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The builder of an on-the-road electric vehicle (EV) has no problem in selecting a battery today because he has little choice. For small vehicles he must use a lead-acid golf car battery, while for a larger vehicle he may choose the heavier but more durable industrial-type lead-acid battery. This situation is changing rapidly. The technical literature is filled with recent papers recounting advances in one battery type or another(1-8). Each new battery offers a different combination of energy density (which defines the range capability of the vehicle), power density (which relates to the acceleration capability), cycle life and cost (the battery economic parameters). To an EV manufacturer, this flood of data raises two questions; (1) how do I evaluate the various candidates for my job?, and (2) when can I expect a new battery to be ready for my vehicle? This paper will suggest answers to these questions.

For the first time in the United States there is now a comprehensive Government-supported electric vehicle battery research and development program being conducted by the Energy Research and Development Administration. This program is supporting many different candidate EV batteries. Those which are receiving the greatest support are shown on table 1. Developments are separated into three time frames: near-term (1-2 yr.), intermediate-term (3-5 yr.) and long-term (>5 yr.) For the near-term systems, an improved state-of-the-art lead-acid battery is being developed which ERDA

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believes will offer increases in all three performance parameters coupled with lower cost. These improvements will be achieved through a combination of structural and electrochemical changes designed specifically for the EV application. Significant progress in this direction was reported by Varta(8) and others at the Electric Vehicle Symposium in Dusselodorf last Fall.

The key to the improvement of the nickel-iron system lies in developing an economical iron electrode which delivers a higher energy density without sacrificing the attractive life characteristics long associated with the Edison cell.

In the intermediate term, the advanced lead-acid battery is expected to play a major battery role in the EV field. It is expected to have the same performance but lower cost than the near term version. In addition, the nickel-zinc battery which offers a substantial increase in energy density is expected to reach a cost competitive position and achieve the necessary cycle life. The problems with nickel-zinc batteries are well known; limited cycle life and high cost. Several approaches have been suggested for solving these problems including improved separators(3) and vibration of the zinc electrode to promote better plating.

The long-term thrust of the ERDA program empasizes the use of highly energetic reactants in an effort to achieve a further, large increase in energy density. One exception is the metal-air systems which are comparable to the nickel-zinc battery in performance but would require a longer development time frame. The development of a low cost air electrode is a formidable problem which may be aided by related research in the fuel cell field. Both the low temperature zinc-chlorine battery and the high (300-450^{0} C) temperature alkali metal batteries carry with them substantial problems which presently limit life and today's costs are driven by the use of special materials of construction and assembly techniques.

However, the projected performance and cost values which will result from solution of these problems are so attractive as to make a major effort worthwhile.

It must also be recognized that the ERDA battery program is not supporting only electric vehicles. Batteries for utility load leveling are also an important technical goal which influences the technical thrust of the program. Since the high energy systems are most attractive for this purpose, the distribution of funds for ERDA supported R & D presently favors the advanced systems by a ratio of about 4-to-1.

Another strong influence is the presence of private capital for research. For example, the zinc-chlorine battery is receiving significant funding from EPRI and EDA for the load-leveling application. This, coupled with what appear to be more tractable technical problems could result in the Zn-chlorine battery being ready for EV use sooner. It also appears that private funding for development of near and intermediate term batteries for EV's has increased in the past few years. When combined with ERDA support, this may accelerate the development pace of these batteries as well.

This list by no means covers all candidate batteries, nor does it even list all of those which ERDA supports. The lithium-water-air battery and low temperature organic electrolyte systems are two other approaches to reaching the long-term goals. My purpose however is not to describe all such systems, but rather to discuss what these batteries may mean to the vehicle manufacturer and purchaser.

