LEAD INDUSTRIES ASSOCIATION

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NEW YORK 17, N. Y.

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SUBJECT: "THE CHOICE OF BATTERY SYSTEMS"

To Members of the Lead Industries Association:

We believe that you will be interested in the attached paper on "The Choice of Battery Systems," which was delivered at the 1961 SAE International Congress and Exposition of Automotive Engineering in January of this year. Certainly no paper on this subject could come from a more authoritative source.

Since our supply is limited, copies in quantities up to 10 may be obtained from us on request free of charge, and additional copies at 10 cents per copy.

Very truly yours,

Secretary

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Att.

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THE CHOICE OF BATTERY SYSTEMS

By

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The Choice of Battery Systems

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IT SEEMS APPROPRIATE now, just after the centennial of Gaston Planté's invention of the lead-acid accumulator, to review the battery field and evaluate the status of the lead battery, as compared to other competitive systems.

For a long time, the lead-acid battery has been the workhorse in the field of secondary batteries. The relative simplicity of the electrochemical reaction, high cell voltage, absence of criticality in physical configuration, and a generous supply in nature of rather inexpensive basic materials are all factors which have contributed to the commanding position of lead-acid batteries. Lacking this fortunate combination of good technical and economic features, other systems were relegated to a position of secondary importance, while industrial development emphasized the lead-acid work. And, contrary to the remark so often heard to the effect that the battery in your automobile today is no different than those used some 40 years ago, the facts are quite different. There has been a great improvement in the battery during this period--improvement in its electrochemical performance, in the energy-density ratio, in packaging, and in life. Most of this improvement has been the result of years of development wherein progress has been achieved by incremental improvements as opposed to any profound advance which could be attributed to research. The latter has been somewhat neglected. In general, it might be said that research in lead-acid couples has become a reality only in the post-war period. One seldom hears any reference to the electrochemical efficiency of the lead-acid battery. This is quite understandable when, after a hundred years of development, the efficiency is about one-half of what it could, and should, be. Because of the rapidly growing appreciation of the value of research, even to those items of long-standing acceptance, we fully anticipate that the advance in the technology of the lead-acid battery will be greater during the coming decade than during the past half-century.

In the last 20 years, there has been a rapid growth in portable or packaged electrical energy sources. At the same time, there has been a rapidly growing demand for portable power units, or batteries, for specialized uses. In this myriad of new uses, the criteria by which batteries formerly were evaluated have been pretty well upset. In most cases, a single characteristic is of primary importance to the successful application of the battery, other factors being made quite secondary considerations. For example, perhaps in a specialty application, the energy-weight ratio may be all-important; in another, it may be cycle life, or shelf life, or energy-volume ratio, or cost. This situation has aroused new and intensified interest in the development of new battery systems to meet these specialized requirements.

Nearly all of these "new" battery systems are not new, but merely a new look at an old item. The nickel-cadmium and nickel-iron cell constructions were patented at the beginning of the 20th century. The mercury cell owes its origin to the Aron Cell, where it was first proposed as a storage battery in 1866. The use of silver oxide as a positive active material was proposed by Jungner in 1899, and the cell was first patented by Morrison in 1910. Certain types of primary cells also have applications which are part of the traditional marketing area of lead-acid batteries. The modern fuel cell is a direct descendant of Groves' well-known gas cell, which he described first in 1839, and later as a battery of 50 cells in 1842. Rechargeable alkaline cells, in dry-cell configuration, can be traced to the work of Leclanché in the 1850's. Another new form of portable

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electrical energy of concern to us is thermoelectricity, discovered by Seebeck in 1821.

In giving the "new" battery systems a *dusting off*, it is apparent that the challenge to the lead-acid battery comes, not from a new chemistry, but from the application of modern technology to old and well-known systems. Advances in science and engineering have made possible the fabrication of battery systems characterized by high energy-weight ratios, long shelf life, long cycle life, and resistance to extraenvironmental conditions. They have also made available, in many instances, quantities of some elements and compounds at acceptable costs, materials which formerly were considered price prohibitive. Some of the new specialized applications will be best satisfied by the new battery systems. Some of them can be satisfied most economically and efficiently by lead-acid batteries.

The electrochemical systems most prominently considered today for storage battery use are lead-acid, nickel-iron, nickel-cadmium, silver-zinc, silver-cadmium, and fuel cells. The latter is electrochemically, a battery. Back in 1839, it was known as a gas battery, quite a fitting and adequate description. The fuel cell has been well publicized lately. It has a great potential, but much research work remains to be done.

