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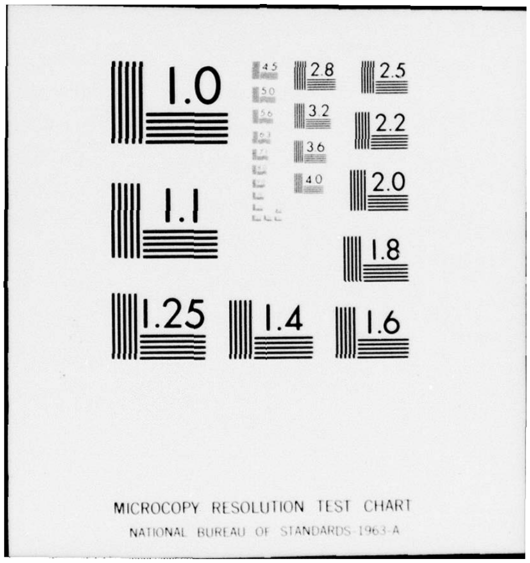

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SURVEY OF CONTINUOUS SOURCES OF ELECTRICAL POWER FOR UNDER-ICE PROPULSION OF SMALL SUBMERSIBLES.

PART II: NEW HIGH ENERGY DENSITY SYSTEMS,

by

10 Thomas T.E. King and Walter W.J. Moroz

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ABSTRACT

New, high energy density electrochemical systems are discussed from the point of view of meeting the forecast electrical requirements for the SDL-1 submersible in the 1980-90 time frame. Three main categories of systems are considered; namely, aqueous, metal/oxygen, and high temperature.

Since most new high energy density systems are still in the conceptual stage, with many engineering problems yet to be resolved, the technical and economic merits are reviewed mainly in general terms. The systems with the best near and long term development potential are critically examined and assessed.

RÉSUMÉ

On a étudié de nouveaux systèmes électro-chimiques à haute énergie massique pouvant satisfaire aux besoins en électricité du submersible SDL-1 de 1980 à 1990. On a examiné trois principales catégories de systèmes: aqueux, métal/oxygène et à haute température.

Puisque la plupart des nouveaux systèmes à haute énergie massique sont encore à l'étude, avec de nombreux problèmes techniques à résoudre, les avantages techniques et économiques ne sont traités que de façon générale. Les systèmes ayant le meilleur potentiel de développement à court et à long terme sont examinés et évalués d'une façon plus détaillée.

INTRODUCTION

In order to meet the forecast electrical requirements for the SDL-1 submersible in the 1980-90 time frame, it will be essential for the proposed battery to have a capacity of 800 Ah or better when discharged at the 6 hr rate. and an energy density of at least 26 Wh/lb and 3 Wh/cu. in. As stated in Part I of this report (1) the only battery system capable of meeting these new requirements at the present time is the silver/zinc system.

Many of the new high energy density systems which are being investigated today and which merit consideration as potential power supplies for small submersibles are still in the conceptual or experimental stage. Workers in the field (2,3) predict that from five to ten years of concentrated research and development will be required before the most advanced of these systems become commercially available.

Developments in advanced battery systems will undoubtedly result from the concentrated effort currently being applied to vehicle propulsion programs to obtain batteries which would have substantially increased energy densities, reliability, and lower costs. Other desired improvements being sought are long shelf and cycle life, durability, low maintenance, safety, and operational simplicity. Difficulties which must be surmounted to achieve these goals are those concerned chiefly with corrosion of materials, temperature, catalysts, packaging and cost. To be realistic it must be accepted that many of these new systems will never progress beyond the conceptual stage.

Of the many high energy density battery systems presently under development, it is anticipated that the major efforts will be concentrated on the nickel/zinc, zinc/oxygen, lithium/metal sulphide, and the sodium/sulphur systems. These are the new systems which presently show the most promise of being successfully developed as batteries for propulsion purposes. The probability of one or more of these systems reaching a practical development stage within the next five to ten years appears high.

