An Untethered MLR

Supporting Stand-in Forces

by Col Omar J. Randall

"Unleash us from the tether of fuel."[1] —Gen James Mattis, former Secretary of Defense

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The 2030 Marine Littoral Regiment (MLR) construct creates an opportunity for the Marine Corps to incorporate alternative energy sources and demand reduction technologies to break the tether of fossil fuels and offer a more sustainable force to the joint and naval commander. The MLR is a future force designed to persist within an adversary's weapons engagement zone to conduct expeditionary advanced base operations in support of fleet and joint operations.[2] As a Stand-in Force, MLRs are envisioned to be mobile, low signature, and relatively easy to maintain and sustain.[3] They embrace demand reduction and sustainment redundancy concepts to mitigate supply line disruption and extend persistence.[4] By design, MLR's can enable aviation operations; however, they do not contain manned aviation organically—eliminating the most demanding consumers of fossil fuels—jets, cargo transports, and tilt/rotary wing aircraft.[5] Moreover, MLRs are planned to be fully operationally capable in 2030 and beyond. This implementation timeline creates sufficient time and decision space to test, evaluate, and integrate alternative energy technologies into the MLR.

The Marine Corps acknowledges this opportunity in their *Concept for Stand-in Forces*,

> Sustainment that does take place inside the contested area requires new approaches to existing techniques and the development of new capabilities, including the following: Demand reduction across the life-cycle of Stand-in Forces, from their design to their employment. For example, including design features like hybrid-electric or fully electric vehicles can reduce future fuel requirements, while focused training on supply discipline best-practices can reduce demand in the near-term.[6]

The Operational Imperative

The *Concept for Stand-in Forces* is prescient in this area. The military must reduce their reliance on fossil fuel to persist in contested spaces against a peer adversary or strategic competitor. The fossil fuel supply chain requires a distribution network of defense fuel supply depots, pipelines, trucks, and tanker ships whose signature creates a lucrative target (Figure 1). Host nation fuel sources are equally vulnerable. Russia's severing of the Ukrainian gas supply in 2009 in retaliation for courting NATO and China's cyberattack on the Indian power grid in 2020 over border clashes should be concerning, given that DOD purchased 48 percent of its fuel from outside the United States in fiscal year 2020.[7] According to a Defense Science Board report on energy systems, "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 effective protection."[8]

The forecasted energy demand of future weapons systems and dispersion of friendly forces will compound this vulnerability. Advanced military platforms tend to drive higher overall energy requirements, which increase demand on the fuel supply chain.[9] A study by the National Academy of Sciences projects that energy requirements

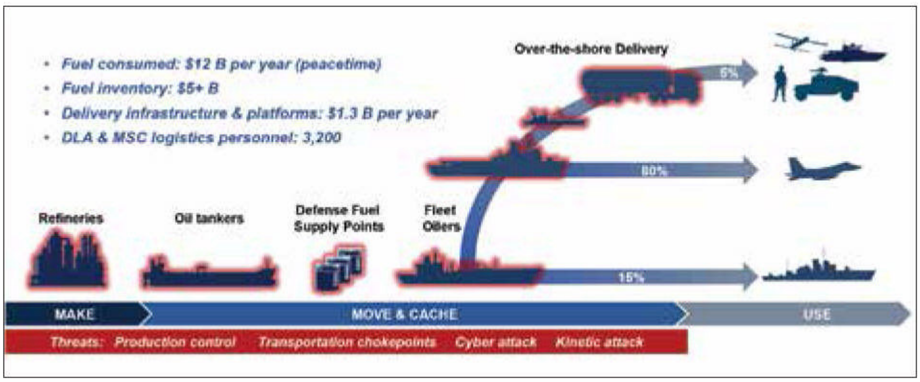

Figure 1. The DOD's global petroleum fuel supply system is expansive and targetable. *(Figure provided by author.)*

for multi-domain operations will increase 37 percent by 2027.[10] Greater unit dispersion to mitigate adversary targeting also increases fuel distribution requirements because of losses in transportation efficiencies. Given these trends, military forces intended to operate in contested areas must address the fossil fuel tether or risk being the most advanced yet least sustainable force.

