U.S.A. EV BATTERY PROGRAMME*

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Introduction

The genesis of the U.S.A. electric vehicle programme is Public Law 94-413 (Electric and Hybrid Vehicle Research, Development and Demonstration Act) passed by Congress in 1976 and later amended by P.L. 95-238 in 1978. As implemented by the Department of Energy (DOE) through its Transportation Programme Office/Electric and Hybrid Vehicle Division, the programme contains five, mission-oriented projects; the ultimate goal of this programme is to attain the successful commercialization of electric and hybrid vehicles (EHVs). The five projects are market demonstration (MD), vehicle evaluation and improvement (VEI), electric vehicle commercialization (EVC), hybrid vehicle commercialization (HVC), and advanced vehicle development (AVD).

The overall programme strategy is based on a balance between *market pull* (MD project) to induce demand for EVHs and *technology push* (VEI, EVC, HVC, and AVD projects) to provide new products of known desirability.

The near-term battery programme, under the auspices of DOE's Electrochemical System Division, is providing direct support to the EVC project; the goal for this project is, in part, to produce electric-vehicle batteries suitable for commercialization in 1986. For the EVC project, it was established that a vehicle range of 100 miles in urban (stop-and-go) driving for a commuter car (50 miles for electric vans) is necessary for achieving this commercialization goal. Tests of state-of-art vehicles, such as the DOE/ETV-1 vehicle designed and fabricated by General Electric and Chrysler, and stationary tests of batteries with the urban driving profile (SAE J227a/D) are used to establish baseline performance data; from these data, development goals for the near-term batteries have been established. The three near-term battery candidates receiving major development emphasis are the improved lead–acid, nickel–iron, and nickel–zinc systems. This key portion of the battery R & D programme is managed for DOE by Argonne National Laboratory (ANL). Recently, the zinc–chlorine battery was added to the list of near-term candidates, and test evaluation of the battery in a vehicle is under way. This effort is managed by the Chicago Operation and Regional Office (CORO) of DOE.

The near-term EV battery project, initiated early in 1978, has an annual expenditure of about US$11 M for FY 1980 and a proposed budget of about US$12 M for FY 1981.

In addition to the near-term EV battery project, other advanced systems for EVs, utility load-levelling and solar storage are being researched. These include Na–S, Zn–Br$_2$ and Redox batteries, which are prospective storage systems, and Li–FeS$_x$ and metal–air (Zn, Fe, Li, or Al) in which the emphasis is on EV application. The U.S.A. is spending a total of US$97 M in 1980, of which US$60 M are funds from industry and US$37 M are provided by DOE. The DOE support is directed towards EVs (US$20 M), utilities (US$10 M) and solar storage (US$7 M).

DOE near-term EV battery programme

The strategy of the DOE battery R & D programme is to explore promising technical approaches which have a clear potential for meeting the DOE near-term vehicle mission requirements. The R & D for this programme is being primarily conducted by nine, private battery developers through cost-sharing contracts with the Government. The batteries fabricated by the contractors are independently tested at the National Battery Test Laboratory (NBTL) of ANL. Furthermore, support research to the industrial efforts is provided by ANL, universities, and other research-oriented organizations.

The central thrust of the battery R & D contracts is the development, design, and fabrication of full-sized cells and modules which are suitable for electric vehicles to be commercialized by 1986. The cells/modules resulting from this effort are placed under characterization testing by the contractors themselves and by ANL in NBTL, used in prototype batteries for engineering and system testing simulations, and placed in electric vehicles for engineering demonstrations to obtain needed field operating data.

The nine industrial contractors of the battery programme are pursuing common development goals for each battery system, except for the zinc–chlorine battery; each contractor is undertaking different technical approaches for achievement of these goals. Table 1 lists the industrial contractors for the four battery systems and the contracts awarded.

A contract to Yardney Electric Corp. for US$1 M over the period 07/77 - 05/79 for nickel–zinc development was terminated by mutual agreement in May 1979.