The new high energy density systems which show promise of meeting the forecast SDL-1 requirement will be considered under three main categories, namely aqueous, metal/oxygen and high temperature systems. However, until the many engineering problems associated with these systems are resolved, it is impossible at this time to assess their technical and economic merits except in general terms.

Fuel cell and nuclear power systems being outside the scope of this study, will not be discussed in this report. The potential of these particular systems for submersible applications are being reviewed by experts in their respective fields (4,5).

AQUEOUS SYSTEMS

The conventional aqueous systems have already been discussed in Part I of this report. A number of new aqueous systems are presently being studied at various research establishments. These include the lithium/water, nickel/zinc, zinc/bromine, nickel/hydrogen, zinc/chlorine hydrate, and the antimony redox battery systems. At the present time, it would appear that of these listed aqueous systems, the nickel/zinc shows the most promise of becoming commercially available within the next five years.

Although not considered new in the same sense as the other aqueous systems mentioned above, the magnesium/silver chloride and magnesium/lead chloride systems have also been included for discussion within this group because of their attractive energy density values and their proven usefulness in many seawater applications.

The magnesium/silver chloride and the magnesium/lead chloride are reserve type primary aqueous batteries which are activated by immersion in seawater and have been extensively used in torpedo propulsion and sonobuoy applications. These systems have been thoroughly studied at DREO.

The magnesium/silver chloride system has an open circuit potential of 1.55V and an achieved energy density of 30-40 Wh/lb. A bipolar construction is utilized to take advantage of the high energy density of the system. Following activation, and during discharge all cells are immersed in a common electrolyte. Unfortunately, with this type of construction intercell shorting is pronounced, increasing greatly with the number of cells employed. In the case of a 120V battery (approximately 100 cells), the parasitic losses due to intercell shorting would be excessive over a six hour period and would lower the energy density appreciably: perhaps as much as 50 percent. At this lower performance level the system would be unable to meet the minimum energy density requirement of 26 Wh/lb.

The use of a cellular configuration in place of the bipolar construction in a common electrolyte (seawater) would help to reduce the power losses owing to intercell shorting but would seriously reduce the current carrying capability of the system as well. It is felt that any gain in energy density so obtained would still not raise the level of battery performance sufficiently to meet the minimum requirement. With regard to cost and irrespective of construction, this battery system is expensive because it uses costly silver material. Also being a primary, there would be the added expense of replacing the battery after every run.

An alternative possibility that was considered, involved the use of a limited number of cells (4-12) in conjunction with a converter. A converter efficiency of 90% or higher would be essential for success because of battery voltage derating: approximately 20% at low temperatures (32°F). Based on available information, it was estimated that to obtain the required SDL-1 power outputs the size of the battery/converter combination would probably be as large as the present battery compartment of the SDL-1: possibly larger. Cost of the converter would be in the neighbourhood of $100,000. Of course, the converter would be re-usable in this application and the cost could be amortized over many missions.

The magnesium/lead chloride system has an open circuit potential of 1.1V and an achieved energy density of 10-30 Wh/lb in 6 hr rate applications, viz. sonobuoys (6). In the bipolar construction, the magnesium/lead chloride battery suffers from the same intercell shorting disadvantages as does the magnesium/silver chloride battery. The possibility of using a cellular construction with or without a converter to improve the energy density also applies. However, at the present time there is considerable doubt whether even with these modifications the system could meet the minimum energy density requirement, especially at lower temperatures. To its advantage, the magnesium/lead chloride battery does not contain expensive materials and is comparatively inexpensive to produce. However, being a primary it must also be replaced after each run.

Technological development of the magnesium/silver chloride and magnesium/lead chloride systems has now progressed to the point beyond which a disproportionate amount of effort is needed to achieve minimal gains. Unless a major technical breakthrough occurs which results in much improved electrode performances, further significant increases in energy density content are highly unlikely. In their present state of development the magnesium/silver chloride and magnesium/lead chloride systems are considered unsuitable for use in submersible propulsion applications.

