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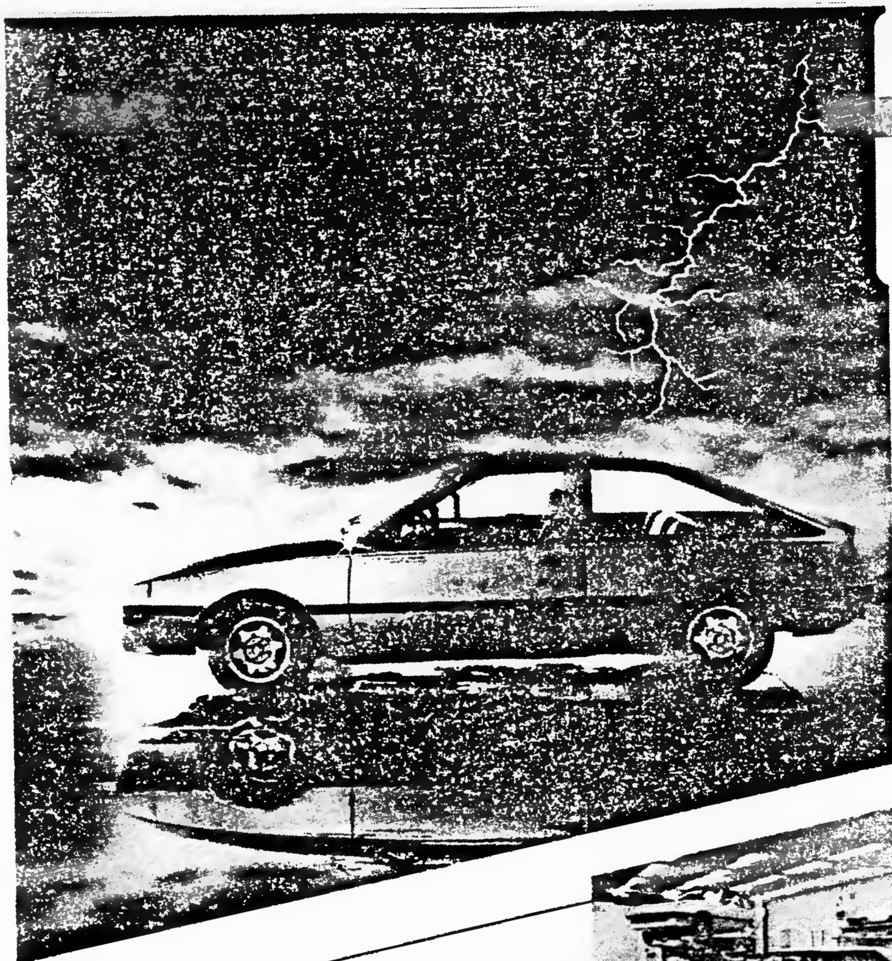
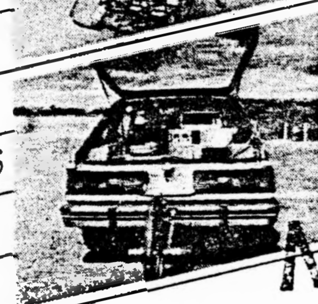


ELECTRIC AND HYBRID VEHICLES PROGRAM

11th ANNUAL REPORT TO CONGRESS FOR FISCAL YEAR 1987



U.S. DEPARTMENT OF ENERGY
ASSISTANT SECRETARY,
CONSERVATION AND
RENEWABLE ENERGY
OFFICE OF TRANSPORTATION SYSTEMS
WASHINGTON, DC 20585

MARCH 1988

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PREFACE

This eleventh annual report on the implementation of the Electric and Hybrid Vehicle Research, Development and Demonstration Act of 1976 (Public Law 94-413, as amended by Public Law 95-238, and Public Law 96-185), referred to as the Act, complies with the reporting requirements established in Section 14 of the Act. In addition to informing Congress of the progress and plans of the Department of Energy's Electric and Hybrid Vehicles Program, this report is intended to serve as a communication link between the Department and all of the public and private interests involved in making the program a success.

During FY 1987, significant progress was made toward fulfilling the intent of the Congress in the Act. There has been continuing interest shown by both the automobile manufacturing and supply sectors of our economy in electric and hybrid vehicles. The three major domestic automobile manufacturers are all devoting some effort towards electric vehicles. Their participation includes cost-shared contracts with the Department of Energy and the Electric Power Research Institute as well as independently funded activities. Research and development efforts in batteries and propulsion components continue to achieve significant progress in providing industry with technology options that will result in vehicles that will be more economically competitive and more acceptable to the public.

1. INTRODUCTION

In March 1987 the Secretary of Energy submitted a Report to the President of the United States, "Energy Security," which was a review of our energy-related national security interests. This Report stated: "Energy-efficiency improvements and the use of alternative fuels for transportation offer great potential for stemming the trend towards increasing dependence on insecure supplies of petroleum. In particular, the potential should be carefully explored for alternative fuel systems-including such possibilities as methanol, compressed natural gas, electricity, ethanol, gasoline-alcohol mixtures, synthetic oil products, and hydrogen." The Department's Electric an Hybrid Vehicles Program is conducting research, development, testing and evaluation activities to assess the use of electricity as an alternative fuel system for transportation.

