*Journal of Power Sources*, 7 (1982) 331 - 342


# JAPANESE EV BATTERY PROGRAMME*

S. TAKAHASHI
*Government Industrial Research Institute, Osaka (Japan)*

## Introduction

In Japan, the National Electric Vehicle Project was started in 1971 and closed in 1977 with an investment amounting to about 5700 M yen. During the first three years of this project, studies were carried out in parallel on components such as batteries, motors, chassis, etc. In the following three years, suitable combinations of these components were selected, and experimental electric vehicles were manufactured and tested (see Fig. 1).

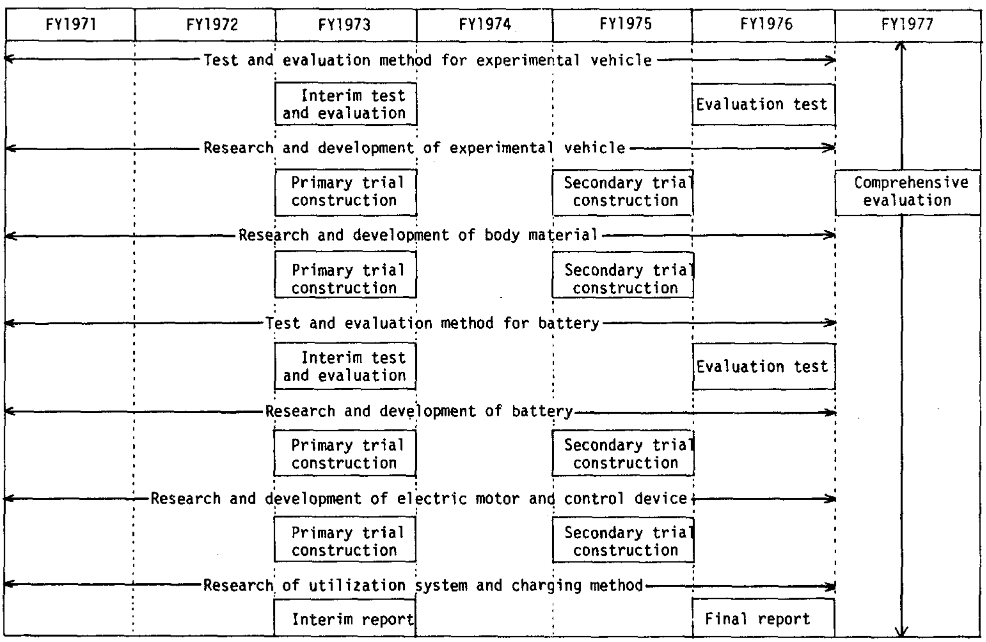


Fig. 1. Research and development status of electric vehicles.

*Paper presented at the NERDDC Workshop on Power Sources for Electric Vehicles, Adelaide, August 23 - 25, 1980.

0378-7753/82/0000-0000/$02.75

## Electric vehicles under development

Table 1 shows the five types of vehicles which were developed. They comprised a lightweight passenger car, a compact passenger car, a lightweight truck, a compact truck, and a bus. These vehicles are abbreviated to EV1 to EV5; the symbols H, N and P indicate that the vehicles were equipped with hybrid, nickel–iron and lead–acid batteries, respectively.

TABLE 1

Experimental electric vehicles under development

| Type of vehicle | | Type of installed battery |
|---|---|---|
| Lightweight passenger car | EV1H | Hybrid composed of iron–air battery and high power lead–acid battery |
| | EV1N | Nickel–iron battery |
| Compact passenger car | EV2H | Hybrid composed of zinc–air battery with stationary electrolyte and high power lead–acid battery |
| | EV2P | High performance long life lead–acid battery |
| Lightweight truck | EV3P | Lead–acid battery with mat-structure cathodes (clad type) |
| Compact truck | EV4H | Hybrid composed of zinc–air battery with circulating electrolyte and high power lead–acid battery |
| | EV4P | Lead–acid battery with mat-structure cathodes (pasted plate type) |
| Route bus | EV5 | Improved type lead–acid battery |

## EV battery development programme

*Battery types under examination*

All the metal–air batteries employed a third electrode for charging because of the difficulty in obtaining a long-life, rechargeable air electrode. Matsushita, Japan Storage, and Sanyo supplied the iron–air and zinc–air batteries installed in EV1H, EV2H, and EV4H, respectively.