In considering the choice of a battery system to best fulfill requirements of an application, many factors other than capacity must be weighed. Usually, it is a compromise of many characteristics, among which are weight, volume, availability, rechargeability, cycle life, stand life, cost, and maintenance. In Table 1 are listed values for 100 amp-hr size batteries at the 10-hr rate for some of these battery systems. It is interesting to note that the lead-acid cell has

Table 1 - Energy Densities of Common Battery Systems - 100 Amp-Hr Size

Battery Type	Voltage Per Cell: Open Circuit	Voltage Per Cell: Av. Voltage	Energy Density for 12-v Battery: No. of Cells	Energy Density for 12-v Battery: whr/lb	Energy Density for 12-v Battery: whr/in^3
Lead-Acid					
Aviation	2.1	1.9	6	13.1	1.0
Ironclad	2.1	1.9	6	13.1	1.36
Automotive	2.1	1.9	6	15.0	1.3
Nickel-Cadmium					
Pocket	1.28-1.30	1.2	10	11.0	0.6
Sintered	1.28-1.30	1.2	10	11.5	0.88
Nickel-Iron					
Tube Type	1.5	1.2	10	10.6	0.92
Silver-Zinc	1.86 On higher plateau 1.58 On lower plateau	1.55	8	85-100	3.0
Silver-Cadmium	1.40 On higher plateau 1.12 On lower plateau	1.04	11	50-75	2.5
O_2-H_2 Fuel Cell					
(Dry chemical fuel storage)		0.7	16	≈ 120	

*Based on room temperature discharges at the 10-hr rate.

one characteristic which sets it apart from those systems with which it is compared; that is, its high cell voltage. This factor offsets the higher density of the lead, and gives, in fact, a better energy-weight ratio than is found in the other "work-type" batteries -- nickel-cadmium and nickel-iron. It is also observed from Table 1 that the silver systems offer very great weight and volume advantages. However, this simple comparison is but the first approximation as to choice of battery systems for a particular application. Extended tables of the performance and economic factors for each system, under various conditions of load and temperature, would be necessary to permit logical selection of the optimum system for a specific application. Nevertheless, it is apparent that where weight and size are critical factors, and cycle life or cost are of lesser importance, the silver-zinc and silver-cadimum systems are to be preferred.

Other factors which affect the choice of a system are shown in Table 2. These factors include ease of recharge, life, and costs. When we consider life and costs, we find that the industrial-type lead-acid battery is better than the other systems on the basis of cost per unit energy output over the life of the battery. Automotive-type lead-acid batteries will have a lower initial cost than any of the systems, but because of its better cycle life, the industrial type is the more economical.

You are all familiar with the characteristic of the lead-acid battery, and know quite well what it will do, and likewise its shortcomings. Considering the lead-acid battery as a standard, what comparative features of the so-called new systems have given rise to the renewed and intensified inter-

Table 2 - Comparison of Battery Systems 100 Amp-Hr Batteries - 12 v

Battery Type		Est. Life	Est. Initial Cost	Cost Year	Cost Cycle
Lead-Acid	Constant potential recharge or stepped current recharge in 5-10 hr				
Automotive		300 cycles 3 yr	$40.	$13.	13¢
Industrial		5-10 yr 1600 cycles	$70.	$9.	4.3¢
Nickel-Cadmium	Recharge at constant potential 7-8 hr				
Pocket		10-20 yr 2000 cycles	$150.	$6.	7.5¢
Sintered	Vented cells can be recharged in 2 hr Sealed cells can be recharged in 10 hr. Require no water	10-20 yr 3000 cycles	$300.	$20.	11¢
Nickel-Iron	Charge at constant potential in 5-7 hr				
Tubular		15-20 yr 2000 cycles	$130.	$7.5	6.5¢
Silver-Zinc	Recharge at constant potential 4-20 hr	1 yr 200 cycles	$800.	$800.	400¢
Silver-Cadmium	Recharge at constant potential 4-20 hr	2-3 yr 500 cycles	$1000.	$400.	200¢

Table 3 - Estimated Battery Sales in the United States - 1959

Lead-Acid	Nickel-Cadmium Nickel-Iron
$625,000,000 Including more than 35,000,000 automotive batteries valued at approximately $400,000,000	$20,000,000 Including a large number of hermetically sealed cells of the button type
Silver-Zinc	**Primary Cells**
$16,000,000 Mostly for military purposes	$150,000,000 Comprising about 1-1/2 billion units Mostly of the Leclanché type and about 80,000,000 hearing-aid batteries (HgO/Zn) valued at $18,000,000