The transportation sector consumed about 14% more oil than the total domestic oil production in 1987. Transportation's share of petroleum consumption has increased dramatically, as other industry sectors have found alternatives, from 51% in 1973 to almost 63% in 1987 (see Figure 1). However, the production of electricity over this same period has been relatively constant, but the fraction of electricity generated from petroleum has dropped from 17%

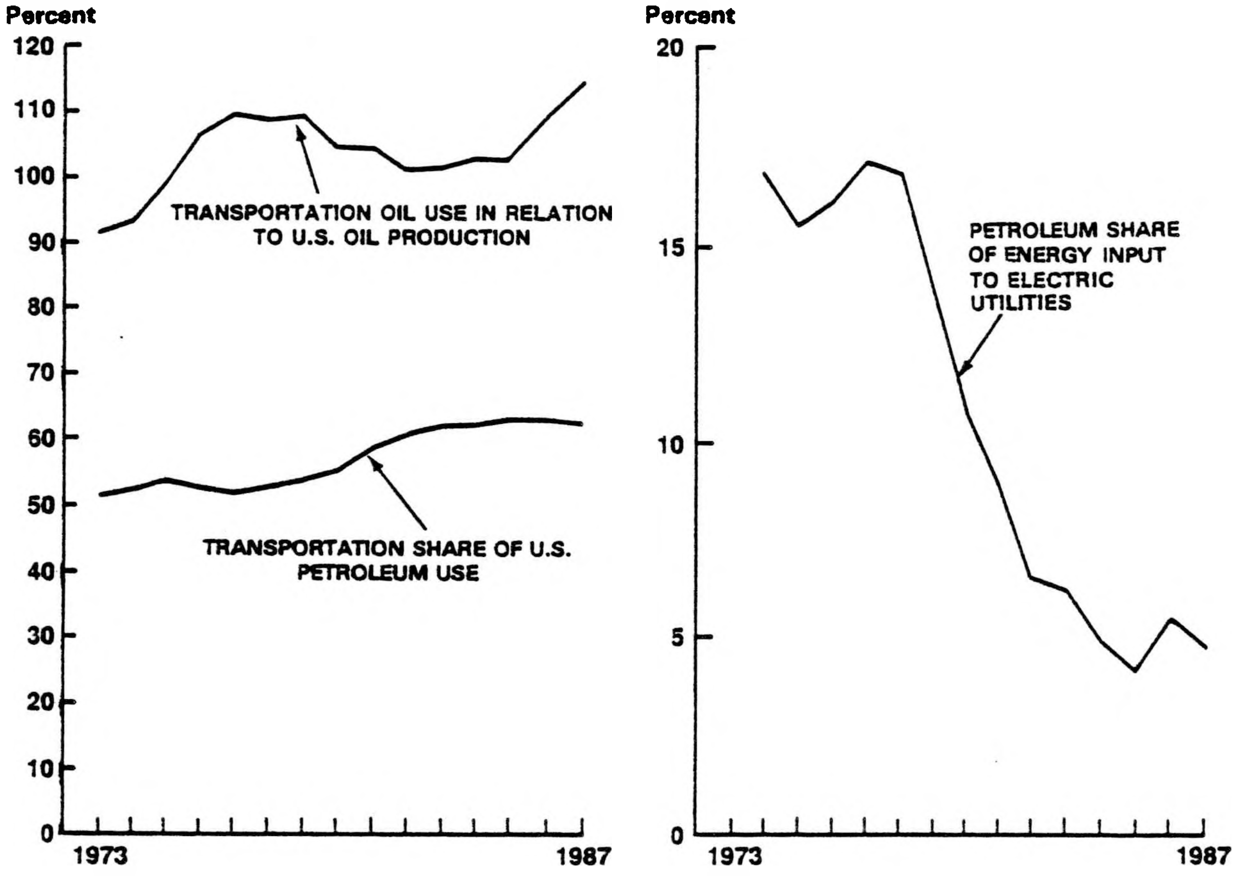

Figure 1. Transportation and Petroleum Use

in 1973 to 4.7% in 1987. Therefore, electric and hybrid vehicles present a link between low petroleum electricity generation and the large transportation sector user of petroleum. Dependence on petroleum in transportation could be reduced by shifting to other energy sources through electricity and electric and hybrid vehicles.

Cognizant of the fuel flexibility inherent in electric vehicles and having just gone through the energy crisis of 1973, Congress passed Public Law 94-413, the Electric and Hybrid Vehicle Research, Development and Demonstration Act of 1976. The Act was to "... encourage and support accelerated research into, and development of, electric and hybrid vehicle technologies. . . ." The Congress and the Administration continued to support this effort with the FY 1987 appropriation for the Electric and Hybrid Vehicles Program (EHV) of $13.275 million; the FY 1986 appropriation was $8.709 million and an additional $2.5 million was authorized to be made available from the electric vehicle loan program and other unobligated EV research funds for ETX-II.

The Act requires that an organizational entity be established to manage the Electric and Hybrid Vehicles Program. The Electric and Hybrid Propulsion Division was established within the DOE Office of Transportation Systems to conduct the assigned management responsibilities. Some supporting battery research has been