During FY 1981, DOE/ANL plans to assess each system in order to focus future resources on the most promising approaches. Later, during FY 1982, one or more of the above candidate systems will be chosen as the most suitable for commercialization.

In order to provide focus to the R & D work, a set of battery development goals specific to the DOE near-term EV mission (100 miles urban range for a commuter car) has been established. Table 2 summarizes the key battery performance and price goals for 1986.

These goals have proven to be useful as ultimate performance targets, but it has become increasingly necessary to form intermediate performance objec-

TABLE 1

DOE near-term EV battery programme

Battery	Contractor	Contract period	Contract value* (US$)
Improved lead–acid	Eltra Corp.	04/78 - 05/81	2 576 969
	Exide Management & Technology Co. (ex - ESB Technology Co.)	02/78 - 01/82	3 385 544
	Globe-Union Incorp.	03/78 - 04/81	3 042 783
Nickel–iron	Eagle-Picher Industries Inc.	03/78 - 02/81	2 074 725
	Westinghouse Electric Corp.	12/77 - 11/80	2 005 306
Nickel–zinc	Energy Research Corp.	04/79 - 03/82	1 096 634
	Exide Management & Technology Co. (ex - ESB Technology Co.)	03/78 - 02/81	3 105 764
	Gould Inc.	01/78 - 09/80	5 736 121
Zinc–chlorine	Energy Development Associates		

*Includes contractors' share.

TABLE 2

Near-term EV battery development goals[a]

Specific energy[b]	56 W h/kg
Specific power[c]	104 W/kg
Cycle life[d]	800 cycles
OEM price[e]	70 US$/kW h

[a]Based on DOE/ETV-1 vehicle with regenerative braking, 100 miles on SAE 227 a/D urban driving, acceleration of 0 - 30 mph in 8 s.
[b]At $C/3$ discharge rate.
[c]Thirty second average pulse at 50% state-of-charge.
[d]Cycles to 80% depth-of-discharge at $C/3$ rate.
[e]At a production level of 100 000 units (25 kW h)/year; in 1977 US dollars.

tives for each battery system. With intermediate objectives, battery technology progress can be more readily measured, and needed studies for vehicle/battery integration for the interim period can be performed.

Technical approaches to battery development

Lead–acid

In the lead–acid EV battery programme, there are two separate, but concurrent efforts, namely, the improved state-of-the-art (ISOA) battery and the advanced lead–acid battery. Each contractor is pursuing a different technical approach.

Exide's approach to the ISOA programme is based upon modifications of their commercially available EV-106 golf-cart battery. Factorial experiments have been carried out to optimize the key design parameters. Four

variables for the positive plate composition, two types of separator materials, two values for the electrolyte concentration, and two forms of cell construction (outside positive and outside negative) were chosen for study. In order to evaluate the 32 different variable combinations, 128 three-cell modules (6 V, 165 A h) were constructed and life-cycle tested.

Based on factorial tests, Exide has identified several combinations which resulted in battery module energy-density greater than 40 W h/kg, the goal for an ISOA battery. However, the cycle life of these modules was limited to 120 cycles when cycled to 80% depth-of-discharge. The main reasons for failure appear to be constriction of electrolyte circulation and an improper charging regime. In order to increase the cycle life, Exide started another series of factorial experiments based on tubular positive plates. This series of experiments consisted of a total of 96 modules. At this time, cycle life of these modules has exceeded 216 cycles, with tests continuing.

For advanced batteries, Exide has investigated two approaches: one used bipolar construction to increase the active material utilization, and the second reduces grid weight by using plastic composite grids. For the bipolar construction, a titanium bi-plate was used. Exide had allowed one year for exploring the feasibility of the bipolar concept. During that time, considerable progress was made. However, after considering factors such as substantially higher material cost, questionable cycle life and marginal energy density (about 20 W h/kg), their final analysis has led to the suspension of the bipolar effort. On the other hand, Exide's development of plastic composite grids looks promising. The negative grid weight has been reduced by 50% without compromising cycle life capability; negative plates incorporating plastic composite grids have achieved over 500 cycles without failure.