The lithium/(sea)water is also a primary system. It has an open circuit potential of 2.0V and a high theoretical energy density of 3860 Wh/lb based on the weight of lithium. Achieved energy densities as high as 1500 Wh/lb of lithium have been reported (7). A 164-KW lithium seawater power system has been proposed to the U.S. Navy by Lockheed (8). It has been stated that the system might deliver up to 100 Wh/lb at a maximum power density of 90 W/lb (9).

Based on another proposal by the same company for a submersible power system, it is estimated that a lithium/water system which could be designed to meet the requirements of the SDL-1 application, i.e. 15-20 KW, would be equal in size but have a system weight of only one-third that of a silver/zinc battery of equivalent output. The development of a low drain lithium/water battery as a substitute for silver/chloride sonobuoy batteries was recently conducted under Canadian Government sponsorship (10).

An attractive feature of the lithium/water system is its simplicity of design. The cell requires neither membranes, amalgams, nor separators. Its power is produced by the direct reaction of lithium with water. A lithium/water battery would not require a pressure compensation system.

Lithium based batteries are of added interest because of the existence of large Canadian deposits of lithium.

Limitations associated with this system are cooling problems, buoyancy changes during operation and mechanical rechargeability while submerged (4). It is estimated that from start of development, 2-5 years would be required to produce a battery for the SDL-1.

The nickel/zinc is a secondary battery system with an open circuit potential of 1.7V and a theoretical energy density of 146 Wh/lb. An achieved energy density of 30 Wh/lb with over 300 cycles under discharge conditions has been reported (11). Cost-wise, this system benefits from using inexpensive materials. Charge-discharge cycling of the zinc electrode is still a major problem causing: shedding, dendritic growth of zinc leading to capacity losses, separator penetration, and ultimate battery shorting. Work is continuing on inexpensive separators for long life operation.

An 800 Ah nickel/zinc battery proposal for small submersibles was made by the Yardney Electric Corp. (12). The 12-28-120V batteries were to have 101 cells, weigh 4,655 lbs and have a volume of 34 cubic feet. Cycle life was estimated to be 300. Approximate cost of the battery was quoted at $113,000. An additional cost of 20% would be required for a pressure compensated battery container.

The nickel/zinc system is considered to be one of the best prospects for successful near-term development (2-5 yrs) as a new high energy density battery suitable for submersible propulsion.

The zinc/bromine system has an open circuit potential of 1.8V and a theoretical energy density of 196 Wh/lb. It has been reported that 200 cycles and 22 Wh/lb have been achieved (11). A small 36 cell unit has been built (13). Estimated cost is expected to be the same as for lead/acid. Zinc dendrites do not present a problem with this system as they are dissipated by reaction with the bromine, therefore long cycle life can be expected.

The major disadvantage of the system is its rapid self discharge; approximating 100% in four days. This can be off-set by a continuous trickle charge or might even be entirely eliminated by the use of an improved separator. Although bromine is a toxic material, it is easily detectable by odor before it becomes injurious. If the battery compartment is located outside the hull this should not present an operational problem.

Much development effort must yet be put into this system before it can be seriously considered for applications like submersible propulsion.

The nickel/hydrogen is a recently developed system with an open circuit potential of 1.36V and a theoretical energy density of 177 Wh/lb. An energy density of 25 Wh/lb and 1.0 Wh/in^3 for modular cell and common pressure vessel designs has been achieved (14).

Present cell designs operate within a heavy sealed pressure vessel of Inconel material, at pressures of 400 psi. New high pressure designs (2000 psi) are expected to improve the volume energy density of this system to 3.0 Wh/in^3. New methods of hydrogen storage (metal hydrides) are also being investigated. These offer further advantages of reduced battery volumes at relatively low pressures (100 psi), and volume energy densities of 3.5 Wh/in^3.