Table 4 - 1959 Production Figures for Battery Metals (in Short Tons)

	Lead	Nickel	Cadmium	Silver	Zinc
USA Mine Production	253,300	11,600	4,300	800	417,000
World Production	2,420,200	309,000	10,000	7900	3,071,000
USA Use	1,091,000	112,700	7000	4900	933,800
USA Use for Storage Batteries	380,700	500	100	120	25,000*
Percentage of Total USA Use	34.9	0.4	1.4	2.5	2.7
Average Price ($ per lb.)	0.122	0.74	1.40	13.30	0.115

*Including dry cell batteries.

est in these batteries? The nickel-cadmium system is, of course, no stranger, and has maintained a relatively strong competitive position for many years. It has several attractive features, among which are long cycle life, good charge acceptance, sealability, and the ability to withstand abuse. While these desirable characteristics are offset to a great extent by its cost and low energy-weight and volume ratios, nonetheless, in certain applications its advantages are such as to make it the logical choice. No practical system today can match the energy-weight and volume ratios of the silver-zinc battery. It is also characterized by excellent high rate capability and it is susceptible to ready operation in the sealed condition. High cost and short cycle life, however, preclude its widespread use, except in those very special applications, chiefly military usage, wherein weight and volume are of overriding importance. The silver-cadmium cell is, in general, similar to the silver-zinc. It is superior to the latter in cycle life, but because of a lower cell voltage, the energy-weight ratio is less.

The positions which the leading types of batteries have established in the market are shown in Table 3. Primary cells have been included in the table, in order to indicate the extent of the packaged power field covered by this general type of cell. The dividing line which differentiates between primary and secondary batteries is, indeed, a broad, gray area. Recent developments in primary batteries have produced successful rechargable cells, or secondary batteries. Likewise, certain types of activated silver-zinc batteries may be considered as primaries, while sealed secondary batteries have been produced in the past few years which are marketed in the primary battery field.

If we are to consider any of the rival systems as possible replacements for all, or even a significant part, of the lead-acid production, because of any superior electrochemical performance, then let us consider the availability of materials. Shown in Table 4 are the figures for the 1959 national and world production of metals used in batteries. From these figures may be deduced some interesting conclusions. If it is assumed, for example, that but 30% of the lead used in lead-acid batteries enters into the electrochemical reaction in the cells -- the remainder being utilized for grids, posts, connectors, and "inactive" active materials -- the amount of lead used annually in the United States for the electrochemically active component of lead-acid batteries would be 30% of 380,700, or 114,000 tons. Taking into account the difference in densities between lead and cadmium, the Faraday capacities, and the fact that cadmium is used only in the negative plates, it is determined that 31,000 tons of cadmium would be required annually for batteries to replace the lead-acid type. This requirement for batteries alone represents about three times the world's annual production, or more than seven times the annual output in the United States. Looking at it another way, it is calculated that 5 lb of cadmium would be required as replacement for the 19 lb of lead in the average automobile battery. This means a cost of about $8.50 for cadmium, compared to $2.30 for lead, for one of the basic materials alone. Similar considerations apply to nickel and silver. Battery usage is so widespread today that any system, to be widely used, must utilize only those materials which are plentiful. This is particularly true for automotive batteries which account for 90% of the lead used in batteries.

So far, we have considered the choice of only electrochemical systems which are generally considered as storage batteries. There is also a choice of other systems which, although not considered as storage batteries, are capable of fulfilling many of the same requirements for portable packaged power. These include nuclear batteries, thermoelectric cells, air or gas depolarized cells, small rechargeable alkaline cells in dry cell configuration, and the gas battery or fuel cell.

Nuclear batteries offer a great potential but the development of high-rate, high energy-density, inexpensive batteries must await the development of new knowledge. For the foreseeable future, the nuclear battery will have application as a high-potential source, but will be seriously limited in rate performance, watts per pound, and cost. Thermoelectric cells, used for the conversion of heat energy to electrical energy, are merely a new approach to an old problem. The technica[illegible] this field is still developing and currently the systems suffer from low efficiencies, low energy density, and high co[illegible].