Exide has also sub-contracted a computer modelling study of grid design to Battelle Memorial Institute, Columbus, Ohio. The study investigated voltage drop at the conductor lug and current distribution over the plate in a cell. A more uniform current-density distribution with an optimized grid design will result in better active material utilization and thereby yield longer life for the battery. Lower voltage drops provide improved energy and power densities. Two grid designs, *i.e.*, an orthogonal concept and a radical concept, investigated by Battelle led to the following conditions: (1) cell voltage loss can be lowered by at least 50 - 80 mV for a 165 A h size cell; (2) the current-density variation over a 15.5 × 16.0 cm plate can be halved.

Globe-Union's ISOA approach has been the simultaneous optimization of cell design, materials selection, and manufacturing process definition. This optimization has resulted in the selection of a plate size, plate aspect ratio, number of plates, and an acid concentration best suited for electric vehicle application. A low-corrosion grid alloy was identified which promises longer cycle life. In addition, Globe has developed an innovative electrolyte mixing pump which has been shown to increase both energy density and cycle life.

Globe-Union's advanced lead–acid programme relies on further design refinements and a reduction of inactive material weight to achieve even

higher performance. A lead/plastic composite grid is being studied, and a method for its manufacture has been developed. Also, Globe has directed considerable resources to the practical study of the influence of ligno-sulphonate expander materials in the negative electrode. A microelectrode technique is used in the laboratory to produde cycle life data rapidly. These data, in the form of two indices ("high rate index" and "cycle life index") are correlated with comparable data obtained from full-size electrodes in an actual battery. To date, this correlation has proven to be satisfactory. As a result of this work, it has been found that distinct molecular weight fractions of the ligno-sulphonate specifically influence the initial capacity and the capacity maintenance during cycling of the negative electrode.

Eltra's approach is based upon an expanded-metal process for the fabrication of both positive and negative grids. Pb–Ca–Sn alloy (0.08 wt.% Ca) is used as the base metal. Lead–calcium alloys have lower self-discharge rates and less grid corrosion than conventional antimonial alloys. In addition, these alloys have the advantage of low water loss and the absence of poisonous gases such as stibine and arsine during charging. Eltra has optimized the grid thickness for both the positive and negative electrodes using 1.280 sp. gr. sulfuric acid as the electrolyte and is experimenting with a number of separators such as PVC, rubber, microporous polyethylene, and non-woven polypropylene. Eltra has installed a pilot-line facility for producing the expanded-metal grids and for manufacturing EV and SLI batteries at the Prestolite Division in Toledo, Ohio. The pilot-line is operational at this time.

For the advanced battery, Eltra has investigated electrode composition and processing parameters that appear to influence energy density and cycle life. A proprietary additive has been identified that can be added to the electrolyte to reduce shedding of positive active material. The use of pre-formed tetra-basic lead sulphate in the positive plate is also expected to produce a longer cycle life battery.

Nickel–iron

The two developers have common performance goals, but offer differing approaches to the technical problems.

Westinghouse is emphasizing development of a battery which has adequate performance and a low initial cost. However, this development will not compromise the promise of long cycle lives inherent in nickel–iron battery electrochemistry. Westinghouse uses sintered wool current-collectors for both the positive nickel and negative iron electrodes. The positive electrode steel wool is nickel-plated in order to avoid undesirable irreversible side reactions within the cell. The nickel hydroxide active material is impregnated into the positive electrode by either of two processes which are under parallel development, namely, electrochemical or pasted. Electrochemical impregnation (also called electroprecipitation) is at a more refined state of development at this time. During the current project, Westinghouse has improved the performance of the electrochemically-prepared positives by 10% and has reduced the manufacturing costs as well. Since the nickel positive is

generally the performance and cost limiting component in nickel–iron bat-
teries at normal temperatures, these improvements translate directly into
product improvements. However, the pasted positive electrode process,
which requires further development, offers potentially lower production
costs. Iron negative electrodes are prepared at Westinghouse by pressing an
iron oxide paste into the prepared steel wool substrate followed by sintering
at a high temperature in a reducing atmosphere.