The nickel–iron batteries installed in EV1N were supplied by Matsushita. They used similar nickel electrodes to those in nickel–cadmium batteries, and a sintered-type iron electrode. These electrodes were isolated by a thin, microporous resin separator. The development of manufacturing technology to reduce costs and a study to improve the charge–discharge efficiency of this battery are now in progress.

The lead–acid batteries used in the route bus EV5 were of tubular type and supplied by Yuasa. Shin-Kobe supplied the lead–acid batteries used in

EV3P and EV4P. The batteries installed in the latter vehicle were of a pasted-plate type with the positive electrodes covered in a special mat. These serve as clad-type electrodes and the production procedure is much simpler than for the normal clad-type electrodes. At the end of 1979, Shin-Kobe completed the development of these mat-structured electrodes for mass production. Shin-Kobe emphasizes two aspects that enhance the quality of the battery. One is the protection of active materials in order to increase cycle life. The other is to improve the grid by using corrosion-resistant alloys. Mass produced units have a performance of 40 - 50 W h/kg and a cycle life exceeding 1000 cycles.

## Battery performance data

Table 2 gives details of the test procedures carried out on the batteries.

TABLE 2

Battery test procedures

| Test | Procedure |
|---|---|
| Capacity test by constant current | Performed using a constant current at 5 hour rate |
| Capacity test based on a driving pattern | Performed in a modelled power or current pattern |
| Load factor test | Performed by three or four types of constant current discharge |
| Life test by constant current | Performed by a 5 hour rate constant current |
| Life test by a driving pattern | Performed by a modelled current pattern |
| Charging efficiency test | Batteries were charged using three or four types of electric charging quantity, including 100% charge, and their capacities were checked by a 5 hour rate constant current discharge |
| Self-discharge rate test | Capacities were measured fortnightly, monthly, and three months after batteries were fully charged. |
| Residual capacity indicator test | Performed along with battery capacity test and load factor test |

Energy densities obtained from the capacity and load factor tests are given in Table 3. The values in parentheses are the net values. It can be seen that the net energy density for the sodium–sulphur battery at 0.2 *C* is very low, due to the fact that a significant amount of electricity was used for battery heating. However, as the discharge current increases, the internal heat generation due to ohmic resistance increases. So, at about 0.8 *C*, the heat is balanced, and a rather high net energy density is obtained.

TABLE 3

**Energy density values obtained from capacity and load factor tests**

| Battery | Vehicle | 0.20 *C* | | 0.30 *C* | 1.00 *C* | Driving pattern |
|---|---|---|---|---|---|---|
| | | Target (W h/kg) | Result (W h/kg) | Result (W h/kg) | Result (W h/kg) | Result (W h/kg) |
| Iron–air | EV1H | Over 70 | 81.0 (79.0)* | 41.0 (40.0) | — | — |
| High power lead–acid | EV1H | 40 | 42.0 | — | 32.0 | 24.0 |
| Iron–nickel | EV1N | 60 | 82.5 | — | 62.5 | 75.0 |
| Zinc–air | EV2H | Over 80 | 131.5 (126.5) | 90.0 (85.5) | — | — |
| High power lead–acid | EV2H | Over 30 | 35.5 | — | 27.5 | 27.0 |
| Lead–acid | EV2P | 50 | 50.0 | — | 32.5 | 48.5 |
| Lead–acid | EV3P | Over 50 | 51.5 | — | 30.5 | 45.0 |
| Zinc–air | EV4H | Over 80 | 116.5 (109.0) | 78.5 (72.5) | — | — |
| High power lead–acid | EV4H | Over 40 | 46.5 | — | 34.5 | 40.5 |
| Lead–acid | EV4P | Over 50 | 51.5 | — | 29.0 | 45.5 |
| Lead–acid | EV5 | Over 40 | 42.5 | — | 25.5 | 38.0 |
| Sodium–sulfur | — | Over 80 | 90.5 (3.0) | — | 60.5**(59.0) | 72.0 (14.5) |