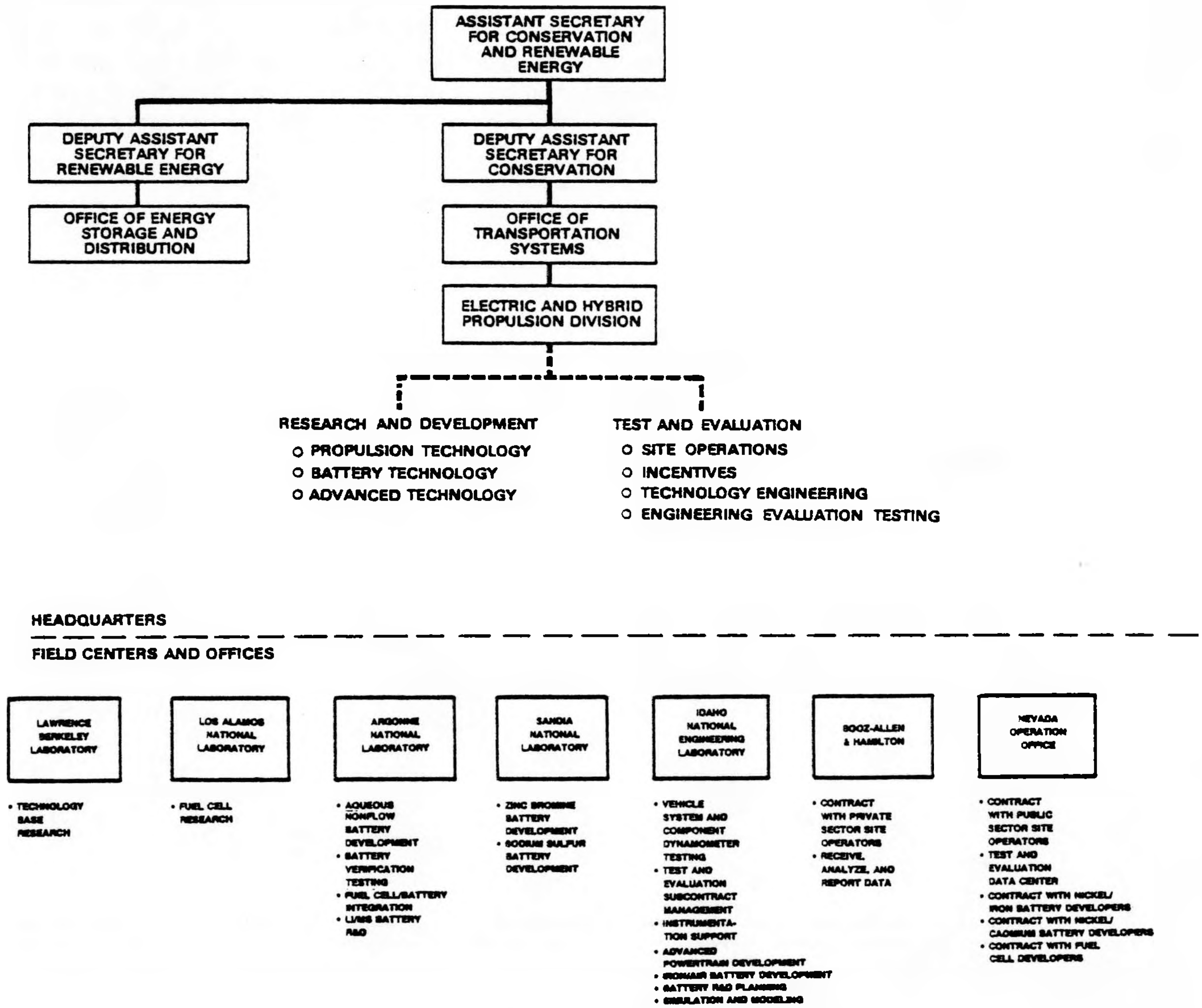

Figure 2. EHV Program Structure

Table 1

Major Participants in the Electric and Hybrid Vehicles Program

Automotive Companies	Cost Share of Contract*
Ford Motor Company	5%
Component and Propulsion System Companies	
Booz-Allen & Hamilton	13%
Eaton Corporation	5%
Energy Research Corporation	27%
General Electric	5%
Battery Companies	
Chloride Silent Power	19%
Eagle-Picher Industries	25%
Johnson Controls, Inc.	25%
Westinghouse	8%
Universities	
Georgetown University	14%
Massachusetts Institute of Technology	
University of Alabama	
Virginia Polytechnic Institute	
University of Florida	
Fleet Testing Site Operators[1]	
GTE	73%
Long Island Lighting Co.	60%
Detroit Edison	60%
Northrop Corporation	34%
Philadelphia Electric Co.	49%
Arizona Public Service	42%
University of Hawaii	38%
City of Alexandria, Virginia	50%
City of Huntsville, Alabama	57%
United States Navy	80%

[1]The variance in the cost-share percentage by site operators is due to the different activities and contractual arrangements with the site operators. The United States Navy is using its own operation and maintenance funds to operate the electric vehicles transferred at no cost by the Department of Energy from completed site operator contracts. Therefore, the cost share from the Navy is relatively high (80%).

*All contracted efforts are with fee waiver.

conducted by the Office of Energy Storage and Distribution. The current program structure and principal responsibilities of the organizational units are shown in Figure 2.

The major participants in the Electric and Hybrid Vehicles Program are listed in Table 1. They include major automotive companies, battery, component, and propulsion system companies, universities and electric vehicle users from private firms, utilities, the U.S. Navy and State and local government agencies. On Table 1 the cost sharing commitment of the participants is also given. Figure 3 is a milestone chart of major programmatic efforts completed and planned under each of the program elements.

The thrust of the Electric and Hybrid Vehicles Program in FY 1987 continued to be on battery and propulsion subsystems development up to the level of the testing and evaluation of proof-of-concept vehicles. The progress being