Figure 2. Information available at radiant.com. (Figure provided by author.)

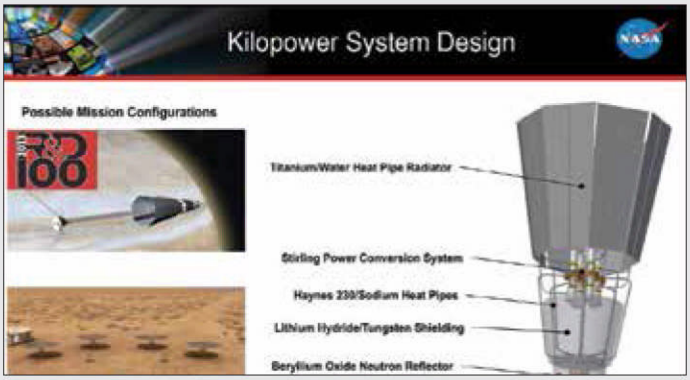

Figure 3. KRUSTY design and mission configuration. (Information available at: https://www.nasa.gov.) (Figure provided by author.)

Figure 4. Holos micro reactor onboard a flatbed. The Holos microreactor can be scaled from a minimum of three MWe to a maximum of thirteen MWe for Holos Quad generators and comprised within a single transport container. The Air Force intends to field a similar prototype micro nuclear reactor at Eielson AFB, AK, by 2027 to allow that remote site to reduce reliance on coal.[17] (Information available at Image Forbes.com and holosgen.com.) (Figure provided by author.)

Possible MLR Alternative Energy Configurations

Electric Energy. An electric MLR using all battery-electric technology reduces the tactical distribution vulnerabilities created by moving bulk fuel while lowering thermal and acoustic signatures. However, expanding this technology beyond computers and light vehicles presents two significant challenges: recharging power and recharging time. Recharging a battery-electric JLTV in 15 minutes would require a 2.6 MW power source.[11] That is the power consumed by 800 American homes. This type of infrastructure requirement means that battery-electric technology is not practical enough on a large scale in an expeditionary environment and is likely not well suited for a highly mobile force such as an MLR.[12]

A hybrid-electric MLR would be better than all-electric; it captures the fuel and signature reduction benefits of an all-electric approach while avoiding many drawbacks. Hybrid electric technology relies on a fossil fuel powered engine combined with regenerative braking to charge the vehicle's battery. Hybridization obviates the massive recharging requirements found in all battery electric vehicles. Research shows that for both vehicles and command operations centers hybridization can reduce fuel consumption by 40–60 percent.[13] However, hybridization still requires fossil fuel at the tactical edge, which does not entirely untether the MLR from the supply chain.

Go Nuclear

Portable micro nuclear reactors would represent a significant technological leap in sustaining the MLR. Recent developments in nuclear technology have made micro reactor designs much safer and on a smaller scale. Former SpaceX engineers at Radiant raised $1.2 million to develop the first portable nuclear zero-emissions power source. Radiant claims its micro reactor can operate up to eight years without refueling, power the equivalent of 1,000 homes, and fit into a shipping container (Figure 2).[14] NASA's KRUSTY (Kilopower Reactor Using Stirling Technology) micro reactor was designed to power Mars and lunar missions (Figure 3). In 2018, the smaller KRUSTY reactor demonstrated the ability to produce 4kWt in 1.5 hours.[15] While micro rector technology is promising, it becomes limited when applied to environments where the force must be highly mobile and low signature. Designs similar to Radiant and Holos (Figure 4 on previous page) will require some form of material handling equipment, and even at 6.5m tall, NASA's KRUSTY displaced up to 800C of heat.[16]

Enter Hydrogen: Future Fuel Used Successfully in Past Combat Operations

A MLR equipped with hydrogen-powered platforms could fill the gaps in areas that all-electric, hybrid, and nuclear configurations fall short. Hydrogen-powered platforms use electrochemical fuel cells, which convert hydrogen gas and atmospheric oxygen into electric power. Hydrogen's energy density allows it to provide power at ranges comparable to battery-electric without adding more weight (Figure 5). More importantly, hydrogen refueling times are similar to fossil fuel vehicles enabling rapid resupply.[18] Another key advantage of hydrogen is its ability to