*The values in parentheses are practical values calculated by considering the accessories.
**Value obtained from the 0.80 *C* discharge

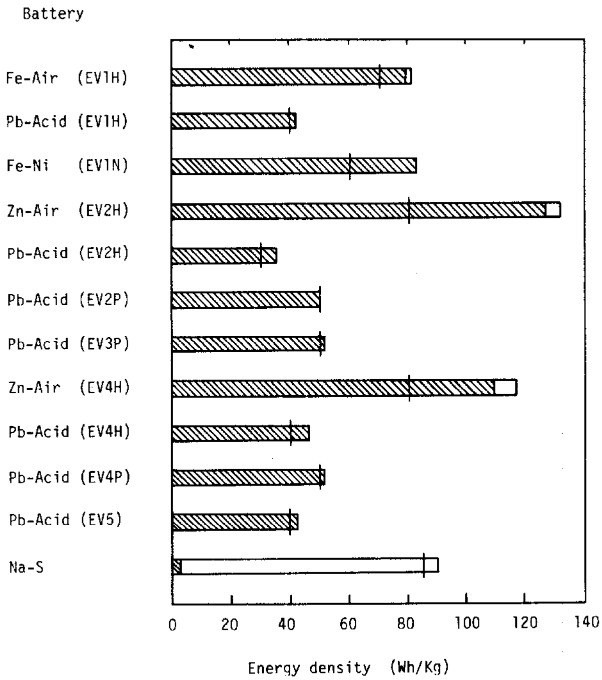


Fig. 2. Energy density obtained from capacity test using constant current.

The energy density values obtained from the capacity test using constant current are shown in Fig. 2. The hatched sections denote the net values which take into account the accessories such as blowers, pumps and heaters. The clear areas denote the apparent values while the vertical lines indicate the target values.

The discharge characteristics of the developed batteries are shown in Fig. 3. The batteries can be classified into four types according to their characteristics, *viz.*, metal–air, lead–acid, nickel–iron and sodium–sulphur batteries. Metal–air batteries provide high energy density, but their power output is low. Lead–acid batteries provide low energy density but their power output is high. Nickel–iron batteries provide high energy density and also high output. The characteristics of the sodium–sulphur battery are peculiar. This system provides a maximum energy density at 35 W/kg output and this is due to the energy loss in heating at lower power densities (*v.s.*).

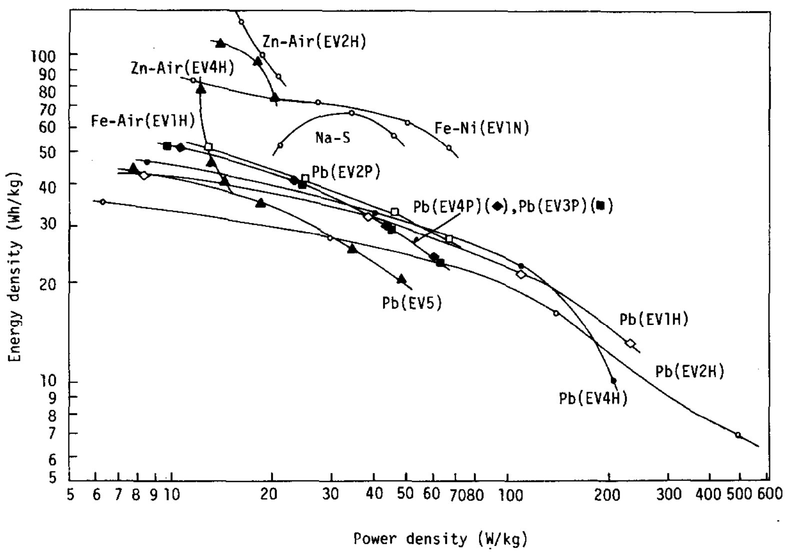


**Fig. 3. Relation between energy density and power density of batteries developed in the Japanese National EV Project. EV1H, EV1N: lightweight passenger car; EV2H, EV2P: compact passenger car; EV3: lightweight truck; EV4H, EV4P: compact truck; EV5: route bus.**