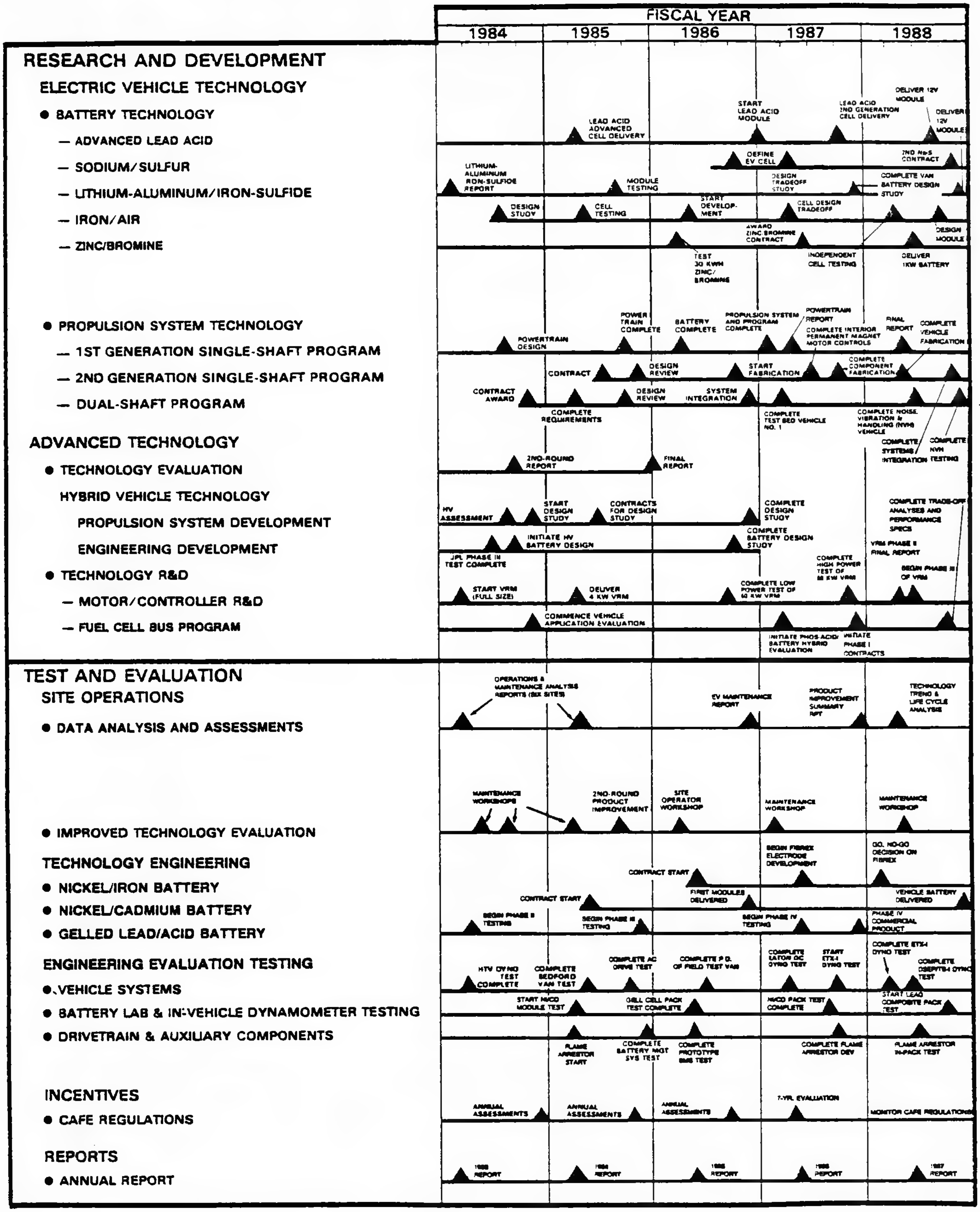

Figure 3. Milestone Chart

made in developing electric and hybrid vehicle technologies will be described beginning with highlights of recent accomplishments in FY 1987. Detailed descriptions of the program activities during FY 1987 will be given on battery and propulsion systems development and the testing and evaluation of new technology in fleet site operations and laboratory testing. In accordance with the reporting requirements of the Act, the Annual Report contains a status report on incentives and use of foreign components and concludes with a List of Publications resulting from the DOE program.

2. FY 1987 ACCOMPLISHMENTS

Significant progress occurred in each of the Electric and Hybrid Vehicles (EHV) Program areas during FY 1987. The following are highlights of those achievements.

RESEARCH AND DEVELOPMENT

- Johnson Controls, Inc. (JCI) completed the design and development of the equipment and processes necessary for the fabrication of full-size cell components specifically tailored for the flow through lead-acid battery concept. This prototype tooling now permits flow-through lead-acid cells to be fabricated in significant quantities and in a much more reliable and reproducible manner.

- Idaho National Engineering Laboratory (INEL) awarded a multi-year contract to Westinghouse Electric Corporation for the development of iron-air batteries for electric vehicle (EV) propulsion. This contract incorporates air-electrode research and development (R&D) to improve its power and life characteristics and hardware scale-up to demonstrate full-size EV battery capabilities. During FY 1987 the peak power of full-size EV prototype cells containing two 400 cm^2 air electrodes on either side of a double-faced center iron anode was increased threefold through compositional, structural, and processing refinements in the production of air electrodes. Cells with this type of power capability, projected power density of >100 W/kg for a weight-optimized cell, are scheduled for independent evaluation in early FY 1988.

- Sodium-sulfur advanced battery development for electric vehicle applications continues to make progress at Chloride Silent Power, Ltd. During FY 1987, cell and module design criteria were established and alternative conceptual designs were proposed. The contract final deliverable was redefined to be a battery specifically designed for road testing in the ETX-II experimental vehicle. The contract statement-of-work was modified to reflect this change. The battery goals, derived from the vehicle and sub-system requirements, are a specific energy of 90 Wh/kg and a specific peak power of 90 W/kg.

- Sandia National Laboratories (SNL) awarded a contract to JCI for the multi-year engineering development of zinc-bromine electric vehicle technology. The contract amount is $2.4M over three years. Under this contract, JCI has begun conducting core technology R&D that supports the development of the contract deliverable, which is a proof-of-concept electric vehicle battery.

- The JCI, zinc-bromine technical effort achieved progress on component development directed at improving materials durability, such as dimentionally stable electrodes and flow frames. A new cell stack using high density polyethylene was designed and will be evaluated early next year. Progress was made in stack sealing techniques and improving control systems. An 8-cell stack was delivered to SNL for evaluation. It is currently meeting design goals.

- A 36-V lithium/metal sulfide battery was constructed by Argonne National Labo-

ratory (ANL) and Gould, Inc. and tested at ANL under simulated electric van operation conditions. The Li-alloy/FeS battery delivered twice the normal range of the van with a battery one-half the weight of lead-acid, it is designed to replace. The improved, low-cost, high-temperature vacuum insulation developed for the battery operated successfully in this 7.5 kWh test, with a heat loss of less than 200 W expected from a full-size battery.