In addition, Westinghouse has designed an active gas and electrolyte
management system for its battery that controls and minimizes the safety
hazard associated with hydrogen gas generated during charging. This system,
which features circulating electrolyte, can be either installed with the battery
on-board the vehicle, or made a part of the battery charger, depending on
the particular characteristics and mission of the vehicle. On-board electrolyte
circulation offers the potential for active battery cooling during discharge if
an associated heat exchanger for electrolyte cooling is also installed.

The Eagle-Picher nickel–iron battery features a high performance
approach using a proprietary nickel positive electrode and iron negative elec-
trodes from the Swedish National Development Company. The Eagle-Picher
positive electrode is electrochemically impregnated using a powder-metallur-
gically-prepared porous, sintered nickel plaque. Conventional plaque fabrica-
tion relies upon a continuous wet slurry method that is limited to plaques
which are less than 1 mm thick. However, the particular characteristics of
the electric vehicle application demand nickel electrodes which are 2 - 3
times this thickness. Eagle-Picher has concentrated on developing electrodes
of this thickness that can be economically produced, and have uniform, high
performance. The Swedish National iron electrode consists of a sintered iron
plaque. This plaque is manufactured using iron powder, and active material
impregnation can be accomplished simultaneously with plaque preparation.
Iron electrodes are the key element needing development to improve the low
temperature performance of the nickel–iron battery. Also, trace elements in
the iron electrode have been identified which significantly affect the perfor-
mance. Historically, a trace amount of sulphide ion has been found to have
beneficial effects. Swedish National has also identified a ribbed, sintered
PVC separator which is suitable for nickel–iron batteries. The Eagle-Picher
nickel–iron system has a noticeably improved energy efficiency — 67% *vs.* a
more typical 50% — in recent tests. This improvement is attributed to the
iron electrode being used.

Nickel–zinc

All contractors have attempted to reduce battery life-cycle costs (*i.e.*,
the amortized battery cost plus cost of operation during lifetime) while
maintaining or improving performance, but each has taken different ap-
proaches to achieve that end.

Gould is developing improved separator systems to extend cycle life.
Microporous as well as membrane-type separators have been investigated.
Microporous separators, such as Celgard (polypropylene) and inorganic/

organic composites, have been de-emphasized because they are susceptible to accumulation of zinc within the pores of the separator, which leads to cell failure. Gould has developed membrane-type separators based upon cross-linked polymeric films, which remain zinc-free, are stable in KOH, have low ionic resistivity, and are capable of low-cost production. In addition, a new synthetic wicker material has been utilized as an interseparator. A number of proprietary additives, both to the zinc electrode and to the electrolyte, have also been investigated for extending cycle life. The role of the additives is to alter the characteristics of zinc dissolution and deposition in such a way as to suppress dendrite formation and shape change in the zinc electrode. Small (5 A h) cells with such additives have operated for 250 deep cycles, whereas control cells containing no additives only operated for 60 cycles. In the area of thermal management, Gould has developed a model that accurately por-trays heat generation and rejection rates during actual battery operation. This has led both to the redesign of cells from a capacity of 400 A h to 225 A h (thinner cell) and to the redesign of modules to include cooling channels between cells in order to provide better thermal control. Gould believes that the development of advanced fabrication techniques for sintered nickel elec-trodes, coupled with their superior performance, will reduce the life-cycle costs sufficiently to make the sintered electrode as economically attractive as the non-sintered, plastic-bonded nickel electrode.