The results of the two types of life tests are shown in Table 4. One is a life test based on the 5 h rate constant current discharge and the other is based on pattern discharges. The target values were only specified for the constant current life test. All batteries, except the fixed-electrolyte-type zinc–air battery, exceeded their target values. The pattern life of the high power lead–acid battery for EV2H was about 68 000 patterns, and this corresponds to about 980 cycles.

Table 5 summarizes the charging efficiency test results. The iron–air battery gave the lowest charging efficiency followed by the zinc–air battery.

TABLE 4

Life test data

| Battery | Vehicle | Life (5-h, cycle) | | Life (pattern, cycle) |
|---|---|---|---|---|
| | | Target | Result | Result |
| Iron–air | EV1H | 200 - 300 | 352 | — |
| High power lead–acid | EV1H | 200 - 300 | 601 | 193 |
| Iron–nickel | EV1N | 1 000 | 1218 | 1031 |
| Zinc–air | EV2H | 200 - 300 | 138 | — |
| High power lead–acid | EV2H | 200 - 300 | 265 | 67 750 patterns |
| Lead–acid | EV2P | Over 500 | 522 | 334 |
| Lead–acid | EV3P | Over 500 | 701 | 679 |
| Zinc–air | EV4H | 200 - 300 | 241 | — |
| High power lead–acid | EV4H | Over 300 | 308 | 202 |
| Lead–acid | EV4P | Over 500 | 556 | 511 |
| Lead–acid | EV5 | Over 800 | 1647 | 1560 |
| Sodium–sulphur | — | 50 - 100 | 92 | 54 |

TABLE 5

Results of charging efficiency test (on the basis of W h)

| Battery | Vehicle | Charging efficiency (%) | Charge rate (%) |
|---|---|---|---|
| Iron–air | EV1H | 18.5 (18.3)* | 150 |
| High power lead–acid | EV1H | 70.0 | 125 |
| Iron–nickel | EV1N | 48.6 | 150 |
| Zinc–air | EV2H | 37.0 (31.9) | 110 |
| High power lead–acid | EV2H | 68.0 | 125 |
| Lead–acid | EV2P | 66.6 | 125 |
| Lead–acid | EV3P | 68.5 | 125 |
| Zinc–air | EV4H | 31.8 (30.9) | 125 |
| High power lead–acid | EV4H | 66.8 | 125 |
| Lead–acid | EV4P | 67.1 | 125 |
| Lead–acid | EV5 | 65.8 | 125 |
| Sodium–sulphur | — | 81.3 (0.6) | 100 |

*The values in parentheses are practical values calculated by considering the accessories.

The lead–acid battery efficiency was constant at ~ 70%, while the efficiency of the nickel–iron battery was between those for the zinc–air and the lead–acid batteries. The sodium–sulphur battery provided a remarkably high charging efficiency.

*Development of improved lead–acid battery*

The approaches that were tried for the development of improved lead–acid batteries are shown in Table 6. Adoption of thinner electrodes resulted

TABLE 6

Approaches to the development of improved lead–acid batteries

| Object | Approaches | Achievements | Resulting problems |
|---|---|---|---|
| Electrode | Adoption of thinner electrodes | High energy density and high power density | Poor life |
| | Pressurized casting of grids | Long life | Higher manufacturing cost |
| | Grid design improvement | Long life, high power density and high energy efficiency | None |
| | Atomization of active materials | High energy density | Poor life |
| | Use of lighter material for grids | High energy density | Poor life |
| Electrolyte | Use of concentrated electrolyte | High energy density | Poor life |
| | Adoption of thin separator | High power density and high energy efficiency | Poor life |
| Battery structure | Adoption of new composite materials | Life improvement | Higher manufacturing cost |
| | Adoption of bipolar electrodes | High energy and power density | Poor life |
| | Adoption of electrolyte circulation | High power density | Increased weight and volume |

in higher energy density due to the lower weight and higher utilization rate of active materials, and also higher power density due to the increased reaction area. However, life characteristics were sacrificed because of increased corrosion and lower mechanical strength. Pressurized casting gave mechanically strong grids but increased the manufacturing cost. Generally speaking, any improvements made resulted in problems in other areas.