- In Phase I of the Fuel Cell/Battery Powered Bus Systems Program, two-year, cost-shared contracts were awarded for the system design and integration of phosphoric acid fuel cell/battery hybrid propulsion systems. Energy Research Corporation will examine an air-cooled phosphoric acid fuel cell system, while a R&D team consisting of Booz-Allen & Hamilton, Chrysler, and Engelhard will examine a liquid-cooled phosphoric acid fuel cell system. In Phase I each contractor will demonstrate the proof-of-feasibility by assembling and evaluating a 30 kW brassboard propulsion system.
- In support of the EV battery R&D activities, laboratory tests were conducted at ANL to evaluate the ability of advanced battery systems to perform the mission requirements of electric vehicles. Simulated vehicle operations including the Federal Urban Driving Schedule and other driving profiles were conducted on full-size nickel-iron, zinc-bromine, sodium-sulfur, and lithium/iron-sulfide battery systems. Developmental hardware from flow-through lead-acid, nickel-iron, and nickel-cadmium battery R&D programs were also evaluated. The evaluation results provided a measure of the success of the battery development efforts and provided insights into the direction the research programs should take.
- The DOE Task Force completed its review of EV battery R&D goals and finalized the Battery R&D Goals Report. Comments received from the EV and battery industry were incorporated into the final version of the report. The new set of goals, which are based more on real-world conditions than previous goals, will provide better bases for industry to make quality decisions for future technologies.
- The development effort on the first test-bed vehicle (TB-1) for the Dual-Shaft Advanced A.C. Propulsion System Program (DSEP), including the integration of nickel-iron batteries, was completed and testing was initiated.
- All designs and fabrication of the major subsystems of the Single-Shaft Advanced A.C. Propulsion Technology Program (ETX-II) were completed. This advanced propulsion system utilizes new materials in an interior permanent magnet motor. Putting the propulsion system in an unsprung rear-axle environment for the first time contributes to its producibility and reduction in costs.
- A peer group panel composed of industry, laboratory and government personnel reviewed the EHV propulsion technology research and development effort. The mission of the panel was twofold: (1) to conduct an objective, independent assessment of the DSEP and ETX-II programs; and (2) to assess the contribution of these two programs to the overall Electric and Hybrid Vehicles Program. Basic conclusions were positive towards the program effort and recommendations (as described on page 33) were made for program improvement.
- INEL awarded an 18-month contract to Sheladia Associates, Inc., to assist in the development of a multi-year EV power source R&D program plan. Sheladia's team of ten power source and EV consultants are working, together with representatives from six National Laboratories, to conduct a mission-directed power source assessment for the IDSEP van. Results from the assessment will be used to develop a five-year R&D program plan for DOE's sponsorship of selective power source technologies.

TEST AND EVALUATION

- Johnson Controls Inc., under contract to INEL, developed flame attenuation hardware capable of inhibiting or mitigating the force of a hydrogen ignition in either nickel-iron or lead-acid batteries. Independent testing of this capability was started at INEL.
- A commercially developed sealed lead-acid battery from the Concorde Battery Corporation successfully completed the standard battery capacity test cycles in the INEL battery laboratory. A complete battery pack delivered 119 ampere-hours at the 3-hour discharge rate with a specific energy of 25 Wh/kg.
- The University of Alabama completed the development of a uniform module charging algorithm and installed it in a vehicle to determine how well it adapts to battery needs as the battery ages and what effect it has on vehicle range-reliability with battery age. This testing is being done in a vehicle that incorporates Phase IV Gel/Cell lead-acid batteries.
- The government-industry cost-shared Gel/Cell battery program was completed. It resulted in a family of semi-industrial battery models that have been modified to accommodate traction applications: a 6V-200 (6 volt 200 ampere hour), a 12V-100 (12 volt 100 ampere hour), and a 2V-600 (2 volt 600 ampere hour), model. The 6V-200 and 12V-100 models are inventoried as commercial products by the Industrial Products Unit of Johnson Controls, Milwaukee, Wisconsin; but the 2V-600 is a special order item. The program stimulated a joint venture between Exide and Sonnenschein to build an industrial tubular gelled battery for railroad signal applications.
- Phase III Gel/Cell batteries were field tested in sedans and pickups at 10 sites across the country. Most of the test programs have been completed and the overall conclusion by the sites has been that, in general, the Phase III Gel/Cell reduced the cost of operation and improved cold weather performance over the conventional, flooded, lead-acid battery. However, there has been a slight sacrifice in vehicle acceleration, range and battery life.
- Testing of Johnson Controls, Inc., Phase IV and Concorde Gel/Cell batteries commenced at Detroit Edison Company (DECO) and U.S. Navy sites, respectively. These batteries provide improvements in stored energy and reduced cost of manufacturing over previous Gel/Cell versions. However, cycle life is still to be determined.
- A microprocessor controlled "smart" charger that provides temperature compensation has been used in conjunction with the Phase III Gel/Cells at various sites. DECO reported that during the sixteen month test period, the chargers warned operators immediately of abnormal conditions, such as unequalized charging and inability to achieve the prescribed voltage limit in a given time period. Through these warnings it is believed that the charger prevented serious damage to the traction battery.
- Six General Motors Griffon vans have been tested in commercial fleet service by DECO. During the test period, which started in December 1984 and ended in March 1987, over 90,000 km were driven and approximately 1900 charge cycles were accumulated on the Lucas Chloride tubular lead-acid batteries.
- The Alber Battery Capacity Tester has proven effective at DECO, Navy sites and GTE in isolating weak or bad modules and bad interconnections in battery systems.
- Eagle-Picher introduced National Standard's Fibrex® nickel material into the nickel electrode of their nickel-iron battery technology with improved performance and with a high potential for a 15% cost reduction in material. The development of a thicker sintered-powder nickel electrode has increased the available ca-

pacity by 30% over a battery module of the same size and weight in 1986.