Both the nickel and hydrogen electrodes are well developed, having been extensively used in other systems, namely, the nickel/cadmium and the hydrogen/oxygen fuel cell. The proven, long operational life of these electrodes should result in a battery with excellent cycle life.

The design of the battery compartment in the submersible will of course be governed by the characteristics of the battery (low or high pressure) that is eventually developed and proven suitable for submersible propulsion. The development outlook for the nickel/hydrogen system appears reasonably good. Optimistically, the system may be commercially available in five years' time.

The zinc/chlorine hydrate system has an open circuit potential of 2.12V and a theoretical energy density of 209 Wh/lb. An energy density of 30 Wh/lb has been achieved, with 50 Wh/lb at the four hour rate considered possible (11). This system is complicated, requiring a circulating mechanism, and a refrigeration and storage unit for chlorine hydrate (15). Loss of cooling would result in the release of dangerous chlorine gas. This aspect of the system is still of some concern. The system has already been tested in an experimental car (13).

Although it has been reported that the system is expected to be commercially available within two years (11), it is felt that this is an overly optimistic projection particularity in the case of submersible propulsion.

The antimony redox battery is described in a recent U.S. patent (16). This system, still in the laboratory stage, has an energy density estimated from 25 to 40 Wh/lb. Although information is sparse, this system shows promise for long cycle life; also, no evolution of gas occurs during charge and it can be easily sealed if desired.

METAL/OXYGEN SYSTEMS

The family of metal/air batteries of which the metal/oxygen systems are members, has many attractive features and is being currently investigated by a number of countries, viz. Canada, United Kingdom, United States, France, Germany, Japan, Sweden, etc., for vehicle propulsion applications. Areas of immediate concern include thermal problems, expensive and inefficient catalysts, and the poor rechargeability of the oxygen electrode. Improvements that may occur from this extensive effort into metal/air systems will undoubtedly be applicable and of benefit to the metal/oxygen systems which are of interest for submersible propulsion applications.

Metal/oxygen systems use a metal negative electrode, and a fuel cell type of gas electrode which operates on oxygen, as the positive. Several versions have been developed including primary, secondary, mechanically rechargeable anode types, and others (11). Although zinc is the most commonly used metal for the anode, other metals superior in energy density or offering significant cost advantages are also being considered.

Based on the cost of oxygen in Ottawa together with electrochemical considerations, it is estimated that the cost of oxygen fuel for metal/oxygen systems would be $4.00 per mission: an inconsequential cost. However, the cost of an oxygen storage tank, at $57,000, although an appreciable amount, ($19,000 plus $37,000 for the initial tooling and development) would be a non-recurring cost. A light weight, fibre-glass wrapped aluminum cylinder would weigh about 250-400 lbs. Using Kevlar material it might be possible to reduce this cylinder weight by as much as 50%.

The zinc/oxygen system has a theoretical energy density of 614 Wh/lb and an open circuit potential of 1.65V. Primaries have achieved energy densities up to 150 Wh/lb. The advantages of zinc as an anode material are reactivity, stability, low cost, and some rechargeability. As with other zinc systems, rechargeability of zinc electrodes remains a major problem due to the formation of a soluble zincate, shedding of active material, and dendritic growths. Thermal and other problems with the oxygen electrode also remain to be resolved. Several companies, viz. General Motors, General Dynamics, Leesona-Moos and Sony have extensively investigated this system but owing to presently unresolvable problems many of the original sponsors have terminated development.

A prototype 75W battery for a portable radio application (AN/TRN-30) was developed for the Defence Research Establishment Ottawa by Unican Systems of Canada (17). This zinc/air (oxygen) battery was a primary type designed for low rate and low temperature applications (-40°). Feasible solutions to troublesome thermal and separator problems were worked out during the evaluation trials.