While much emphasis is placed on battery research and development in the electric vehicle literature, it must be realized that new batteries are only useful to the extent to which they allow electric vehicles to fulfill a new role or an old one more successfully. The role for which electrics are being developed is not the same worldwide. In Europe, the emphasis is on delivery vans and buses which their developers believe represent the best opportunity for an early commercial market. This may also reflect the fact that much of the EV development work done in Europe has been financed by private industrial captial for which a near-term return on investment is desired. In Japan, a broad-based Government program(10) which has been underway since 1971 appears to place a balanced emphasis on the personal automobile, delivery truck and bus. In the United States the emphasis is clearly more heavily oriented toward the passenger cars in terms of the number of manufacturers involved, although the two largest vehicle purchases to date have involved delivery vehicles(11, 12). As in Europe, electric vehicle development in the United States has been primarily financed by private capital. One may suggest a number of reasons for the different emphasis in the U. S. For one thing, the door-to-door delivery of goods which makes an electric milk truck attractive in the United Kingdom(13) no longer exists in the U.S. Perhaps the closest thing to it is the suburban or rural mail delivery. Secondly, one-third of American families own more than one car. These second and third vehicles are frequently smaller, and have lower performance than the household's primary car. Thus a market now totalling between 25 and 30 million units exists which can theoretically be penetrated by EV's. Impacting this market can obviously have important energy conservation implications. A recent study by Stanford Research Institute(14) shows that an electric car consuming 0.72 kilowatt hours per kilometer (0.45 kWH/mi) uses less than 40 percent of the energy used by an advanced hydrocarbon-fueled car getting 48.3 kilometers per gallon (30 mpg). Thus ERDA's vehicle battery R&D efforts are oriented toward developing suitable batteries for passenger automobiles.

In order for an EV to be successful it must first be capable of performing the mission assigned to it. Thus, the energy density of a battery is the characteristic which must be used for selection since it bounds the operating envelope of the vehicle. It is also necessary, but not alone sufficient that the battery provide the vehicle acceleration desired by its owner (related to the battery power density), and that it be cost competitive with other ways to do the same job (fixed by battery cost and cycle life). ERDA has determined mathematically the relative range values for a four-passenger vehicle operating at 64 km/hr (40 mph) constant speed when utilizing the batteries presently under development(15). These values, which range from 97 kilometers

(60 miles) for a 1978 lead-acid battery powered car to 290 kilometers (180 miles) for a 1981 vehicle with a high temperature alkali metal battery are shown on table 2. It is important to note that even the maximum range shown here would restrict the vehicle to urban rather than intercity use. It may be possible to extend this range either through battery exchange or rapid charging. Both now seems to have drawbacks. The economics of battery exchange will have to be studied carefully since it requires absorbing the cost of a large inventory of batteries which must be maintained at each station, establishing a substantial urban infrastructure to support the stations, and may place a burden on material supplies because of the need for extra batteries. Rapid charging would require a network of sophisticated, high-powered charging stations since charging in periods of 15-20 minutes will require power levels approaching one megawatt. It appears then that the electric car is best suited for the role of an urban vehicle in the forsecable future. If one could determine the range requirements for an urban car, the type of battery needed could be identified.

Surprisingly little data are available on the way in which people drive their automobiles, largely due to the cost and difficulty of obtaining and testing a representative sample of the population. The most extensive survey available for the United States was conducted in 1969 by the Federal Highway Administration, and called the National Personal Transportation Study. The raw data have been analyzed and published in the form of 11 short reports released between April 1972 and December 1974. The study developed generalized distributions of auto travel which are shown on table 3. Using these data, it is easy to determine that the average daily travel by an automobile involves three to four trips totaling less than 48 kilometers (30 miles). This is no indication of the total range which must be provided because on any given day a vehicle may be used for a wide variety of both numbers and lengths of trips. The desired range is that which allows the owner to combine various trip lengths in any way he chooses each day for at least 95 percent of the days of the year. This latter requirement results from at least two marketing studies as necessary for a commercially successful vehicle(16, 17). Using a computer technique called a Monte Carlo Simulation, the author was able to synthesize randomly chosen combinations of the numbers of trips and trip lengths on a daily basis for a hypothetical year of driving(18). The number of trips per day varied from none to ten, and the distance traveled from a few kilometers to over six hundred. However, the number and length distributions for travel and total annual travel distance matched the NPTS survey results. The process was repeated day by day for 400 total years. The results are shown on Fig. 1. It can be seen that the range required to provide a car useful on 95 percent of the days of the year for all driving is 132 kilometers (82 miles). Note that this should represent a worst case or upper limit because the travel statistics upon which these results are based involve all travel including long vacation trips and makes no distinction between urban and intercity driving.

Evidence available at this time supports the belief that the intermediate-term nickel-zinc battery and others with equivalent energy density capabilities can provide this range. Several advanced electric vehicles which NASA has tested for ERDA have demonstrated ranges of 129 kilometers (80 miles) at 64 kilometers per hour (40 mph) and 64-121 kilometers (40-75 miles) on the SAE J227a Schedule B (Urban) driving cycle using conventional lead-acid traction battery technology. These values will increase significantly with the development of improved batteries and should double when the intermediate batteries become available.

