting metrics and measures must drive consideration of logistical and operational tradeoffs. For example, while renewable and hybrid systems may have a larger embarkation footprint than conventional power systems, the potential for reduced maintenance, reduced operational risk due to fuel or battery logistics, and "quiet" power are tradeoffs that must be weighed.

## b. Storage Systems

Capabilities include any means of storing energy for use by an energy consumer system.

**Architecture.** Desired attributes include scalability, commonality and interoperability with Service and Joint energy storage capabilities, adaptability to advances in commercial battery technology and efficiency improvements, and suitability for transportation on naval shipping and strategic airlift. Design considerations:

- Integration with input/harvesting capabilities;
- Sizing to efficiently support daily energy demand.

**Performance.** Focus metrics on energy "density" (e.g., *kW·h per mass or volume*), recharge rate (*watts/hour*), and power (*kW*).

### c. Transfer Systems

Capabilities include power distribution systems and interfaces consisting of cables, connectors, distribution panels, converters, inverters, transformers, or other means of delivering power, in the required form, from a harvesting or conversion source to energy consumer applications.

**Architecture.** Desired attributes include scalability, interface commonality and interoperability with Service and Joint systems. Design considerations include complexity, size, and weight consistent with expeditionary employment.

**Performance.** Focus metrics on architecture, conversion efficiency ($kW_{output} / kW_{input}$), maximum acceptable weight (*lbs.*), maximum acceptable area (e.g., $ft^2$, $m^2$), and maximum acceptable volume (e.g., $ft^3$, $m^3$).

### d. Consumption Systems

**Aircraft platforms.** Capabilities include all manned and unmanned aircraft.

**Architecture.** Desired attributes include power management of onboard systems, crew feedback, fuel efficient propulsion, and tailorable/efficient ground power and propulsion. Design considerations:

- Lightweight materials;
- Coatings that reduce drag and/or weight;
- Systems that permit full and/or tailorable functionality at reduced power and fuel demand during ground operations;
- Fuel and engine system ability to accept multiple fuel types.

**Performance.** Focus metrics on the balance between minimizing fuel demand and maximizing in-flight performance parameters that are central to the aircraft mission [e.g., *payload ton-hr/*$lb_{fuel}$, *horsepower-hour/*$lb_{fuel}$, $(lb_{fuel}/hr)_{maximum\ endurance}$, $(lb_{fuel}/hr)_{maximum\ range}$].

**Ground mobility platforms.** Capabilities include all ground combat and tactical vehicles.

**Architecture.** Desired attributes include power management of onboard systems, crew feedback, and exportable power system interface commonality/interoperability with Service and Joint systems. Design considerations:

- Lightweight materials;
- Friction-reducing coatings, materials, techniques;
- Efficient components and onboard electronics;
- Environmental control methods and systems that minimize energy demand;
- Systems that deliver power by the most efficient means for each operational mode;
- Opportunities to utilize renewable or waste energy onboard or for exportable applications;

- Power schemes that match load to demand or that use prioritized load-shedding;
- Power system maintainability, size, and weight consistent with the vehicle mission.

**Performance.** Focus metrics on the balance between minimizing fuel demand, maximizing vehicle dynamic performance, meeting static power demands (exportable power and silent watch/engine-off operations), and protection. For example, compound metrics such as payload-ton-mile per gallon (*payload ton-mpg*), or passenger-mile per gallon (*passenger-mpg*) over the vehicle mission profile may be effective provided they sufficiently capture the vehicle's primary mission capability (i.e. *payload-ton-mpg* is appropriate for vehicles with a primary mission to move cargo, trailers) without introducing an unintended bias (e.g. *ton-mpg* favors heavier vehicles with no connection between the weight and capability). Stationary operational modes should be addressed using metrics such as maximum gallons per hour at idle ($GPH_{Idle}$); and maximum gallons per hour or kW·h per gallon required to produce on-board or exportable power in stationary (and/or "silent watch") modes with the vehicle's prime mover engine off (e.g. $GPH_{Stationary}$, $(kW \cdot h/gal)_{Stationary}$).