An 800 Ah zinc/oxygen battery proposal for small submersibles was recently received from the Yardney Electric Corporation (12). The 12-28-120V battery was to have 179 cells, weigh 2,159 lbs and occupy a volume of 30 cubic feet. No costs were provided by the company since considerable development work had yet to be completed. Details of this battery concept have been reported (18).

The iron/oxygen system has a theoretical energy density of 550 Wh/lb and an open circuit potential of 1.2V. A practical energy density of 50 Wh/lb is expected. After zinc/oxygen, the iron/oxygen system shows the most promise of achieving early development. Disadvantages of the iron/oxygen system are; inability to operate at high current densities over long periods of time, bulk and complexity. Auxiliary systems which are needed for oxygen circulation, and temperature and pressure control, account for about 10% of the system weight. Cycle life is cathode limited (11).

Other metal/oxygen systems using anodes of magnesium, aluminum, titanium, cadmium, chromium, sodium and calcium are also being studied. Many difficulties remain to be resolved with these systems and until some significant technological breakthrough occurs, the prospects of their availability within the next decade appear remote.

HIGH TEMPERATURE SYSTEMS

At the present time research being done on the high temperature systems is primarily being directed at vehicle propulsion applications.

These systems, which operate at temperatures up to 650°C (1200°F) are attractive because they offer high power densities and high energy densities. However, in their present state of early development they are not considered suitable as power supplies for submersibles. Problems that have yet to be overcome include corrosion of materials, hazards of liquid alkali metals, battery start-up time, and initial heat source requirements.

Until these problems and hazards have been resolved and the systems approved for vehicle use, they should not be considered for submersible applications. Naturally, allowances would have to be made in the design of the submersible battery compartment to accommodate such systems. For instance, high temperature batteries will have to be housed in appropriately insulated, non-pressurized compartments that are preferentially located external to the main hull for safety reasons. This design would facilitate jettisoning of the battery in an emergency situation.

A number of high temperature systems are currently being investigated of which the most promising are sodium/sulphur, lithium/sulphur, lithium/tellurium tetrachloride and lithium/chlorine. Perhaps, the outstanding characteristic of these systems is their potential for quick, high rate recharges (15-30 minutes) (9). If the major problems are resolved and the expected goals achieved, then within the next 10-15 years these batteries will probably displace most battery systems being used and considered for propulsion purposes.

The sodium/sulphur system has a theoretical energy density of 312 Wh/lb and an open circuit potential between 1.8 and 2.1V, depending on the state of charge. The basic operating principle involves the separation of the molten reactants, sodium and sulphur, at 300°C by a sodium ion conducting ceramic membrane of beta-alumina. In this battery, beta-alumina acts as a solid electrolyte. The Ford Motor Co. has been carrying out research on this system since 1966. Other studies have been reported in England, France and Japan. Another type of solid electrolyte being investigated (Dow Chemical Co.), consists of a highly basic glass, loaded with sodium oxide, with conduction by transfer of sodium ions. A large cell area is achieved by paralleling thousands of glass capillaries containing the sodium oxide into bundles of tubes.

The Ford Motor Co. developed a 12 volt battery reportedly capable of delivering 42 Wh/lb. The projected performance is anticipated to be 150 Wh/lb and 100 W/lb. These high temperature cells have to be exceptionally well matched or alternatively, sophisticated charge control methods must be used to compensate for the system's lack of an overcharge mechanism. Problems with cracking of the beta-alumina and corrosion of cell cases by the sulphur and polysulphide reaction products have prevented rapid development of this cell.

Of all the high temperature battery systems under investigation the sodium/sulphur battery shows the most promise for vehicle and other propulsion applications. The system combines high energy density with very low cost materials and good rechargeability.

The lithium/sulphur system has a theoretical energy density of 700 Wh/lb and an open circuit potential of 2.25V. This system has a fused salt electrolyte (LiI-KI-LiCl eutectic) and can deliver high energy and power densities of the order of 100 Wh/lb and 60 W/lb. Laboratory cells have achieved 2000 charge-discharge cycles and several thousand hours of operation (3,13).

