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HIGH ENERGY METAL HYDRIDE FUEL CELL POWER SOURCE,(U)
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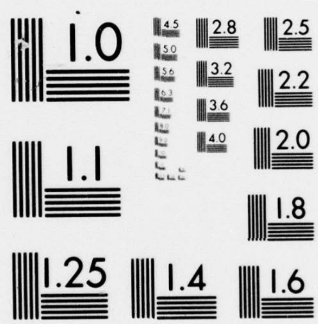
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6 HIGH ENERGY METAL HYDRIDE FUEL CELL POWER SOURCE,

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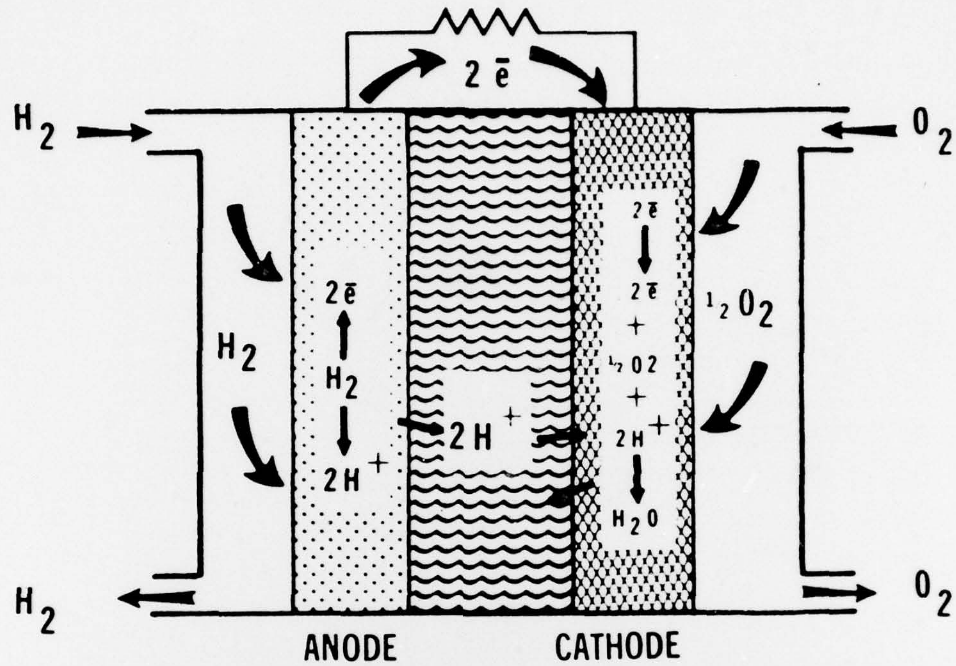
10 WALTER G. TASCHEK, [redacted] CORNELIUS E. BAILEY, JR., MR.
US ARMY MOBILITY EQUIPMENT RESEARCH AND DEVELOPMENT COMMAND
FORT BELVOIR, VIRGINIA 22060

INTRODUCTION

A fuel cell is a device which produces electricity cleanly, silently and efficiently. Like the familiar dry cells and lead acid batteries, fuel cells work by virtue of electrochemical reactions in which the energy of a fuel and an oxidant are directly transformed into direct current electricity. Unlike batteries, however, fuel cells do not consume the chemicals that are part of or stored within their structure. The reactant chemicals used by fuel cells are supplied from an external source. This feature, in principle, allows the fuel cell to operate as long as fuel and oxidant are supplied and reaction products removed.

Figure 1 illustrates the operation of a fuel cell. Hydrogen is supplied to the anode where it electrochemically reacts on a catalytic surface in contact with the electrolyte (an acid in this case). Oxygen, or air is supplied to the cathode where it also electrochemically reacts on a catalytic surface in contact with the electrolyte. The anode and cathode reactions occur simultaneously when a load is applied to the external circuit. When the circuit is interrupted or the supply of either reactant is halted, the reaction stops.

The fuel cell's high efficiency, and high energy density, prompted its development for space applications. Fuel cells were successfully developed for GEMINI, and APOLLO missions and today alkaline electrolyte fuel cells are an established technology for space applications.