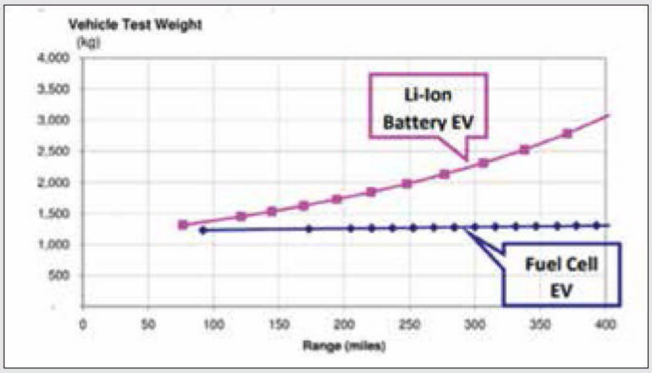

Figure 5. Weight of electric vehicles powered by lithium-ion batteries versus hydrogen tanks and hydrogen fuel cells. (Source: Presentation by Aristeidis Tsakiris Copenhagen Centre on Energy Efficiency [C2E2], available at https://c2e2.unepdtu.org.). (Figure provided by author.)

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Figure 6. The ZH2 is a hydrogen-powered vehicle undergoing user evaluation in Hawaii with 25th Infantry Division. (Information available at https://www.army.mil). (Figure provided by author.)

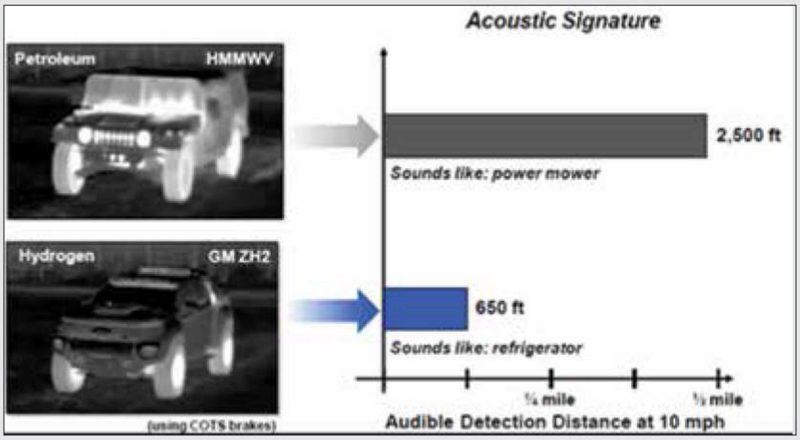

Figure 6.1. Signatures of a combustion engine vs. hydrogen fuel cell vehicle. (Courtesy of MIT Lincoln Laboratory, based on data from Kevin Centeck, Army Ground Vehicle Systems Center.) (Figure provided by author.)

be produced from multiple feedstocks. This advantage creates redundancy for the MLR in sourcing their fuel and improves supply chain resiliency in contested spaces.

Hydrogen use in the military is not new. The Army Air Service used tens of millions of cubic feet of hydrogen fuel safely in aviation operations for artillery spotting and surveillance during the First World War.[19] In the Second World War, the Army produced its hydrogen in the field using small chemical plants on four-wheeled vehicles.[20] In January 2017, the Army began official testing the Chevy Colorado ZH2, a vehicle powered by hydrogen gas; it has a low thermal and acoustic signature, can power a squadron level tactical operations center, and produces potable water as a byproduct of hydrogen production (Figure 6).[21] Today, multiple high endurance unmanned aerial systems use hydrogen, and the Defense Logistics Agency supplies four national stock numbers of hydrogen to the Services.

The primary limitation for hydrogen is that it is bulky to store as a compressed gas and is energy-intensive to produce in the field. Although hydrogen is the most abundant element in the universe, it is rare in its pure form (H_2). It must be separated from other molecules such as water (H_2O), methane (CH_4), or more complex hydrocarbons. Steam methane reforming and electrolysis are the most common means of producing pure hydrogen.[22] The steam methane reforming process is a byproduct of natural gas production, and electrolysis uses an electric current from another energy source to split water into hydrogen and oxygen.[23] The resource intensity needed to produce hydrogen means it is typically done at industrial sites, and it is often compressed or liquefied for transport via pipeline or truck.