- Arizona Public Service Company (APSC) tested improved battery interconnectors and thermal measuring devices which reduce the chances of a battery explosion. The improved battery interconnectors have completed one year's operation without major operating problems. The thermal measuring devices are standard infrared sensing equipment, which detect excessive battery compartment temperatures, and permits thermal mapping which can help to identify defective cells.
- New dc/dc converters by Eaton and Soleq were tested at DECO and LILCO. These converters with higher 12V current outputs alleviate the winter load problem. At DECO, three Eaton prototype dc/dc converters and three production Soleq converters were installed in VW Rabbits, whereas LILCO evaluated four Soleq dc/dc converters in Eagle-Picher Escorts. Minor problems have been encountered with the Eaton converters but the Soleq converters have been operating without problems since November 1986.
- Evaluation of two South Coast Technology (SCT) Rabbits with improved nickel-zinc battery systems was completed at DECO. The system demonstrated good driving performance, good operation in cold weather, low water consumption and good energy efficiency. However, the short cycle life of current technology nickel-zinc batteries is considered a major barrier to its widespread use in transportation applications.
- Transistorized controllers have been successfully substituted for the older SCR controllers in vehicles operated by GTE and LILCO. The operation and reliability of these new controllers has proven so effective that the fleet managers want to replace all the controllers in the fleet with the transistorized version.
- An analysis of the effects of field variables, such as vehicle use patterns, driving conditions and driver techniques on the life expectancy of commercial, lead-acid batteries, was completed. It was found that manufacturing batch variation is a major cause of differences in field service life expectancy. It was further noted that a trip length, which resulted in discharging the battery pack to half its rated capacity, was found to maximize battery life.

3. RESEARCH AND DEVELOPMENT

Research and Development activities (R&D) are assigned to two areas: Electric Vehicle Technology (including Battery Technology and Propulsion System Technology) and Advanced Technology (including Hybrid Vehicle Evaluation, Component Development, and Fuel Cell/Battery Powered Bus System Development). The activities conducted in FY 1987 within each of these R&D elements are described below.

ELECTRIC VEHICLE TECHNOLOGY

Battery Technology

The objective of the Battery Technology Research and Development Activity is to advance promising battery technologies to levels of maturity that will allow industry to make quality decisions regarding their potential viability as foundation technologies for commercial product development. To this end the DOE conducted research and development on flow thru lead-acid, lithium aluminum-iron sulfide, iron-air, sodium-sulfur, and zinc-bromine battery technologies during FY 1987. Major R&D contracts have been awarded to industrial developers of these batteries for electric propulsion. Each of these contracts will culminate with the fabrication and delivery of full-size battery systems for evaluation and testing in electric vans. The chart in Figure 4 provides the current status of these electric vehicle battery technologies. Figure 5 shows a photograph of each of the various battery candidates currently under development for the Electric and Hybrid Vehicles Program.

Flow Thru Lead-Acid Battery

R&D activity for the flow thru lead-acid battery is managed for DOE by Argonne National Laboratory (ANL). This activity includes battery technology R&D, experimental evaluation of development hardware, and battery application studies and assessments.

Johnsons Controls, Inc., (JCI) continued the development of an advanced lead-acid battery under a four-year $3.3 million contract which was initiated in December 1985. JCI, the world's largest manufacturer of automotive batteries, also provides a 25% cost-share of the contract costs. The objective of the R&D effort is to improve the performance and life of lead-acid batteries to meet the mission requirements of electric vans. The work is based on an innovative concept whereby the forced flow of electrolyte through the porous lead and lead dioxide electrodes is employed to achieve a dramatic increase (85%) in the utilization of these materials. During FY 1987, JCI completed the design of equipment and techniques for the fabrication of full-size cell components specifically tailored for the flow-through concept, including redesigned grids and the development of processes for molding polypropylene frames around each electrode. This prototype tooling has permitted developmental cells to be fabricated in significant quantities in a more reproducible and reliable manner. In addition, progress was also attained in extending the cell lifetimes by 100%. The hand-fabricated cell constructed during FY 1986 had a life of only about 20-50 cycles; the new cells constructed with prototype tooling during FY 1987 routinely achieved 80-100 deep discharge cycles in tests conducted at JCI and at ANL.

Lithium Aluminum-Iron Sulfide Battery

ANL continued its leadership role in the development of the lithium/metal-sulfide battery under programs co-sponsored by the DOE, the Electric Power Research Institute, and the Ten-

Electric Vehicle Battery R&D Technology Status

Battery	Developer	Designation	Status*	Specific Energy (Wh/kg)	Specific Peak Power at 50% DoD (W/kg)	Projected OEM Cost (1987 $/kWh)	Cycle Life (Cycles to 80% DoD)**	Cost/Cycle/kWh (1987 $)
Flow-Thru Lead-Acid (Pb/A)	JCI		C	47	104		> 80	
			BG	56	79	72	450	0.16
Zinc/Bromine (Zn/Br_2)	JCI	Z30	B	55	88		> 35***	
			BG	75	79	75	600	0.12
Lithium Aluminum/ Iron Sulfide (Li Al/FeS)	ANL/Gould	9 Cells 12V	M	100	90		> 150	
			BG	100	106	91	600	0.15
Sodium/Sulfur (Na/S)	CSPL	PB (10.0 Ah)	C	166	210		> 1000	
			BG	100	106	91	600	0.15
Iron/Air (Fe/Air)	Westinghouse		C	70	50		> 120	
			BG	100	106	91	600	0.15

*Status: C, Cells; M, Modules; B, Battery
**Depth of Discharge.
***Current R&D Core Program is Aimed at Improving Cycle Life While Maintaining Specific Energy & Power.
BG: Mission Directed Goals for EV Battery R&D Based on IDSEP Van and Tested Under Simplified Federal Urban Driving Schedule (SFUDS).

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Figure 4. EV Battery R&D Technology Status

nessee Valley Authority. During FY 1987, a 36-V, 7.5-kWh Li-alloy/FeS battery was constructed, which successfully met the energy and power requirements needed in an electric van simulation in a test at ANL. The test showed that the Li-alloy/FeS battery could more than double the normal range of the van with a battery that weighed one-half as much as the lead-acid battery it is designed to replace. In addition, an improved low-cost, high-temperature, vacuum-insulation enclosure was developed for the battery which minimized the heat loss expected for a full-size battery to less than 200 W.