The intermediate batteries have reached the point where full-scale battery tests in vehicles is possible. Several Ni-Zn and Ni-Fe vehicle batteries have been built for this purpose. NASA-Lewis Research Center designed a 300 ampere-hour vehicle battery incorporating improvements from aerospace battery research. Test batteries, shown on Fig. 2 were built by two commercial battery companies. Testing in an Otis P-500 van produced the results shown on Fig. 3. Range at constant speed increased by 90 percent while the range over the J227a

Schedule B driving cycle improved by 105 percent. In a test of the nickel-zinc battery in the Copper Electric Town Car, shown on Fig. 4, a range of 235 kilometers (146 miles) at 64 kilometers per hour (40 mph). This work is predated by an advanced battery demonstration conducted by the Electricity Council in the United Kingdom. The Council built and tested a 50 kWH sodium-sulfur battery (Fig. 5) in a Bedford Van (Fig. 6) in 1973. The battery which had an energy density of 63 wH/kg (29 wH/lb) was reportedly propelled the van for 129 km (80 miles) on a single charge. The Argonne National Laboratory will test a lithium-metal sulfide battery in a van in 1978, and will follow this with a test in a small 4-passenger vehicle in 1979.

In addition to battery development, propulsion system and vehicle engineering offer an additional way to increase range and performance. Very preliminary track test results indicate that carefully engineered vehicles have significantly greater ranges than those whose drivetrains are simply assembled from available components. It appears that increases in EV range of 50-75 percent could be achieved through propulsion component and system engineering.

There is a high probability that the ERDA battery research and development program, coupled with ERDA-supported propulsion system and vehicle R&D will produce the technology for an acceptable urban automobile within the next 3-5 years. However, technical acceptability alone will not be sufficient. The vehicle must also be producible at a reasonable cost and likewise operate at costs which are acceptable to the owner, and the battery is the key element in both cost issues. Carr(2) of Eagle-Picher has shown that among the 3 leading near and intermediate term candidates, lead-acid will yield the lowest first cost, Ni-Zn the greatest range and Ni-Fe the lowest overall cost. Analyses of these types are difficult to make and evaluate because they assume certain life and performance characteristics which are dependant on the way in which the battery is used. As a result, for a specific application the estimation of battery operating costs is less likely to lend itself to analysis than are other costs associated with a vehicle. It may in fact require at least some field experience to finally decide which is the best of the new batteries for electric vehicles for your purposes.

REFERENCES

1. Y. Breelle and C. Lombard, "Pile A Hydrogene Pour Les Applications Traction," presented at the Fourth International Electric Vehicle Symposium, Dusseldorf, Germany, Aug. 31 - Sept. 2, 1976, paper no. 32.9.
2. E. Carr, et al., "Near-Term Advanced Electric Vehicle Batteries," presented at the Fourth International Electric Vehicle Symposium, Dusseldorf, Germany, Aug. 31 - Sept. 2, 1976, paper no. 31.1.
3. A. Charkey, "Development of Large Size Nickel-Zinc Cells for Electric Vehicles," presented at the Fourth International Electric Vehicle Symposium, Dusseldorf, Germany, Aug. 31 - Sept. 2, 1976, paper no. 32.3.
4. A. A. Chilenskas, et al., "Design and Testing of Lithium/Iron Sulfide Batteries for Electric Vehicle Propulsion," presented at the Fourth International Electric Vehicle Symposium, Dusseldorf, Germany, Aug. 31 - Sept. 2, 1976, paper no. 32.2.
5. W. Fischer and W. Baukal, "The Na/S Cell as a Source of Motive Power for Electric Vehicles," presented at the Fourth International Electric Vehicle Symposium, Dusseldorf, Germany, Aug. 31 - Sept. 2, 1976, paper no. 32.6.
6. A. D. Galbraith, " The Lithium-Water-Air Battery for Automotive Propulsion," presented at the Fourth International Electric Vehicle Symposium, Dusseldorf, Germany, Aug. 31 - Sept. 2, 1976, paper no. 32.4.
7. S. Gross, "Review of Candidate Batteries for Electric Vehicles," in Energy Conversion: Volume 15 (New York: Pergamon Press, 1976), p. 95.
8. W. Vielstich, "The Development of Electrochemical Power Sources for Electric Traction," presented at the Fourth International Electric Vehicle Symposium, Dusseldorf, Germany, Aug. 31 - Sept. 2, 1976, paper no. 32.7.