Major problems that must yet be overcome include high temperature corrosion, and the breakdown of separators and feed-through seals. If the complex engineering problems can be resolved without the need for costly materials, then the system should be competitive with the lead/acid system. It is estimated that the resolution of these problems will take at least several years.

The lithium/tellurium tetrachloride system has a theoretical energy density of 510 Wh/lb and an open circuit potential of 3.1V. The electrolyte is a fused salt of lithium and potassium chlorides operating at 400°C. The negative electrode consists of an alloy of lithium and aluminum which remains solid at the operating temperature. Long cycle life (2000 cycles) and high current densities (2 A/cm^2) have been achieved with a screen encapsulated lithium electrode. The positive electrode is a porous, high surface area carbon polymer doped with tellurium tetrachloride (19). In addition to the corrosion and other problems, the eventual procurement of these batteries may be further aggravated by the limited availability of tellurium: total world production being only 100-200 tons/yr.

The lithium/chlorine system has a theoretical energy density of 1050 Wh/lb and a high open circuit potential of 3.46V. The electrolyte used is lithium chloride and the operational temperature is 650°C. The negative electrode is molten lithium. Chlorine gas absorbed within porous carbon constitutes the positive electrode. The major problems associated with this system are corrosion of materials by hot lithium, inefficient storage of chlorine gas, and hazards to safety due to high temperatures and use of chlorine.

Another version of this system employs a fused eutectic electrolyte of lithium chloride and potassium chloride, and operates at the lower temperature of 450°C. The negative is a solid alloy of lithium and zinc which circumvents the corrosion problems associated with the use of molten lithium. The system has good cycle life and low shelf discharge characteristics. A current density of 0.5 A/cm^2 has been achieved on discharge. An energy density of 120 Wh/lb at the two hour rate is anticipated with large batteries (11).

Other high temperature systems with theoretical energy densities around 500 Wh/lb and with open circuit potentials between 1.7 and 3.9V are also being investigated. Many common problem areas viz. corrosion of materials, dendritic growths, separators, etc., remain to be resolved before these systems, now in the laboratory stage, become commercially feasible.

SOLID STATE AND ORGANIC ELECTROLYTE SYSTEMS

The solid state systems which have been developed to date are considered "unsuitable" for propulsion applications because of their low discharge current capability, use of expensive materials, and low energy density. The principal advantages offered by these systems are long life, long storage, and ease of maintenance. At this time, it would be premature to attempt to predict their potential for submersible propulsion applications.

Most of the high energy density organic electrolyte secondary batteries being developed today use lithium as the negative electrode. The principal drawback to the use of these systems for propulsion applications is that they are inherently limited to slow charge rates, greater than 16 hours. Despite the research effort being expended on these systems to find the solutions to problems of passivation, poor electrochemical activity, and low conductivity, it is doubtful that they will ever be suitable for propulsion applications like the SDL-1.

PRIMARY SYSTEMS

In addition to the three water activated primary battery systems already described for this propulsion application namely, magnesium/silver chloride, magnesium/lead chloride, and lithium/water, other new high energy density primary systems are also being investigated. Many of these new systems use lithium electrodes, viz. lithium/polycarbon monofluoride, lithium/sulphur dioxide, lithium/cupric sulphide, and lithium/thionyl chloride.

Despite their high energy density content, it is unlikely that these primary systems will ever prove suitable as prime power sources for submersible propulsion purposes because of their low current drain capabilities. The high cost of these systems is another drawback. However, applications might include emergency power and extended range uses for submersibles.

BATTERY SELECTION CRITERIA

There are a number of criteria which are important to the evaluation and selection of new candidate battery systems for the SDL-1 submersible. As mentioned in the introduction these are, high energy density, long battery life, long shelf life, low maintenance, low cost, operational simplicity, and safety.