MIT's Lincoln Laboratory researchers have developed a methodology to produce hydrogen using scrap aluminum and seawater. They found that by pre-treating the aluminum with gallium and indium, they could create the conditions for the "activated" aluminum to react with water. The reaction rapidly produces large quantities of hydrogen, which can be used on-demand or captured and compressed for use in hydrogen-fueled platforms.[24]

A group of Marine enlisted and officers—infantry, logisticians, and concept developers at MCWL—worked with MIT's Lincoln Laboratory researchers to incorporate this method into their Secure Alternate Fuel Environment (SAFE) concept for operational energy.[25] This concept uses cached activated aluminum by units in highly contested areas to self-supply their hydrogen fuel and proposes using hydrogen procured from regional allies during peacetime and in less-contested areas.[26] The SAFE concept could be a game-changer for Stand-in Forces such as the MLR as it avoids the tactical distribution vulnerabilities of fossil fuels without compromising mobility (Figure 7 on following page).

Field tests with Marines capturing aluminum-derived hydrogen have demonstrated viability in austere environments.[27] By incorporating hydrogen-fueled platforms into the MLR, Marines at expeditionary advance bases throughout the Pacific could produce or receive hydrogen fuel from countless sources: Australian coal gasification, Malaysian natural gas, or aluminum scavenged from a junkyard in the Philippines. Of note, Japan has recently announced its intention to build the world's first full-scale hydrogen supply chain by 2030.[28] Such a diversity of fuel feedstock near

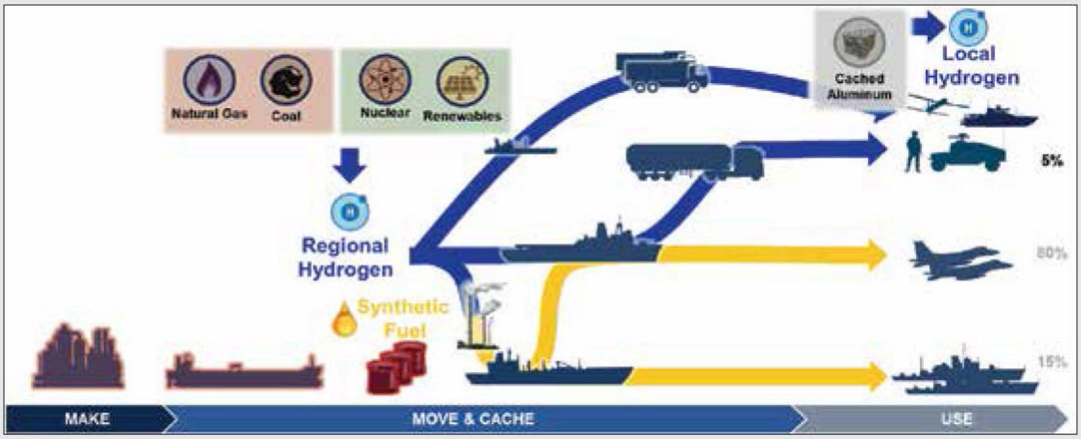

Figure 7. Beyond Tactical Applications: Overview of the Secure Alternate Fuel Environment (SAFE) operational energy concept for DOD contested fuel logistics. *(Figure provided by author.)*

Mineral needs vary widely across clean energy technologies

Critical mineral needs for clean energy technologies

	Copper	Cobalt	Nickel	Lithium	REEs	Chromium	Zinc	PGMs	Aluminium*
Solar PV	●	○	○	○	○	○	○	○	●
Wind	●	○	◐	○	●	◐	●	○	◐
Hydro	◐	○	○	○	○	◐	◐	○	◐
CSP	◐	○	◐	○	○	●	◐	○	●
Bioenergy	●	○	○	○	○	○	◐	○	◐
Geothermal	○	○	●	○	○	●	○	○	○
Nuclear	◐	○	◐	○	○	◐	○	○	○
Electricity networks	●	○	○	○	○	○	○	○	●
EVs and battery storage	●	●	●	●	●	○	○	○	●
Hydrogen	○	○	●	○	◐	○	○	●	◐

iea

Figure 8. The Role of Critical Minerals in Clean Energy Transitions, IEA, Paris. (Information available at https://www.iea.org.) *(Figure provided by author.)*

their point-of-use would dramatically complicate the targeting of fuel supply lines and create redundancy for the MLR.[29]