ACID ELECTROLYTE

ANODE REACTION — $H_2 \rightarrow 2H^+ + 2\bar{e}$

CATHODE REACTION — $\frac{1}{2}O_2 + 2H^+ + 2\bar{e} \rightarrow H_2O$

OVERALL

$$H_2 + \frac{1}{2}O_2 \rightarrow H_2O$$

Figure 1. General Construction and Reaction Equations for Fuel Cells

Concurrent to the development of fuel cells for space applications, the US Army Mobility Equipment Research and Development Command (MERADCOM) led development efforts on phosphoric acid fuel cells for terrestrial applications. Phosphoric acid fuel cells typically operate in the range of 150 to 200°C. They can operate on air and hydrogen rich fuel streams derived from liquid fuels such as methanol and the logistic hydrocarbons. The fuel stream carbon monoxide content must be low, typically less than three percent. Using concentrated phosphoric acid electrolyte at 150 to 200°C temperatures greatly simplifies electrolyte control of water produced by the electrochemical reaction. The water simply evaporates into the reactant fuel and air streams. Aklaline electrolyte fuel cells must use pure oxygen and hydrogen because the electrolyte reacts with carbon dioxide in air and reformed fuel streams.

MERADCOM is currently developing a family of Silent, Lightweight Electrical Energy Plants (SLEEP). The SLEEP power plants will comprise the 0.5 through 5 KW range and will operate on reformed methanol and air. These fuel cell power plants are expected to replace corresponding gasoline engine generator sets now in the field.

Today the phosphoric acid fuel cell is a strong contender for commercial base load electrical power generation and for industrial and residential applications.

LOW POWER APPLICATIONS

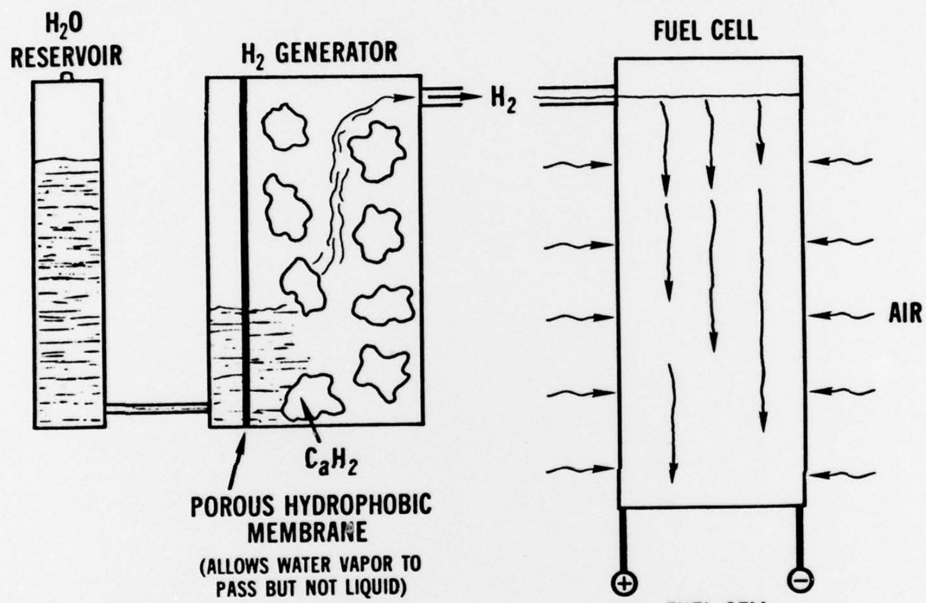
The need for smaller, high energy density power sources, in the one to 100 watt range, to power tactical surveillance or communications equipment was recognized several years ago, but development efforts on fuel cells in this realm were unsuccessful for two reasons; a practical fuel cell for low power, low maintenance operation was not available and, hydrogen generators utilizing high energy fuels were complex and required handling and disposing of caustic materials.

Research efforts at MERADCOM have solved both of these shortcomings. First, a hydrogen generator has been developed which utilizes calcium hydride and water.[1] Hydrogen is produced according to the fuel cells demand by utilizing diffusion control principles. Consequently the water source is not contaminated and the reaction product, lime, poses no disposal problems. The hydrogen generator can be sized for any power output and for a wide range in mission lengths.

Secondly, a hydrogen/air fuel cell utilizing a solid polymer electrolyte (SPE) was found to operate well at low temperatures. Since the electrolyte is solid, product water formed simply drains off. Aqueous liquid electrolyte fuel cells will pick up water at normal ambient temperatures. This water accumulation is undesirable and must be removed for extended operation.