Energy Research Corporation (ERC) is emphasizing the development of a Ni–Zn battery with a low initial cost. Efforts are focused on the nickel electrode, which is the most expensive component in the battery. The tech-nical approach is based upon the development of a low-cost, plastic-bonded electrode fabricated from chemically precipitated nickel hydroxide. This electrode contains about 30% graphite as a conductive diluent in place of the conventional sintered nickel-powder plaque. The cost of the plastic-bonded electrode is projected to be half that of a comparable sintered nickel elec-trode. To achieve longer lifetimes in their Ni–Zn cells, ERC is investigating cast-film separators. Two separator materials, cross-linked polyvinyl alcohol and a thermoplastic-based composite, have been developed with low ionic resistivities and are currently undergoing life-cycle evaluation in 20 A h test cells. An additional approach to achieve the same objective is through the use of additives in the zinc electrode to reduce shape change. The development of sealed cells is also being pursued by ERC as a means to reduce mainte-nance (eliminate addition of water) and possibly to extend life. To keep hydrogen and oxygen pressures low in sealed cells, auxiliary electrodes or pocket catalysts are being employed to promote recombination of these two gases. Early results are favourable, but much additional work will be required before cell capacities, which have been found to be limited during charge by gas pressure build-up, are equal to those of standard vented cells.

Exide is pursuing a unique cell design approach based upon vibrating zinc electrodes. When the zinc electrode is vibrated during charging, the life-time limiting problems of zinc dendrite formation and electrode shape change are surmounted. Since vibration is required only during charging,

most of the added weight required for vibration could be incorporated into an off-vehicle charger. The vibrating zinc electrode also results in high utilization of negative active material. Consequently, much less zinc is required. Thus, the ratio of negative-to-positive theoretical capacity is only 1.2 for the vibrating anode cell, compared with a ratio of 2 - 4 for conventional Ni–Zn cells.

The emphasis of the present work at Exide is to increase the gravimetric and volumetric specific energy of the system, while retaining the long cycle-life capability. To this end, the following design changes are being examined in Ni–Zn cells: higher specific capacity nickel electrodes, thinner zinc electrodes, and smaller inter-electrode spacing. The nickel electrode improvements consist of replacing the pocket-type electrode (75 - 90 A h/kg) used in the past by a suitable high capacity electrode (110 - 140 A h/kg). Several types are being evaluated, including electrochemically impregnated sintered nickel (Matsushita), pasted metal wool (D.A.U.G. Mercedes), and layered nickel foil (INCO's CMG electrode). The plastic-bonded nickel electrode of Exide was found to have excessive swelling in the unrestrained structure inherent in the vibrating anode cell and was therefore removed from consideration. A reduction in thickness of the zinc electrode, at constant capacity per plate, has been made possible as a result of special charging techniques that create much denser zinc deposits on the negative substrate without the loss of high-rate discharge capability. In addition, the denser zinc deposits are more adherent; as a result, slumping of active material from the vibrating electrode has been largely eliminated. Studies are now underway to evaluate the effect of inter-electrode spacing and to determine its optimal value. A reduction in spacing from the 2.5 mm used in previous cells to 1.5 mm, if feasible, would result in a 20% improvement in volumetric energy density, concomitant with a yet to be determined increase in specific energy. Other studies are aimed at selecting a negative electrode substrate material that will reduce the present self-discharge rate of 8% loss in capacity on a five-day charged stand.

The Ni–Zn battery R & D contract with Yardney was terminated by mutual agreement on May 31, 1979 at the end of Phase I of their development programme because Yardney decided that the business risk was too great to continue further cost-sharing with DOE. The Phase I programme had focused on reducing the initial battery cost and improving component lifetime. Early in the programme, a failure-modes analysis established that the negative electrode was responsible for capacity degradation during cycling. The use of additives and binder in the zinc electrode, improvements in the separator system, and an alternative charging technique were employed to mitigate this problem. Subsequent attempts to increase cell life emphasized combining the strengths of both membrane and microporous-type separator materials. Initial efforts to reduce cost dealt primarily with the development of a plastic-bonded nickel electrode. However, the poor performance (reduced capacity at high discharge rates and low volumetric energy density per plate) led to the abandonment of this approach in favour of the sintered

electrode. The cost of the sintered electrode was reduced by fabricating a thicker, more porous plaque, as well as streamlining the manufacturing process. Collectively, these steps reduced the amount of nickel, labour, and processing required for this electrode.