Risk Assessment

Military planners must acknowledge near-term strategic logistics risks before adopting alternative energy sources and demand reduction technology. Today, we do not have complete control of the technology's supply chain. Batteries, specifically rechargeable batteries, are vital for most alternative energy technology. According to the International Energy Agency, "China is the world leader for battery manufacturing, accounting for around 70 percent of global capacity, followed by the United States (13 percent), Korea (7 percent), Europe (4 percent) and Japan (3 percent)."[30] Alternate energy technology also requires varying amounts of precious minerals not entirely produced by the United States. (Figure 8, 8.1 on following page). The Nuclear Infrastructure Council has also expressed concerns with obtaining sufficient domestic high assay low enriched uranium to fuel micro nuclear reactors.[31]

These near-term strategic logistics risks should not preclude implementation for a future force. The growing international demand for carbon-reducing technologies combined with Allied efforts to control their supply chains will sufficiently diversify production and prevent a single state monopoly over the next two decades. Nearly 130 countries, including the United States, have set net zero emission targets by 2050.[32] (Figure 8.3 on following page) This global demand will necessitate opening new mines globally and spur supply chain protections. In June 2020, the White House announced that it would leverage $17 billion in loan authority to support the domestic battery supply chain.[33] The Department of Energy and its national labs are already proposing interim means to address the high assay low enriched uranium supply chain by "downblending" used nuclear fuel from government-owned reactors.[34]

Historical precedent supports this assessment. Salt was a strategic mineral before the advent of the refrigerator.[35] Coal was a strategic resource in the era of steamships. As a result of scarcity concerns, world governments took steps to diversify production and protect their supply chains. Today, salt and coal are among the most attainable resources globally.

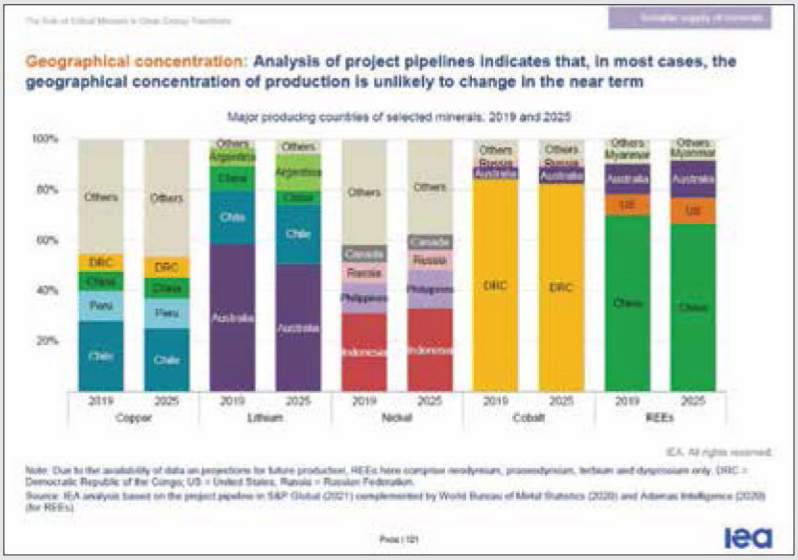

Figure 8.1. The Role of Critical Minerals in Clean Energy Transitions, IEA, Paris. (Information available at https://www.iea.org.) *(Figure provided by author.)*