MINIATURE HYDROGEN GENERATOR

Pure hydrogen is generated by the reaction of water with some metal hydrides or alkaline earth metals. In the example shown in Figure 2 the reaction of water vapor with calcium hydride supplies hydrogen on demand by the fuel cell. Water from the reservoir flows into the water chamber adjacent to porous hydrophobic membrane. Water vapor diffuses through the membrane and spontaneously reacts with calcium hydride to produce hydrogen.



H_2 GENERATOR

$$C_aH_2 + 2H_2O \rightarrow C_a(OH)_2 + 2H_2$$

(LIME)

FUEL CELL

ANODE $H_2 \rightarrow 2H^+ + 2E$

CATHODE $\frac{1}{2}O_2 + 2H^+ + 2E \rightarrow H_2O$

OVERALL $H_2 + \frac{1}{2}O_2 \rightarrow H_2O$

Figure 2. Schematic Diagram of Metal Hydride Fuel Cell Power Sources

At no load, hydrogen is not consumed and the pressure within the reaction chamber increases, thereby forcing water into the reservoir and out of the water chamber. This action reduces hydrogen production. As hydrogen is consumed by the fuel cell, the water level will self-adjust to generate only the required amount of hydrogen. Refueling is easily accomplished by dumping the lime and adding more fuel and water.

Hydrogen generation rate increases as temperature increases due to higher vapor pressure, but since production is self regulated according to demand it simply means that the water level will drop with increasing temperature for a given demand rate. Conversely, at low temperatures the water level tends to be higher. Below an operating temperature of $0^{o}C.$, pure water freezes. The hydrogen generation reaction, however, is exothermic. Design calculations indicate that only a moderate amount of insulation would be required to keep the hydrogen generator above freezing while operating in ambient temperature down to $-40^{o}C$. Also, it appears possible that salt water or antifreeze will allow the hydrogen generator to start up and operate in 0 to $-40^{o}C$ temperatures. For the very cold ambient temperatures, a small portion of the high energy fuel would be converted into heat, this action will promote bootstrapping of the hydrogen production rate.

The hydrogen generator shown on Figure 3 was designed, fabricated and successfully demonstrated for applications where abnormally high hydrogen production rates could occur. The porous hydrophobic membrane will pass liquid water if pressures exceeding 0.25 atm occur across the membrane. To prevent direct contact of fuel and liquid water, a dual membrane approach was used. This generator is identical in principal and function to the one discussed previously (Figure 2) except that it uses a dual membrane. If the excessive demand for hydrogen occurs and the differential pressure of 0.25 atm is exceeded, then water will be pulled through the first membrane and out the hydrogen port. The water will never flow directly into the fuel chamber.

Many prototype hydrogen generators have been developed in-house. Capability of operation at very low power levels (1 watt) and at hydrogen production rates equivalent to 100 watts have been demonstrated. These generators covered a fuel capacity range of 20 grams to 500 grams. This is equivalent to net electrical energy output of 20 to 500 watt hours (WH) respectively. It is significant that larger sized generators could operate efficiently at high and very low loads.

Hydrogen generators using water activated metal hydrides based on the Kipp principle are well known. In most Kipp generators liquid water directly contacts the fuel with the consequence of eventual water and fuel contamination. After each mission, the remaining fuel must be removed and the unit cleaned to remove reaction products. The reaction typically forms an insoluable sludge and lye. The