**Non-mobility systems.** Capabilities include all systems not intended to transport persons, equipment, supplies, or weapon systems (e.g., C4ISR, Intel, FP, life support, weapon systems).

**Architecture.** Attributes include interface commonality and interoperability with Service and Joint power systems and adaptability to multiple sources of power. Design considerations:

- Establishing SoS boundary where necessary to enable trades in both supply- and demand-side energy performance;
- Minimizing the need to heat and cool electronics and personnel;
- Minimizing energy demand when the materiel solution is performing the intended mission;
- Minimizing or eliminating energy demand when the materiel solution is not performing the intended mission (i.e., at rest or in a standby mode).

**Performance.** Focus metrics on system energy demand (*kW·h/day*) given power loads (*kW*) in relevant states or modes (e.g., standby, average power, surge power, peak power) that represent the operating envelope. When defined system boundaries include both energy producer and consumer components, metrics should also include system fuel demand as a consumption rate (e.g., *GPH, GPD*).

**Table** 1 summarizes the EP KSA and KPP architecture considerations and metrics.

**Table 1. Energy Performance KPP/KSA Summary**

| Energy Performance Class | Energy Architecture Attributes | Energy Performance Metrics | | | |
|---|---|---|---|---|---|
| | | Energy Demand | Conversion Efficiency | Energy Density | Fuel Demand |
| **Conversion** | • Scalability<br>• Interoperability<br>• Adaptability to energy consumer systems | | $\frac{kW \cdot h}{Gal_{fuel}}$ | $(kW \cdot h)_{produced}$ per mass, area, or volume | GPH or GPD |
| **Harvesting** | • Scalability<br>• Interoperability with harvesting, storage, production | | $\frac{kW_{harvested}}{kW_{available}}$ | $(kW \cdot h)_{harvested}$ per mass, area, or volume | |
| **Storage** | • Scalability<br>• Commonality<br>• Interoperability<br>• Adaptability to commercial/ technology advances<br>• Military transportation suitability | $\frac{watts_{recharged}}{h}$ | $\frac{kW_{output}}{kW_{input}}$ | $kW \cdot h$ per mass, area, or volume | |
| **Transfer** | • Scalability<br>• Interface commonality<br>• Interoperability | | $\frac{kW_{out}}{kW_{in}}$ | | |
| **Aircraft** | • Onboard power management<br>• Crew feedback<br>• Fuel-efficient propulsion<br>• Tailor-able/ efficient ground power/ propulsion | | $\frac{HP \cdot h}{lb_{fuel}}$ or $\frac{\text{Payload-ton} \cdot h}{lb_{fuel}}$ | | $\left(\frac{lb_{fuel}}{h}\right)_{max\ endurance}$ and $\left(\frac{lb_{fuel}}{h}\right)_{max\ range}$ |
| **Ground Mobility** | • Onboard power management<br>• Crew feedback<br>• Exportable power interface commonality & interoperability | Onboard systems: $\frac{kW \cdot h}{day}$ | Mobile: $\frac{HP}{Gal}$<br>Stationary: $\frac{kW \cdot h}{Gal_{fuel}}$ | Energy Storage: $kW \cdot h$ per mass, area, or volume | Mobile: $\frac{\text{Payload (or Passenger)-Ton} \cdot \text{miles}^1}{Gal}$<br>Stationary: GPH |
| **Non-Mobility** | • Interface commonality<br>• Interoperability<br>• Power source adaptability/flexibility | $\frac{kW \cdot h}{day}$ | $\frac{kW_{True}}{kW_{Apparent}}$ | | GPH or GPD |

Abbreviations: kW = kilowatt; kW·h = kilowatt-hour; GPH = gallons per hour; Gal = gallon; GPD = gallons per day; HP = horsepower

Note: [1]Nautical miles used for waterborne platforms (e.g., amphibious vehicles)