The use of concentrated electrolyte will increase the energy density. However, as Fig. 4 shows, the life of the lead–acid battery decreases with increasing electrolyte concentration. Table 7 gives the mean weight ratio of the parts of commercial SLI batteries and those of improved high energy density lead–acid batteries. The ratios of both the electrodes and the electrolyte were much increased in the improved batteries compared with the commercial SLI batteries.

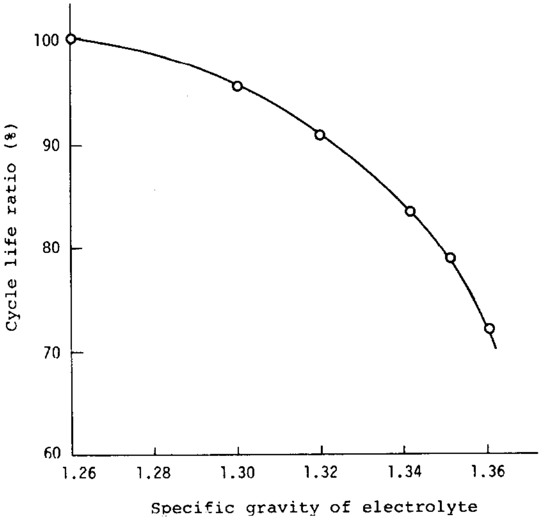


Fig. 4. Typical influence of electrolyte concentration on cycle life of lead–acid battery.

TABLE 7

Weight ratio of parts in lead–acid batteries

| | Commercial SLI batteries (%) | | High energy density batteries developed in the project (%) | |
|---|---|---|---|---|
| Negative plate | 20 | 67 | 33 - 36 | 89 - 91 |
| Positive plate | 19 | | 22 - 24 | |
| Electrolyte | 28 | | 33 - 34 | |
| Others* | 33 | | 9 - 11 | |

*Others include pole, strap, separator, case, etc.

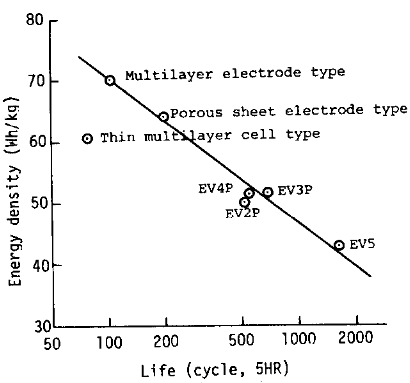


Fig. 5. Relation between life and energy density of lead–acid batteries.