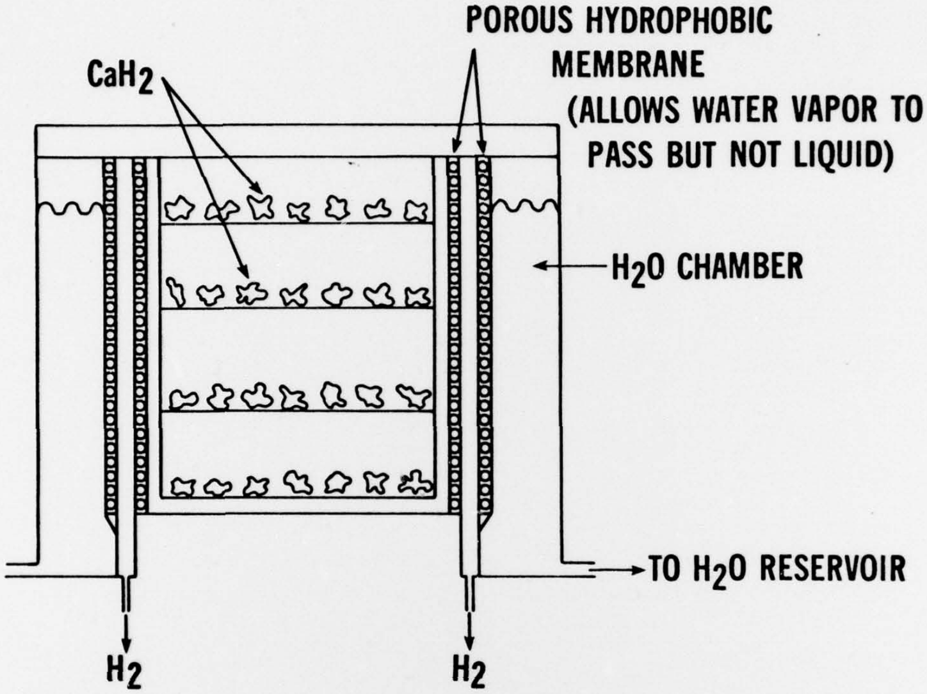


Figure 3. Cross Section of Double Membrane Hydrogen Generator

sludge will solidify and become difficult to remove if the unit is not cleaned. Kipp generators are simple to design, construct, and operate, but they are difficult to maintain and not suited for applications requiring varying periods of standby operation. The miniature hydrogen generators on the other hand will not contaminate the water supply, keep reacted fuel in convenient, disposable paper cartridges and do not require clean out.

SPE FUEL CELL

Figure 4 shows one of MERADCOM's early model hydrogen generators coupled to an SPE fuel cell stack that was purchased from General Electric. The SPE fuel cell operated simply and reliably and provided an excellent match with the miniature hydrogen generators. It, however, utilized costly materials and its design was not amenable to low cost construction. (Components were developed for high power space applications where material costs are secondary to performance.)

For low power applications a less expensive approach geared to more compact assembly of lower power density cells was needed.

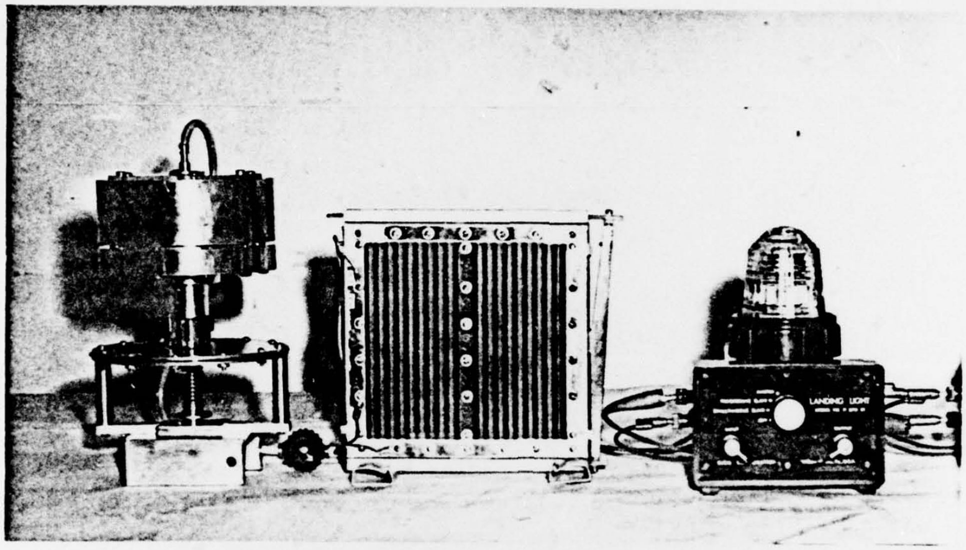


Figure 4. Hydrogen Generator and GE Fuel Cell Stack Powering Landing Lights

Firms experienced with fuel cells were briefed on MERADCOM's results and encouraged to respond to a competitive RFP for the design, development, and fabrication of thirty, 3 watt, 6 V SPE fuel cell stacks. Engelhard Industries won the competition.