High energy density is considered of prime importance. For an 800 Ah battery to fit the existing battery compartment of the SDL-1 it is mandatory that the system has an energy density of at least 26 Wh/lb and 3 Wh/cu. in. It should be noted that battery systems that will require auxiliary equipment such as pumps, fans, and tanks may fail to meet the stringent energy/space requirements. In addition their need for more involved maintenance would complicate operations.

Long battery life is important in order to minimize maintenance and costly battery replacement. Long shelf life or activated stand capability is also desirable. An ideal battery should retain all of its charge during inactive periods. However, a discharge rate equal to that of the lead/acid system (1% per day) would probably be acceptable. A fast recharge capability would also be an important consideration to meet emergency situations.

Safety in submersible applications is a prime consideration. The use of molten salts and dangerous materials in batteries are hazards that must be recognized and controlled at all times. The battery should be capable of being easily maintained, handled or replaced.

The cost of the battery should be low enough to be competitive with other propulsion sources.

EVALUATION SUMMARY

Only a few of the many new high energy systems being considered at present will within the next 15 years reach a stage of development sufficiently advanced to be of interest as power sources for submersibles. It would appear that the best near term prospects, that is, for completion within the next five years (1980), would be the nickel/zinc and possibly the nickel/hydrogen systems. Limited cycle life is the main drawback of the nickel/zinc system, but optimistically this problem will be resolved.

For long term prospects, within 5-15 years (1990), there are several candidate systems that show promise of being developed into practical propulsion batteries. However, at the present time it would be most difficult to predict which, if any of these systems, will be successful. Even the most questionable system can suddenly become attractive should a technological breakthrough occur. In any event those systems which receive adequate financial support are the most likely to succeed.

The most promising of the long term systems now under development are the lithium/water and the high temperature systems such as, sodium/sulphur, lithium/sulphur, lithium/chloride and lithium/tellurium tetrachloride. Major problems that must be overcome before these systems can be seriously considered for submersible propulsion include overheating and corrosion of materials, coupled with improvements to separators and to energy densities.

The energy density projections and development prospects for the new high energy density systems are listed in Table I.

A watching brief should also be kept on systems such as zinc/bromine, zinc/chlorine hydrate, iron/oxygen and antimony redox. These may, with concentrated research, also become serious contenders for submersible propulsion applications.

TABLE I

New High Energy Density Systems:
Energy Density Projections and Development Prospects

System	Energy Density Wh/lb		Development Prospects	
	Theoretical	Projected	1980	1990
Aqueous				
Magnesium/Silver Chloride	200	30-40	poor	fair
Magnesium/Lead Chloride	165	10-30	poor	poor
Lithium/(Sea)Water	3860	>50	fair	good
Nickel/Zinc	146	>30	good	very good
Zinc/Bromine	196	>20	poor	fair
Nickel/Hydrogen	177	25-35	good	good
Zinc/Chlorine Hydrate	209	>30	poor	fair
Antimony Redox	>125	>25	poor	fair
Metal/Oxygen				
Zinc	614	140	fair	good
Iron	550	50	fair	fair
Aluminum	3718	100	poor	fair
High Temperature Systems				
Sodium/Sulphur	312	75-100	fair	good
Lithium/Sulphur	700	100	poor	good
Lithium/Tellurium Tetrachloride	510	40-60	poor	good
Lithium/Chlorine	1050	120	poor	good
Others				
Primary Systems			poor	poor
Organic Electrolyte			poor	poor
Solid State			poor	poor

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New, high energy density electrochemical systems are discussed from the point of view of meeting the forecast electrical requirements for the SDL-1 submersible in the 1980-90 time frame. Three main categories of systems are considered; namely, aqueous, metal/oxygen, and high temperature.

Since most new high energy density systems are still in the conceptual stage, with many engineering problems yet to be resolved, the technical and economic merits are reviewed mainly in general terms. The systems with the best near and long term development potential are critically examined and assessed.

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