Estimates have been made of material requirements for future Ni–Zn batteries. Because the Ni–Zn technology is in the development stage, considerable latitude exists in the design of batteries, creating a broad range of estimates for the type and quantity of materials required. Additives, such as cobalt, may be reduced or even eliminated by substitutes. Values given in Table 3 are based upon a battery having sintered nickel electrodes, nickel grids and tabs, a negative-to-positive theoretical capacity ratio of 2.5, and a cobalt hydroxide/nickel hydroxide ratio of 0.05.

TABLE 3

Estimated requirements of materials per Ni–Zn EV battery

Material	Requirement (kg/kW h)
Nickel	3.50
Zinc	1.90
Cobalt	0.069
Copper	0.086
KOH	3.96
Plastic	0.85

Based upon 100% utilization of positive active material and a cell voltage of 1.6, a minimum of 1.37 kg of nickel is required per kW h. However, nickel is also used in the substrate (for sintered electrodes), in grids and tabs, and for plating cell terminals and connections. Thus, the total nickel required is about 3.5 kg/kW h. If nickel-plated tabs and grids are used, the total nickel requirements can be reduced by 10%. If plastic-bonded nickel electrodes are used instead of sintered ones, the substrate can be eliminated, and although utilization may be reduced somewhat, nonetheless, total nickel requirements would be cut in half.

The theoretical minimum amount of zinc required is 0.76 kg/kW h. In order to avoid capacity decay and passivation effects, however, most zinc electrodes will contain from two-to-four times that theoretically required. The vibrating zinc electrode of Exide is an exception and is designed to contain only 20% more than theoretical. A cost breakdown of components is given in Table 4. Raw materials costs, together with the manufacturing cost of converting the raw materials into battery components, are presented.

Battery technology status

The present status of technology, because of the different initial approaches and emphasis, varies from contractor to contractor. Figure 1 shows

TABLE 4

Manufacturing cost estimate* for Ni–Zn EV battery

Component	Cost (US$/cell)		
	Materials	Conversion**	Total
Nickel electrode	16.39	10.54	26.93
Zinc electrode	6.37	3.00	9.37
Hardware	2.20	—	2.20
Separator	1.30	0.98	2.28
Electrolyte	0.46	—	0.46
Assembly	—	6.62	6.62
US$/cell	26.72	21.14	47.86
US$/kW h	32.78	25.94	58.72

*Based upon a production level of 1300 batteries per year (25 kW h, 500 A h cells).
**Manufacturing cost of converting the raw materials into battery components.

*Electric and Hybrid
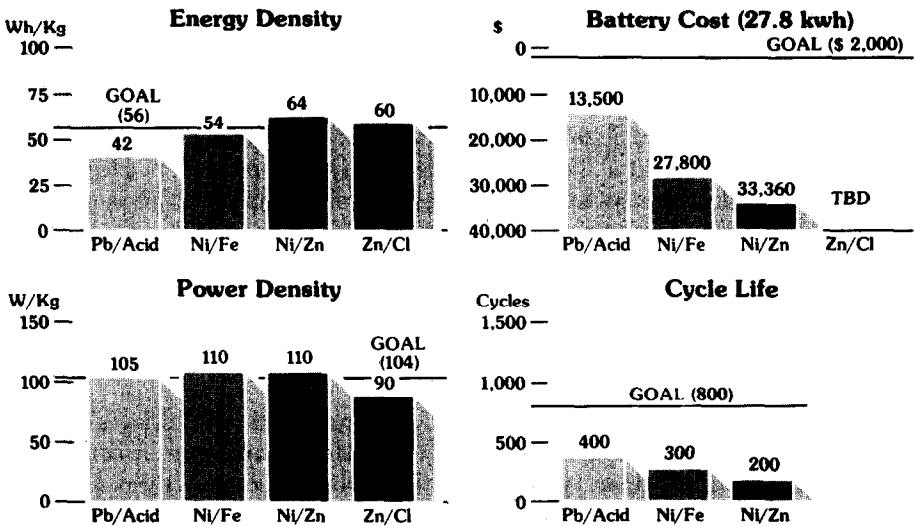Vehicle Program*   **BATTERY PERFORMANCE – 1980 STATUS**