A photograph of a 3 watt stack is shown on Figure 5. Electrodes and bipolar separator plates developed for phosphoric acid fuel cell stacks were used with the SPE. The carbon based bipolar separator plates allow compact construction of cells in electrical series. The three watt stacks contain 8 cells to directly provide the nominal 6 V output. This construction technique was easily scaled up to a 24 V DC output at 20 watts. No limitation in power rating is foreseen. A 3 watt stack has been operated for more than 10,000 hours with no appreciable drop in performance.[2]

The SPE 3 watt stacks and in-house developed hydrogen generators were combined into a compact power source for landing/marker lights.

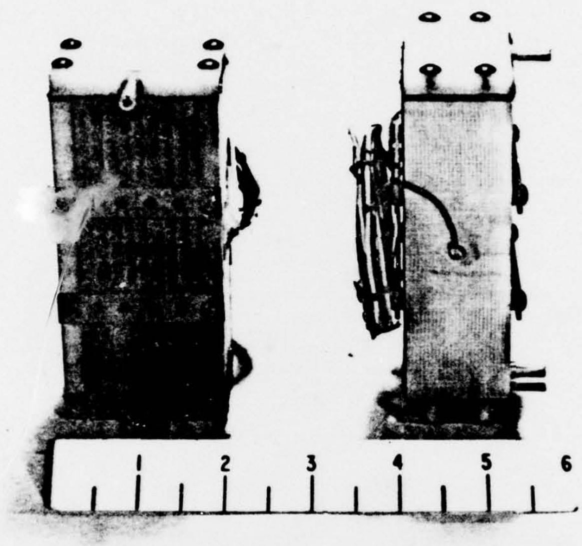


Figure 5. 3 Watt Engelhard Fuel Cell Stack

Ten units were fabricated and frequently demonstrated. Figure 6 is an accurate portrayal of the units. The unit is activated by inserting a paper cartridge containing calcium hydride into the fuel chamber, replacing the cover, and adding water. The power source requires no moving components and once activated requires no maintenance until fuel or water are exhausted. Refueling takes less than one minute on these prototype units. One charge of fuel (70 grams) operated the landing light for over 80 hours compared to 20 hours for the lantern battery power source designated for the light.

Success in this area prompted more serious evaluation of the low power market within the Army. What was found in general was that power requirements less than 1 watt were typically met by primary batteries and tactical requirements from 10 to 100 watts and higher were almost always filled by secondary batteries. For this latter situation the need for better power sources is most evident.