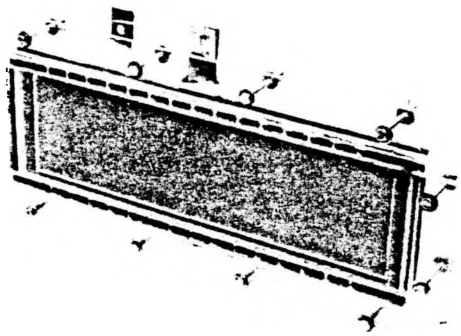
Iron-Air Battery

Idaho National Engineering Laboratory (INEL) manages and administers the engineering development of iron-air batteries at Westinghouse Electric Corporation. A multi-year, $5.5 million cost-shared (8%) contract was awarded to Westinghouse in January 1987. It emphasizes air-electrode development and hardware scale-up to a full-size battery for evaluation in an electric van. With the increases being sought in air-electrode power and cycle life, iron-air cells could achieve the desired performance and operating characteristics for an EV power source. During FY 1987 the compositional, structural, and processing refinements achieved in the fabrication of 400 cm^2 bifunctional air electrodes led to a threefold increase in the peak power deliverable from full-size EV cells >100 W/kg projected power density for a weight-optimized cell. Experimental cells of this type are being built for independent evaluation.

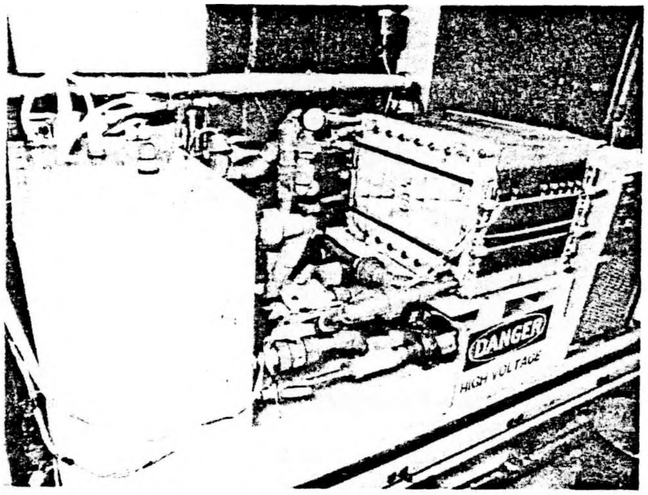
Sodium-Sulfur Battery

In September of 1986, Sandia National Laboratories (SNL) initiated a 19% cost-shared contract with Chloride Silent Power, Ltd., (CSPL) to conduct the core technology R&D and engineering development of the sodium-sulfur technology. SNL is responsible for material research, component evaluation, and environmental testing, including technical direction of the development contract. The three-year, $1.5M ef-

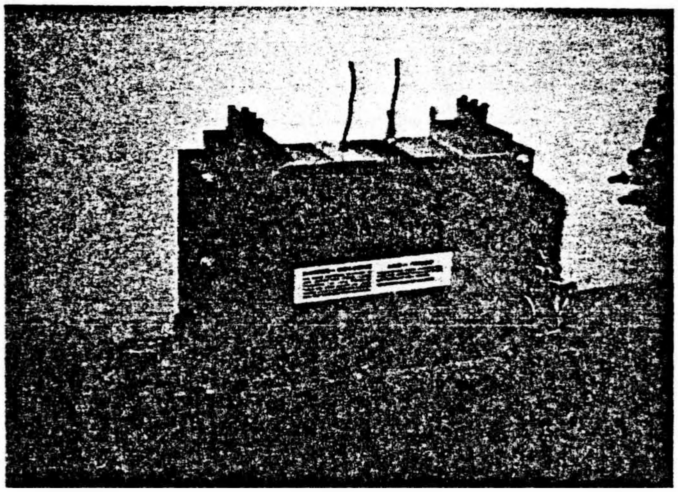
Figure 5. EV Battery Candidates



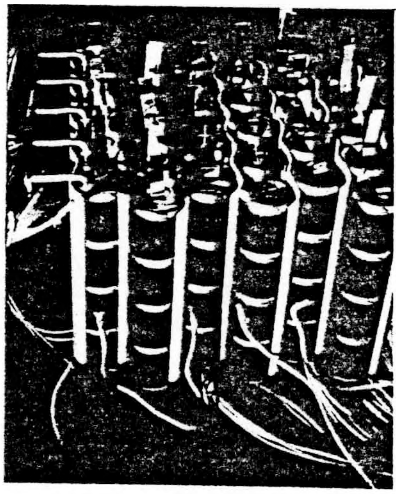
Iron-Air



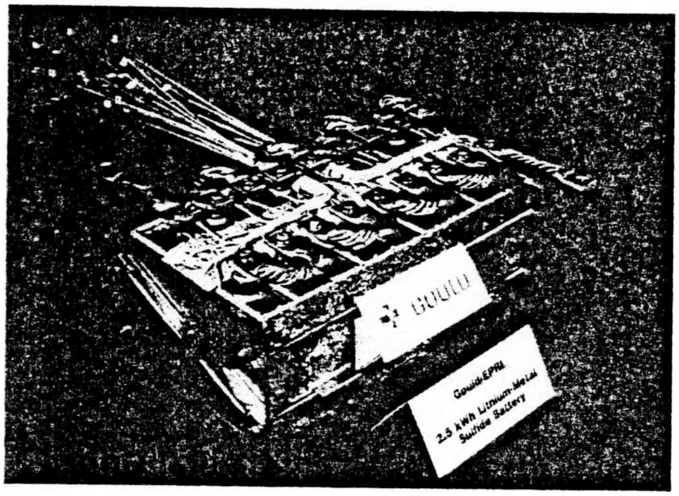
Zinc-Bromine



Flow Thru Lead-Acid



Sodium-Sulfur



Lithium Aluminum Iron-Sulfide

fort is aimed at the development and evaluation of low-cost, long-life cells and proof-of-concept batteries that demonstrate high specific energy and high specific power for electric vehicle applications. During FY 1987, CSPL established cell and module design criteria, proposed alternative conceptual designs, adopted the ETX-II application for establishing the contract deliverable battery goals, and performed preliminary systems development of thermal controls and cell interconnection strategies.