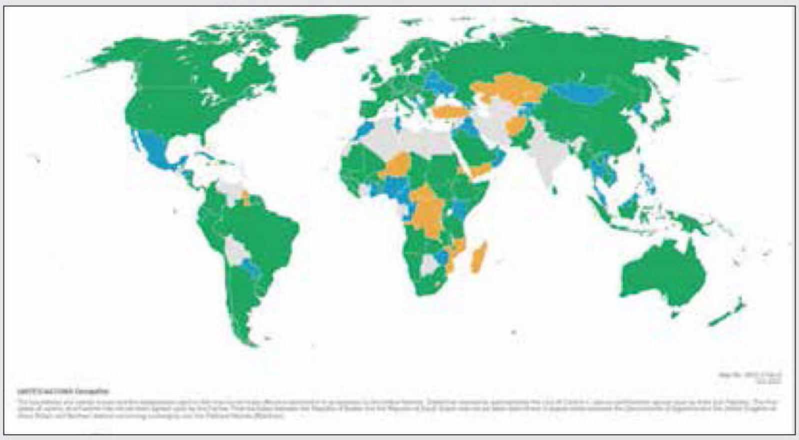

Figure 8.2. Countries with Net Zero Commitments. (Information available at https://www.un.org.) *(Figure provided by author.)*

What Is the Best Choice for the Marine Littoral Regiment?

Diversification. MLRs should employ multiple alternate energy sources to untether from fossil fuel and increase sustainability. MLRs could use electric, hydrogen, and nuclear technologies without compromising mobility, signature, or lethality. Small battery-electric powertrains could power MLR C2 and ultra-light platforms (e.g. sensors and ULTVs) that have reasonable recharging requirements. At the same time, aluminum-reacted hydrogen fuel could be used for medium and heavy platforms that require long endurance, larger payloads, and short refueling times, such as tactical vehicles, generators, heavy equipment, and unmanned aerial systems. As described in the SAFE concept, activated aluminum feedstock could be cached or airdropped to remote EABs to serve as forward fuel. Micro nuclear power may not be a good fit inside the MLR. However, it might be used in a supporting role such as bringing online new advanced naval bases, restarting bases after an attack, or powering mobile electrolysis farms supplying hydrogen or its derived synthetic fuel to the MLR from lesser contested spaces.

The timing is right for the Marine Corps to untether from fossil fuel.

The timing is right for the Marine Corps to untether from fossil fuel. The recent advances in alternative energy sources and demand reduction technology are creating an early window of opportunity for low signature, mobile, non-aviation intensive formations like the MLR. Through continued research and experimentation, the Service should explore incorporating these technologies into the MLR and other Stand-in Forces, knowing that global demand and allied efforts will buy down near-term risks associated with the alternative energy supply chain.

Notes

1. Former Secretary of Defense Gen James Mattis (ret), then Commander of 1st MarDiv, reportedly made this statement reflecting on his 2003 march up to Baghdad during Operation Iraqi Freedom.

2. Headquarters Marine Corps, *Tentative Manual for Expeditionary Advanced Base Operations*, (Washington, DC: April 2021).

3. Gen David H. Berger, "A Concept for Stand-in Forces," *U.S. Naval Institute Proceedings*, (November 2021), available at https://www.usni.org.

4. Department of the Navy, *A Concept for Stand-in Forces*, (Washington DC: December 2021).

5. *Tentative Manual for Expeditionary Advanced Base Operations*.

6. *A Concept for Stand-in Forces*.

7. Donghu Park, Michael Walstrom, "Cyberattack on Critical Infrastructure: Russia and the Ukrainian Power Grid Attacks," University of Washington, (October 2017), available at https://jsis.washington.edu; Inskit Group, "China-Linked Group RedEcho Targets the Indian Power Sector Amid Heightened Border Tensions," *Recorded Future*, (February 2021), available at https://www.recordedfuture.com; and Department of Defense, *FY20 Operational Energy Annual Report*, (Washington, DC: May 2021).

8. Department of Defense, *Task Force on Energy Systems for Forward/Remote Operating Bases*, (Washington, DC: August 2016).

9. Department of Defense, *2016 Operational Energy Strategy,* (Washington, DC: February 2016).

10. Staff, *Powering the U.S. Army of the Future,* (Washington, DC: National Academies of Sciences, Engineering, and Medicine, 2021).

11. Ibid.

12. Ibid.

13. Staff, *Technical Report TR-1181, Tactical Power Systems Study*, (Hanscom Air Force Base, MA: MIT Lincoln Laboratory, 2014).