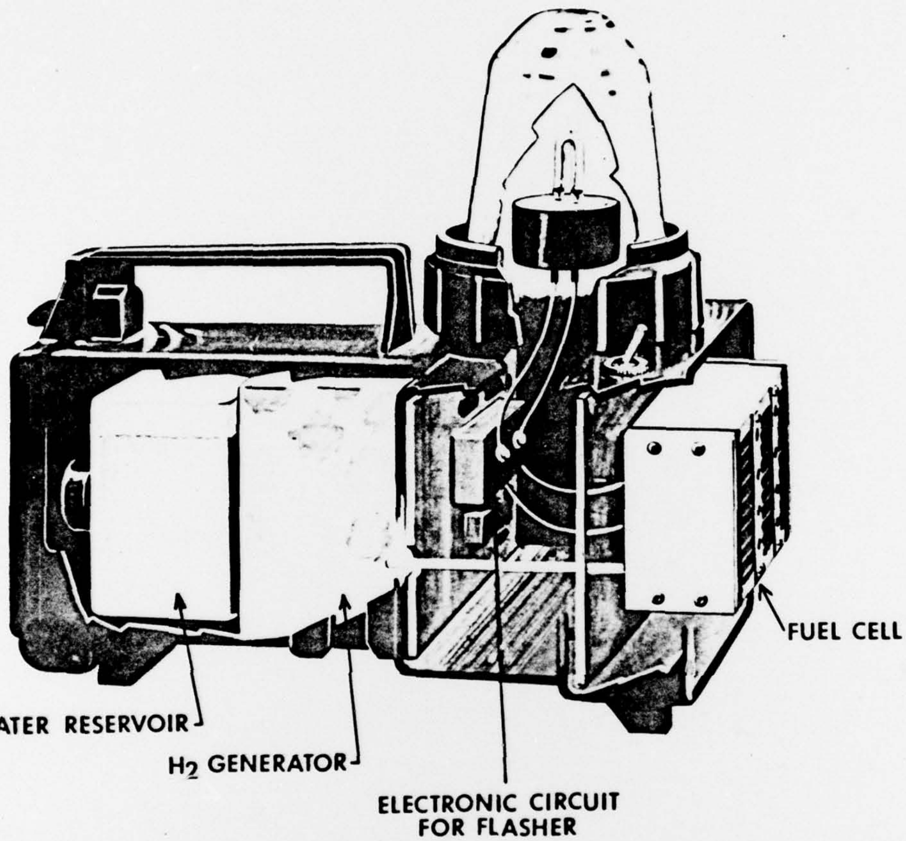


Figure 6. Cutaway of Marker Light Featuring Fuel Cell Power Source

Figure 7 shows what we term the "gray area". In this realm, we feel, that existing power sources are not available. Consequently, operational and mission effectiveness is compromised. The letters noted on the chart are actual battery power sources and these are identified on Table 1. Most of the equipment listed is tactical but several commercial applications are included as a frame of reference. One can extend operational capability into the "gray area" by doubling up on power sources, by running a lengthy power cord, by operating a noisy 0.5 or 1.5 KW generator set at a low load or run the equipment off a vehicle battery with the vehicle operating to charge the battery.

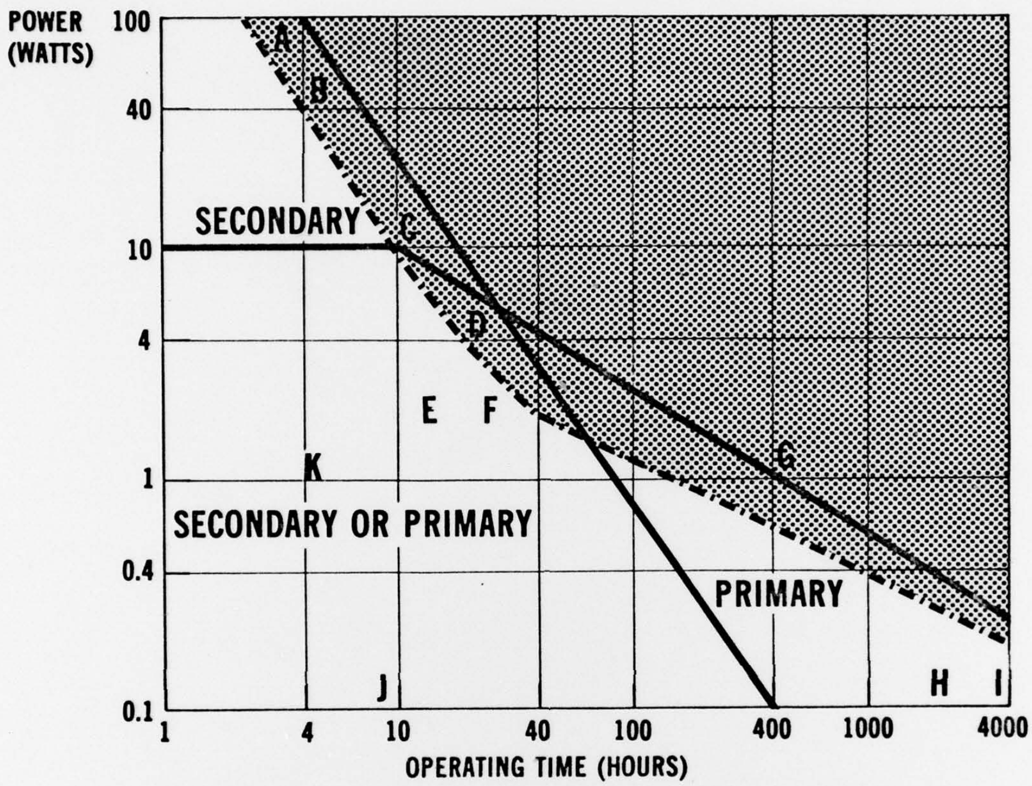


Figure 7. Gray Area Concept of Tactical Missions for Power Sources

Other approaches have been tried but not with widespread success. Thermoelectric generators are feasible but are not efficient, have a high thermal signature, are generally not adaptable to varying loads, and are expensive. The hand crank generator is fine for emergency operations but not for most tactical or remote application.