Fig. 1. Interim status of battery performance — 1980.

the 1980 interim status of each of the four battery systems in terms of specific energy, specific power, cost, and cycle life; the 1986 goals are also shown in this Figure. Most of the battery candidates will be able to achieve performance close to the required energy and power densities; however, the achievement of cost and cycle life remains as a major effort for further devel-
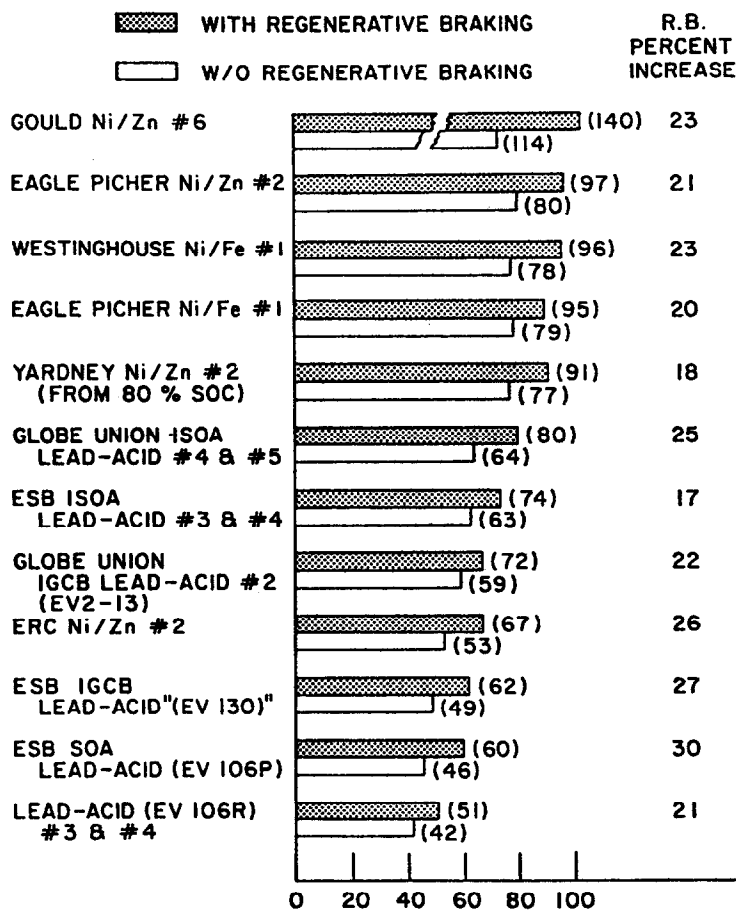
Fig. 2. Projected number of miles travelled in one complete discharge of the battery powering the ETV-1 electric vehicle performing the SAE J227a/D driving schedule.

opment. The high battery cost shown in Fig. 1 reflects the cost of a one-of-its-kind experimental battery. With mass production, the battery cost is expected to approach that of the programme goal, *viz.*, US$70/kW h. Each battery candidate has advantages and disadvantages, and a choice among them is difficult at present. In FY 1982, past progress of each battery system will be critically assessed, and the most suitable technologies for commercialization will be chosen.

In addition to the standard performance characterization test of the interim battery technology, ANL's NBTL also conducts tests based on simulated driving profiles, which simulate the conditions a battery would be subjected to in an actual vehicle. These driving simulation tests are based on the SAE J227a/D urban driving schedule as traversed by the ETV-1 electric vehicle.

Figure 2 illustrates the comparative ranges (in miles) obtained, with and without regenerative braking, from simulated driving profile tests applied to the three major battery technologies. Of the battery systems tested, the highest projected range was achieved by the Gould Ni–Zn battery: 140 miles with regenerative braking. Commercially available lead–acid battery (EV-106) exhibited the lowest projected range; *viz.*, between 51 miles and 60 miles with regenerative braking. The projected ranges for the other batteries were between these two values. The use of regenerative braking resulted in a significant range extension, about 17% - 30%. These simulation tests were performed on battery modules which generally consisted of 4 - 6 cells connected in series. Thus, the need for more expensive tests on full-size EV batteries has been largely eliminated during the interim development stages.