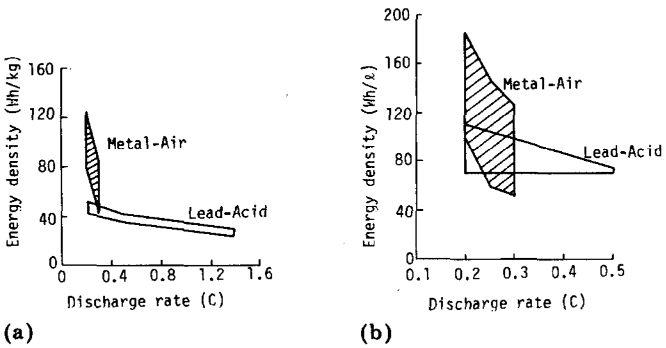


**Fig. 6. Energy density (a) W h/kg, (b) W h/l of metal–air and lead–acid batteries.**

The relation between the life and energy density of lead–acid batteries is given in Fig. 5. The upper three batteries (multilayer, porous sheet and thin multilayer types) were developed in the first stage of the project and the lower four batteries (EV4P, EV3P, EV2P and EV5) were developed in the second stage. The relation is quite linear, with only the thin multilayer cell type battery deviating from the line. This particular battery is a bipolar type, and its poor performance suggests that this design will be very difficult to develop. Figure 6 shows the relations between the discharge rate and the energy density for the metal–air and the lead–acid batteries. The advantage of metal–air batteries is high W h/kg at lower discharge rates. However, from the viewpoint of W h/l, the metal–air batteries were comparable with the lead–acid batteries.

## National Battery Energy Storage System Project

The battery energy storage system project started in Japan in November 1980. Table 8 shows the targets for this project; the candidate

TABLE 8

National Battery Energy Storage System Project

| | |
|---|---|
| Target | |
| Energy efficiency (AC-AC) | > 70% |
| Lifetime | 1500 cycles (ten years) |
| Location | Urban area |
| Cost | Competitive with hydraulic storage |
| Storage capacity | 10 - 20 MW |
| Candidate batteries | |
| Na/S, $Zn/Cl_2$, $Zn/Br_2$, REDOX, $Pb/PbO_2$ | |
| Investment | |
| 17 billion yen | |
| Period | |
| 11 years (from FY1980 to FY1990) | |

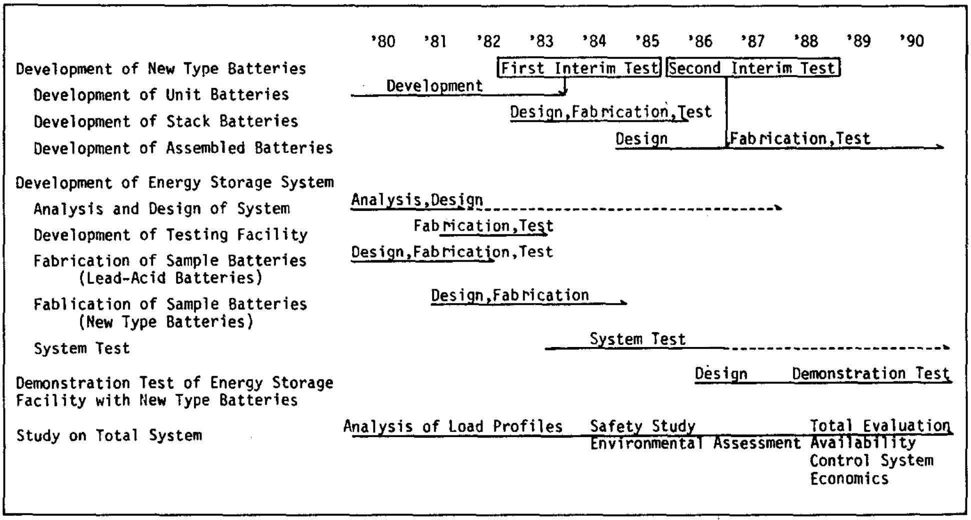


**Fig. 7. Schedule for National Battery Energy Storage System Project.**

batteries are sodium–sulphur, zinc–chlorine, zinc–bromine, redox and improved lead–acid. The total investment over eleven years is estimated at 17 billion yen. Figure 7 shows the overall schedule for the project.

## Japanese EV organizations

After the completion of the National Project, the Japanese Government provided incentives for the popularization of electric vehicles. One of the methods employed was the founding of organizations to promote research and development of electric vehicles. Three organizations, the Japan Electric Vehicle Council, the Japan Electric Vehicle Association, and the Electric Vehicle Engineering Research Association were established under the leadership of the Japanese Government. The relation between these organizations is shown in Fig. 8.