Military tactical power requirements are much more demanding then those of the civilian sector because utility power is frequently not available. Power and mission time of portable power sources are greater and a high premium is placed on energy density. For example, the silver zinc secondary battery is frequently selected because of its high energy density, (low comparative weight) even though it is more costly, shorter lived, and more difficult to maintain than the

EQUIPMENT	AVE. PWR. WATTS	BATTERY TYPE	BATTERY NUMBER	WEIGHT POUNDS	OPER. LIFE HOURS	REFERENCE
ELECTRIC WATCH	0.0001	DRY		0.02	8000	
ELECTRIC CLOCK	0.001	DRY		0.2	8000	
FLASHLIGHT	1	DRY	2 "D" CELLS	0.5	4	K
LANTERN LIGHT	2	DRY	BA 200	2	12	E
BARRICADE FLASHER	5	DRY		21	72	G
CALCULATOR	0.1	DRY OR NiCd		0.2	10	J
MIL RADIOS/TR						
AN/PRC-25	2	MAG.	BA 4386	4	60	
AN/PRC-77	1.8	MAG.	BA 4386	4	64	
AN/PRC-70	6	NiCd	BB-651	12	20	
AN/PRC-70	6	Sil-Zn	BB-536	8	30	D
AN/PRC-1	18	Sil-Zn		8	12	C
RADAR TRANSP						
SST-119	10	MAG.	BA 4386	4	12	
SST-119	10	Sil-Zn		16	70	
GLLD	6	NiCd		8	15	
RADAR SET						
AN/PPS-5	40	Sil-Zn	BB-622	11	5	B
AN/PPS-5	60	NiCd	BB-422	29	3.5	A
MINISID	0.1	LITHIUM		2	1500	H

Table 1. Power Source Applications

VOLTAGE	24-32 V DC
SIZE	4 x 12 x 12 inch
WEIGHT	15 pounds
FUEL CHARGE	1 pound Calcium Hydride
MISSION CAPABILITIES	360 Watt Hours (30 Watts for 12 Hours)

Table 2. Characteristics of 30 Watt High Energy Fuel Cell Power Source

familiar lead acid or nickel cadmium secondary batteries. For tactical equipments, the battery power source is generally considered a component of the equipment that it powers. While there is merit to this concept, it has fostered a proliferation of specialized batteries.

The portable radar set AN/PPS-5 is a good example of an equipment whose operational capability is limited by the power source. This set can be set up by two men in 10 minutes. It requires from 30-42 watts of power during operation. Power is supplied by a BB-622, silver-zinc secondary battery. Silver zinc does not have a good life (cycle or storage), is expensive, and has poor low temperature performance but it does have the highest energy density characteristics of rechargeable batteries. The training manual recommends "using alternate power sources, when possible, to reduce the burden of charging, maintaining, and replacing Storage Battery BB-622 (U) in the radar set. The alternate power sources will facilitate operation of the radar set if battery boxes containing Storage Battery BB-622 (U) are not available."[3] Optional power sources listed include a 29 lb. nickel cadmium storage battery, BB-422 (U); two 12 V vehicle batteries, 2 HN, connected in series; a 28 V Generator Set, PU-532PPS; and a Power Supply, PP-2953 which converts an alternating current source to 28 V DC. The AN/PPS-5 includes a power converter that adapts an external or internal 24 V DC power supply to 6 V DC. Converter inefficiency requires 60 watts external compared to 40 watt internal. Note reference A&B on Figure 7 and Table 1.

A 30 watt fuel cell power source is currently being developed for demonstration with various tactical communications and other electronic equipment, and as a battery charger. An artist concept of the unit is shown on Figure 8. Design characteristics of the demonstration unit are listed on Table 2. The unit will be available for demonstration this summer. A comparison of the high energy power source with available secondary batteries yields the following for a 24 hour, 30 watt mission: One 20 lb. high energy fuel cell power source complete with fuel and water would satisfy the mission. Each additional 24 hour mission would require an additional 2 lb. of fuel and 2 lb. of water.

The same 24 hour mission would require three battery power sources of the types listed in Table 3. Of course, a repeat mission would require additional batteries or charging equipment.