14. Information available at https://www.radiantnuclear.com.

15. Marc Gibson, David Poston, Patrick McClure, Thomas Godfroy, Maxwell Briggs, and James Sanzi, "The Kilopower Reactor Using Stirling TechnologY (KRUSTY) Nuclear Ground Test Results and Lessons Learned," (Cincinatti, OH: International Energy Conversion Engineering Conference, July 2018).

16. Ibid.

17. Department of the Airforce, "Micro Reactor Pilot," (Washington, DC: n.d.).

18. Staff, "5 Things to Know When Filling Up Your Fuel Cell Electric Vehicle," Office of Energy Efficiency & Renewable Energy, (July 2016), available at https://www.energy.gov.

19. Donald Bishop and Dr. Erik Limpaecher, "Looking Back from the Age of ISR: U.S. Observation Balloons in the First World War," *Air Power History*, (Fall 2021), available at https://www.afhistory.org.

20. War Department. *FM4-193, Antiaircraft Artillery Field Manual: Barrage Balloon Gas Generation, Use, Purification, and Service of Hydrogen Generator*, (Washington, DC: n.d).

21. Mr. Jerome Aliotta, "U.S. Army TARDEC Demos ZH2 Fuel Cell Vehicle at Schofield with 25th Infantry," U.S. Army, (February 2018), available at https://www.army.mil.

22. U.S. Energy Information Administration. *"Production of Hydrogen: U.S. Energy Information Administration (EIA),"* (Washington, DC: December 2021), available at https://www.eia.gov.

23. Department of Energy, *Hydrogen Production Fact Sheet*, (Washington, DC: July 2016), available at https://www.energy.gov.

24. Nancy W. Stauffer, "Using Aluminum and Water to Make Clean Hydrogen Fuel—When and Where It's Needed," *MITEI Energy Futures*, (May 2021), available at https://energy.mit.edu.

25. These "Lethal Luminaries" were key contributors to the SAFE concept: Maj Jake Clayton, Maj Doug Baker, Capt Walker Mills, MGySgt Beau Hornsby, GySgt Justin Leibach, LtCol Nate Knowles, Maj Heather Ichord, Col Matt Swindle, Maj Aaron Stone, Capt David Lorio, Maj Greg Lewis, Capt Matt Evers, LtCol (Ret) Gary Lehmann, Col (Ret) Art Corbett.

26. Walker Mills and Dr. Erik Limpaecher, "Need Fuel? Marines Should Make Moonshine Hydrogen," *U.S. Naval Institute Proceedings*, (November 2021), available at https://www.usni.org; and Dr. Erik Limpaecher, "Fuel for Contested Logistics: Secure Alternate Fuel Environment (SAFE) Concept," (November 2021), available at https://nps.edu.

27. Department of the Army, *"Army Engineers Support Marines' Expeditionary Hydrogen Generation Demo,"* (November 2021), available at https://www.army.mil.

28. Julien Bocobza and Clair Tuch, "Hydrogen and Japan", *Norton Rose Fulbright: Project Finance*, (April 2021), available at https://www.projectfinance.law.

29. Walker Mills and Dr. Erik Limpaecher, "Need Fuel? Marines Should Make Moonshine Hydrogen," *U.S. Naval Institute Proceedings*, (November 2021), available at https://www.usni.org.

30. Timur Gul, Aracel F. Pales and Leonardo Paouli, "Batteries and Hydrogen Technology: keys for a Clean Energy Future," *International Energy Agency Report*, (May 2020), available at https://www.iea.org.

31. Staff, "Small Nuclear Power Reactors," World Nuclear Association, (December 2021), available at https://www.world-nuclear.org.aspx.

32. Staff, "Net Zero Coalition," United Nations, (December 2021), available at https://www.un.org.

33. The White House, "FACT SHEET: Biden-Harris Administration Announces Supply Chain Disruptions Task Force to Address Short-Term Supply Chain Discontinuities," (June 2021), available at https://www.whitehouse.gov.

34. Department of Energy. "What is High-Assay Low-Enriched Uranium (HALEU)?", Department of Energy, Office of Nuclear Energy, (April 2020), available at https://www.energy.gov.

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