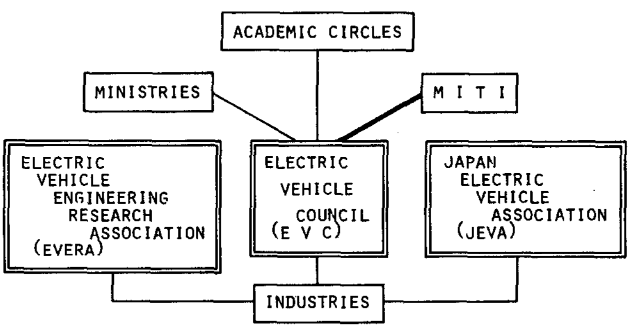


**Fig. 8. Organizations for promoting electric vehicles in Japan.**

*Japan Electric Vehicle Council (JEVC)*

The Japan Electric Vehicle Council was established in 1976. The major function of the Council is to draw up plans for the popularization of electric vehicles in Japan. Table 9 shows the long-term targets for the numbers and cost of electric vehicles for 1983 and 1986, respectively.

TABLE 9

The JEVC long-term targets for popularization of electric vehicles

| Target year | Goal of price reduction | On-the-road vehicles | Off-the-road vehicles |
|---|---|---|---|
| 1983 | Vehicle cost down 50% or more from 1976 level* | | |
| 1986 | | 200 000 | 50 000 |

*1983 price is to be set with reference to FY 1976 price level.

*Japan Electric Vehicle Association (JEVA)*

The Japan Electric Vehicle Association was established in 1976 under the auspices of the Japanese Government. The main objective of the Association is to promote the popularization of electric vehicles in Japan and many enterprises and organizations are now members. The activities covered by the Association include: (i) investigation of technologies concerning production and use; (ii) collection and analysis of data, and information, exhibitions and public relations; (iii) research and investigation concerning efficient use of electric vehicles; (iv) establishment and introduction of standards and specifications; (v) co-operation in the enforcement of the Government's policies and administrative measures.

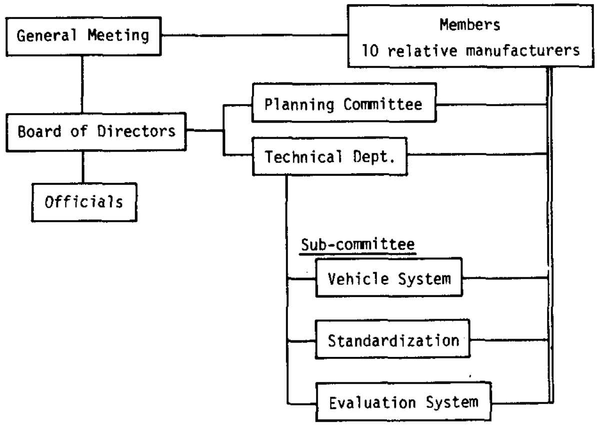


Fig. 9. Organization of the Electric Vehicle Engineering Research Association (EVERA).

*Electric Vehicle Engineering Research Association (EVERA)*

The Electric Vehicle Engineering Research Association was established under the auspices of the Japanese Government in February 1977. The general organization of EVERA is shown in Fig. 9. The objective of EVERA is the research and development of mass-producible commercial electric vehicles. The member companies of EVERA include two leading electric vehicle manufacturers, three big electric component manufacturers, and all the Japanese battery manufacturers.

EVERA's policy for the development of electric vehicles may be summarized in the following way:

(i) Concentration on developing van and pick-up vehicles that are suitable for communication, patrol, small-lot delivery and servicing in urban areas.

(ii) Use of the same chassis for both van and pick-up vehicles.

(iii) Setting up targets for vehicle performance in actual driving situations in urban areas in Japan (mileage per charge: 110 km or over, maximum speed: 70 km/h or over, acceleration: 9 s for 0 to 40 km/h).

(iv) Installation of mass-producible lead–acid batteries with a target lifetime of 600 cycles or over, and a target energy density of 48 W h/kg.

(v) Setting a target for vehicle cost of one and a half times that of equivalent i.c.e. vehicles, assuming manufacture of 1000 units per month. To lower the cost, the same chassis is used for both van and pick-up vehicle.

This Association is a time-limited organization, and the final results will be obtained in 1982. We hope for a favourable outcome, especially with regard to the overall economics.