Remarkable progress has been made in the past 10 years in the development of a practical fuel cell. Most of the reported work in fuel cells done to date involves the use of hydrogen or mixtures of hydrogen and hydrocarbon as the fuel, and oxygen as the oxidizer. While most of the interest in fuel cells is focused on their use as power-generating sources, they also have some potential when utilizing carbonaceous fuels as chemical reactors producing both power and a useful byproduct. Likewise, the fuel cell electrode system is readily adaptable to use in chemical processing. Other features of the fuel cell make it very attractive to certain military applications, ranging from submarine propulsion to auxiliary power units in space satellites, and silent power sources for ground use.

In considering the impact of a practical fuel cell on the storage battery field, one must keep in mind the fact that a fuel cell is an electrochemical battery wherein the "active materials" are stored externally to the cell, and are capable of being fed in continuously. In other words, it is a battery capable of continuous discharge for extended periods of time. Consider, therefore, that the fuel cell consists of two major components:

1. The "active materials" or fuel and oxidant.
2. The assembly of catalytic electrodes, fuel and oxidant handling systems, end product disposal system, electrical connections, electrolyte, and container. The second group of components we will term the "reactor."

Hence, regardless of the watt-hour capacity of the unit, there is a definite fixed weight and volume attributable to the reactor. This, in turn, is directly related to rate and voltage. The fuel cell is, therefore, at a decided disadvantage, weight and volume wise, when applied to uses wherein the demand for continuous power supply is of relatively short duration. A comparison of the energy-densities versus duration of continuous discharge for storage batteries, fuel cells, and solar converters, is shown in Fig. 1. From this figure, it is evident that the theoretical hydrogen-oxygen fuel cell employing fuel storage in the solid state to reduce weight will have a lower watt-hour per pound rating than will a sealed silver-zinc battery, when the duration of continuous power demand is less than 6 hours. Compared to the lead-acid battery, the cross-over point is slightly in excess of 1 hr. For the solar converter in 100% light, the values are 10 hr and 1.5 hr, respectively.

There are many possible types of fuel cells, varying in complexity, as well as efficiencies. And just as in the case of batteries, no one type will best fulfill all applications. The more complex types, in general, wi[illegible] be best suited to fixed installations, while the simpler ones [illegible]ill have more use in portable units. At the present state-of-the-art, it is extremely difficult to predict the economic factors. Yet, to gain widespread use, the fuel cell must be economically competitive with other systems. Because of the great increase in efficiency possible in such a system, we are confident that eventually, it will be not only cost competitive, but wi[illegible] significant economic advantages.

There has been a great amount of publicity relative to the fuel cell--publicity which has aroused widespread interest and excitement, and has resulted in many very extravagant claims. We think that, perhaps, the underlying reason

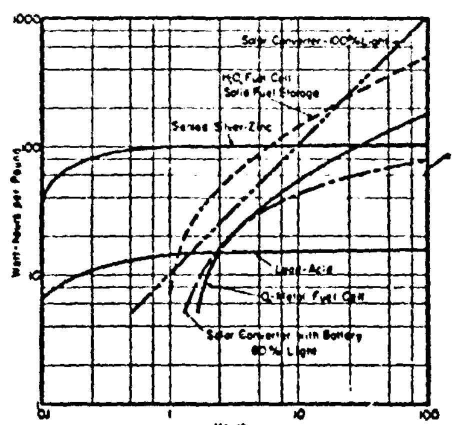

Fig. 1 - Comparison of energy-densities

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for all this may be attributed to the glamour attached to the name "fuel cell." Unfortunately, but few of the claims can be substantiated by factual data on actual performance. To evaluate the possible challenge to the storage battery posed by the fuel cell, one must keep in mind the two points which we have mentioned--that a fuel cell is just another battery, which, first, is capable of long sustained discharge periods; and second, for short periods of discharge is at a decided weight and volume disadvantage compared to the conventional-type secondary batteries. Consequently, we believe that the fuel cell, in general, will create its own markets as an extension of battery applications, rather than as a replacement.

We don't mean to imply that the fuel cell to which we have referred is just around the corner. Such a cell is a few years away, and a tremendous amount of work in research and development yet has to be done before such a system is developed to the point where it may fulfill the role we have predicted. However, in view of today's technological climate and the confidence characteristic of science and engineering, the fact that such a cell is theoretically feasible constitutes sufficient incentive to ensure eventual success.

In 1859, Gaston Planté wrote, "The secondary electromotive force obtained with lead plates in water, acidulated with sulfuric acid, was greater and persisted longer than that of other combinations." A hundred years of battery development work, on which has been built a giant industry, has failed to upset that statement. We believe that for many years to come, the lead-acid battery will continue to maintain its position in the storage battery field as the preferred auxiliary power source for automotive use.