9. "Proceedings of the Symposium and Workshop on Advanced Battery Research and Design," Argonne National Laboratory, report no. ANL-76-8, 1976.

10. N. P. Yao and A. R. Landgrebe, "Battery Development In Japan," Electric Vehicle News, May 1976, Page 10.

11. E. A. Campbell, "Analysis of On-Road Electric Vehicle Experience of 62 U.S. Utilities," 1976, Society of Automotive Engineers, paper no. 760074.

12. D. P. Crane and J. R. Bowman, "United States Postal Service Electric Vehicle Program," presented at the Fourth International Electric Vehicle Symposium, Dusseldorf, Germany, Aug. 31 - Sept. 2, 1976, paper no. 1.1.

13. G. E. Pearson, "EV's as Economical Milk Floats," Electric Vehicle News, August 1974.

14. E. E. Hughes, et al., "Long-Term Energy Alternatives for Automotive Propulsion - Synthetic Fuel Versus Battery/Electric System," Stanford Research Inst., report no. 5, 1976.

15. "Introduction to the ERDA Electric and Hybrid Vehicle Project," ERDA Division of Transportation Energy Conservation, Mar. 1977.

16. S. Kalish, "The Potential Market for On-The-Road Electric Vehicles," The Electric Vehicle Council/Copper Development Association, 1971.

17. G. M. Naidu, G. Tesar, and G. G. Udell, "The Electric Car - An Alternative to the Internal Combustion Engine," (Action, Massachusetts: Publ. Sci. Group, 1974).

18. H. J. Schwartz, "The Computer Simulation of Automobile Use Patterns for Defining Battery Requirements for Electric Cars," NASA TM X-71900, 1976.

TABLE 1*
POTENTIAL ELECTRIC VEHICLE BATTERIES

Batteries	Current (January 1976)				Projected			
	Energy Density W-hr/kg	Power Density W/kg (peak)	Cycle Life	Cost $/KWH	Energy Density W-hr/kg	Power Density W/hr/kg	Cycle Life	Cost $/KWH
Near-Term (1-2 Yr.)								
Lead-Acid (SOA)	30	50	700	100	50	150	>1000	60
Ni-Fe	44	110	>800	1800	60	150	>1000	120
Intermediate Term (3-5 Yr.)								
Lead-Acid (Adv.)	--	---	---	---	50	150	>1000	60
Ni-Zn	77	110	200	800	110	150	>1000	50
Long-Term (>5 Yr.)								
(Zn, Fe)/Air	80-120	40	<150	2000	90	80	>1000	60
$Zn-Cl_2$	<66	<60	<100	>2000	130	150	>1000	50
Li/MS	100	120	<250	>2000	150	300	>1000	40
Na/S	90	100	<200	>2000	170	200	>1000	40

*From Reference No. 9

TABLE 2. - RELATIVE RANGE MILES*

	1978	1980	1981
Lead/Acid	60	80	--
Nickel/Iron	70	90	--
Nickel/Zinc	80	110	--
Zinc/Chlorine	90	--	140
Lithium/Metal/Sulfide	110	--	180
Sodium/Sulphur	--	150	180
Metal/Air	70	--	110

*From Ref. No. 15

TABLE 3. - DISTRIBUTIONS OF AUTOMOBILE TRIPS

TRIP LENGTH (ONE-WAY MILES)	% OF ANNUAL TRIPS	% OF ANNUAL VEHICLE MILES
UNDER 5	54.1	11.1
5-9	19.6	13.8
10-15	13.8	18.7
16-20	4.3	9.1
21-30	4.0	11.8
31-40	1.6	6.6
41-50	.8	4.3
51-99	1.0	7.6
100 & OVER	.8	17.0
TOTAL	100.0	100.0

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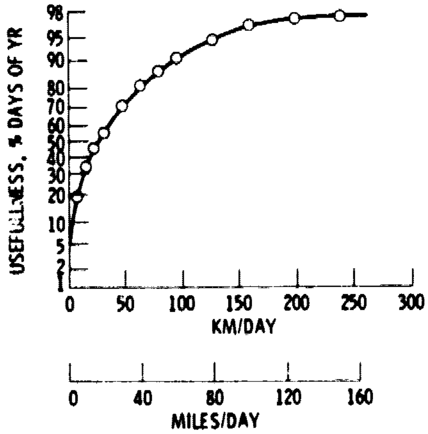

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Figure 1. - Monte Carlo simulation of automobile use patterns

Figure 2. - Nickel-zinc vehicle battery.