During FY 1979, one full-size Ni–Fe and two full-size Ni–Zn batteries were built and shipped to the Jet Propulsion Laboratory (JPL) for tests in a converted VW Rabbit (built by South Coast Technology, Inc.). The purpose of the JPL testing was to uncover any unexpected battery/vehicle interface problems associated with these new batteries and to assess their relative performances. These performance results were then compared with NBTL's tests on battery modules. The effort indicated that there were no serious battery/vehicle interface problems in terms of battery configurations, system voltage, maintenance and safety, etc.

The performance measured at JPL for each full-size battery generally correlated well with the module performance obtained at NBTL, Table 5. The Exide lead–acid battery (EV-130), which was incorporated in the VW Rabbit as delivered, represented the baseline battery and was used as a reference for performance comparison. The JPL testing has been useful in elucidating potential problems in battery/vehicle interface engineering and, more importantly, provided valuable information concerning the power and energy trade-off in battery design. Testing of a zinc–chlorine battery in a VW Rabbit has already begun, and the results will be reported in the future.

Outlook

From the inception of the Near-term EV Battery Programme of DOE in 1978, significant progress in lead–acid, nickel–iron and nickel–zinc battery technology has been made; however, achievement of technical performance goals set forth by DOE is necessary for widespread use of these battery systems in electric vehicle applications. For the lead–acid EV battery, advances have been made in the energy density, from 25 to 30 W h/kg to over 40 W h/kg, and the average peak power density, from 70 W/kg to 105 W/kg. Current emphasis is on the improvement of cycle life to 800 cycles. The prospect for obtaining a lead–acid battery having both high energy density and long cycle life in a few years is very promising. Nickel–iron modules have demonstrated a specific energy of over 50 W h/kg and a specific power of 110 W/kg. Indications are that improved performance in both of these areas

TABLE 5

Battery data from JPL tests on electric VW Rabbit (South Coast Technology, Inc.) and from tests in NBTL

Battery characteristics (108V)	Lead–acid (EV-130)	Ni–Fe	Ni–Zn	Ni–Zn
Contractor	ESB	Westinghouse	ERC	Yardney
Weight, kg	507	542	564	524
Capacity (kW h rated)	19	23	27	29
Specific energy (W h/kg)				
Module, NBTL	32[a]	48	32	46[b]
Battery, JPL	31[c]	44	40	46[b]
Range tests (JPL, miles)				
35 mph (constant)	82	120	121	126
55 mph (constant)	44	74	48	84
Variable[d]	26	48	27	49

[a]Manufacturers' data; battery modules not yet tested in NBTL.
[b]Based on manufacturer's recommended operation at 80% state-of-charge.
[c]Estimate based on test data obtained for constant vehicle speeds of 35 and 55 mph.
[d]Based on SAE J227a/D driving cycle.

can be shown during 1981. Life-times for nickel–iron modules of 300 cycles have been achieved during early 1980 and testing continues. Energy efficiency has been improved from less than 50% to over 65%. Nickel–zinc modules have shown a specific energy of nearly 70 W h/kg and a specific power of 130 W/kg. However, cycle life improvements are still needed (presently demonstrated capability of 120 - 150 cycles) and are expected to be achieved during 1981. Cost reduction (both initial and operating) continues to receive major emphasis by the developers for both nickel–zinc and nickel-iron batteries. In coming years, engineering and manufacturing process development will receive greater emphasis to improve battery lifetime and reliability and to reduce cost. Testing of the new candidate in the near-term batteries, the zinc–chlorine battery, has recently been initiated and its performance will be closely monitored.

Based on the continued technical progress expected in 1980 - 1983, it can be reasonably asserted that these near-term batteries will play a major role in future electric vehicle applications. The trade-off between cost, performance, and life of these battery systems is receiving emphasis. While it would be premature at the present time to select the best systems or specific technical approaches, the DOE management strategy is to continue supporting the development of the approaches most likely to attain the 1986 commercialization goals.