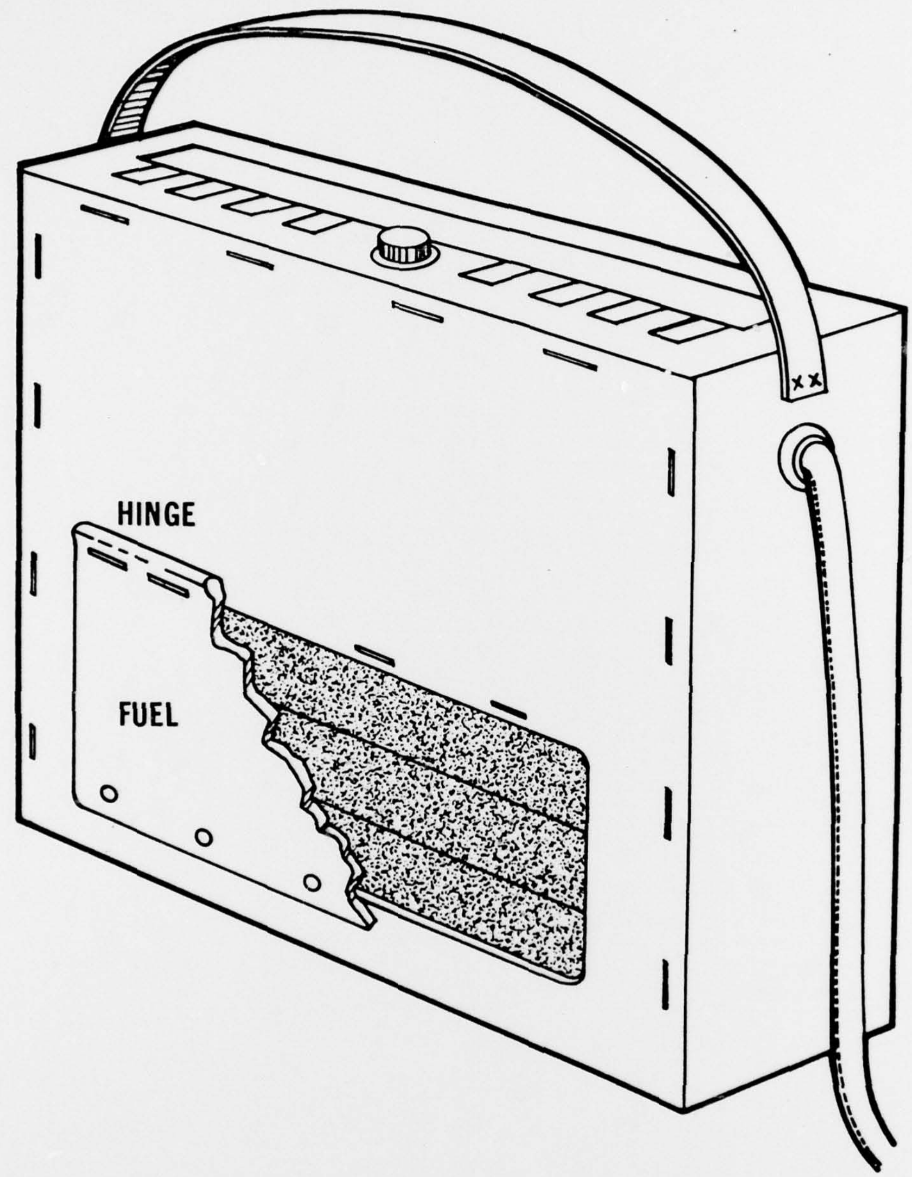


Figure 8. Artist Rendering of 30 Watt Power Source

Battery	Unit Cost[4] $	Weight (lbs)	Capacity at 70°F (WH)
24 V BB501/U	$725	32	308
24 V BB422/U	$231	29	240
6 V BB622/U	$170	11	240

Table 3. Characteristics of A Few Secondary Batteries

Fuel costs for the high energy power source are estimated at 2¢/WH. The logistic burden of storing, maintaining, transporting and charging secondary batteries depends on many factors and the overall costs are likely to be 5 to 20 times greater than those associated with the use of high energy SPE fuel cell power sources.

SUMMARY

The compact, maintenance free miniature hydrogen generator, in conjunction with a solid polymer electrolyte fuel cell represents an attractive electric power source for tactical and remote communications and surveillance equipment. This new electric power source may also be used together with a secondary battery to combine its high energy density feature with the high power density characteristics of secondary batteries. A 30 watt, 28 V power source will be available for demonstration in the near future.

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