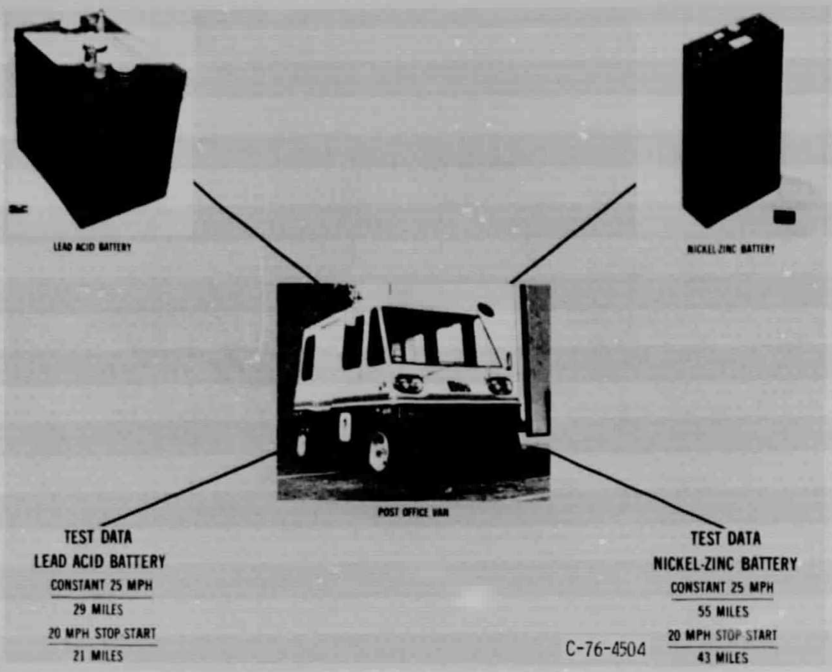

Figure 3.

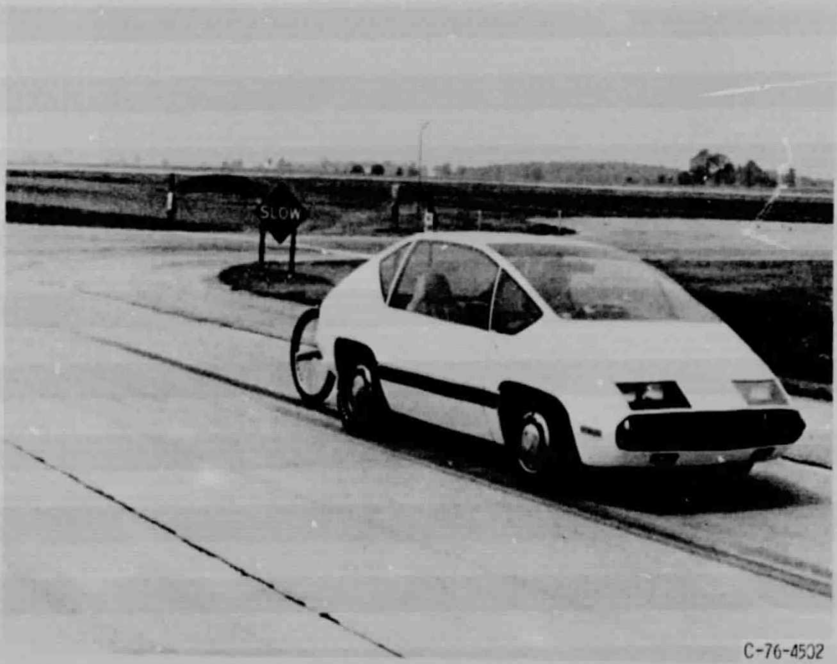

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Figure 4. - Copper electric town car.

Figure 5. - Sodium-sulfur battery modules.

Figure 6. - Na-S battery powered van.