Zinc-Bromine Battery

Sandia initiated a contract with Johnson Controls, Inc., (JCI) in December 1986, to conduct the core technology R&D and engineering development of the zinc-bromine technology. SNL is responsible for material research, component evaluation, and environmental testing, including technical direction of the development contract. The three-year, $2.3M cost-shared (25%) effort is aimed at the design, fabrication, and evaluation of an improved zinc-bromine battery system suitable for electric vehicle propulsion. During FY 1987, JCI initiated the evaluation of alternative types of cathode activation layers used on the bromine electrode; achieved progress on improving materials durability, including dimentionally stable electrodes and flow frames; fabricated a new cell stack using high density polyethylene; and fabricated an 8-cell stack for evaluation at Sandia.

Propulsion System Technology

The objective of the Propulsion System Technology Development Activity is to concurrently advance battery and powertrain technologies in a mission-oriented, integrated fashion within the context of a total propulsion system perspective. These technologies are to be advanced to levels of maturity that will allow industry to make quality decisions regarding their potential viability as foundation technologies for the development of commercial products suitable for electric vehicle applications. In order to enhance the transfer of these technologies to potential manufacturers of derivative commercial products, contracts for development of the technologies have been placed with industrial teams that not only have the necessary development expertise but also have the capability to manufacture related products should it become in their business interests to do so.

The implementation strategy for the Propulsion System Technology Development Activity involves a two-pronged approach that provides a balanced blend of technology advancement versus risk. The two prongs are the Dual-Shaft Electric Propulsion System Technology Development Program (DSEP) and the first and second generation Single-Shaft Electric Propulsion System Technology Development Programs (ETX-I, ETX-II). The DSEP Program is scheduled to be completed in December 1988; the ETX-I R&D Program was completed in October 1986; and the ETX-II Program is currently scheduled to be completed in March 1989. The DSEP Program involves more mature base technologies and, consequently, has a somewhat higher probability of success and more near-term potential. The nickel-iron battery technology and the dual-shaft powertrain technology in the DSEP Program are upgraded generations of technologies that have been under development in the Department's program over the past several years. The technologies of the DSEP Program are therefore more mature and closer to commercialization than the more advanced technologies of the sodium-sulfur batteries and powertrain of the ETX Programs. The more advanced battery and single-shaft propulsion system technologies will require several more years of development to resolve reliability and cost issues before they can be commercialized. Currently expected test bed vehicle performance from the two development efforts is tabled below, although some of the ETX-II quantities are estimates dependent upon the final selections of technology, particularly the battery.

Dual-Shaft Electric Propulsion System Program (DSEP)

The Dual-Shaft Electric Propulsion (DSEP) System Technology Development Program is aimed at advancing electric propulsion technology through the integrated development of a nickel-iron battery, an AC motor and controls, and a two-speed automatic transaxle within a light weight van suitable for use in an urban/suburban environment (the motor and transaxle are arranged on two parallel axes, hence the term

Table 2

	DSEP	ETX-II
Range on FUDS	80 km	>160 km
Acceleration (0–80 km/h)	20 sec	<20 sec to 60% SOC
Gradability Percent Grade	3%	7%
Speed at Grade	88 km/h	48 km/h
Gradability Limit	30%	30%
Top Speed	96 km/h	96 km/h
Payload	545 kg	227–454 kg
Drivability	—	Industry Acceptable
Energy Consumption	280 Wh/km	250 Wh/km

"dual-shaft"). The 54 month program is scheduled for completion in December 1988.

The DSEP program industrial research team includes Eaton Corporate Research and Development, Detroit Center (Southfield, Mi), the prime contractor, with responsibilities for powertrain technologies and propulsion system integration; Eagle-Picher Industries (Joplin, MO) responsible for battery technology; and ASC, Inc., (Southgate, MI) responsible for test vehicle modification and integration. This team is sharing 5% of the research cost.

There were several major accomplishments during the third full fiscal year of the program:

Dynamometer testing of the entire integrated powertrain system intended for the proof-of-concept test bed vehicle (TB-1) was completed. The tests proved successful system operation at steady state, dynamic, and extreme temperatures, and assured subsystem compatibility as well as readiness for vehicle installation.

The first test bed vehicle, an extended version of the Chrysler T-115 mini-van, was made operational. Vehicle conversion for the DSEP powertrain installation was performed by ASC, Inc. The third complete nickel-iron battery pack was furnished by Eagle-Picher Industries and incorporated improvements deemed desirable from tests of the first two battery packs. Installation of the entire powertrain system was completed at Eaton Corporate Research and Development, Detroit Center. Initial shakedown and basic driveability tests were completed at the same location, with satisfactory results.

Extensive vehicle performance tests were conducted at Chrysler Corporation's Chelsea Proving Grounds, reaching or exceeding most original performance goals. (The TB-1 vehicle undergoing test, is presented in Figure 6.) The peak power was observed to fall short of the established program goal, resulting in somewhat reduced vehicle acceleration. Consequently, the power limiting system element, the inverter, was redesigned for higher power, and was fabricated for use in the second vehicle that will be built for the DSEP program—the NVH (noise, vibration, harshness) test vehicle. All other subsystems of the NVH vehicle, a significantly improved powertrain incorporating many innovations resulting from the TB-1 test and development work, were designed and fabricated. Tests of the NVH vehicle are scheduled to start in February 1988.

A major advance in electric vehicle drivetrain technology was achieved with the development of a control feature that electronically eliminates the effect of driveline torsional resonances by sensing the rate of change of traction motor and transaxle output speeds and then correspondingly modulating the traction motor torque to obtain a smooth transaxle output torque delivery. This feature has effected smooth full-load vehicle starts and transaxle shifts without any mechanical or hydraulic torque modulation necessary for either function, and

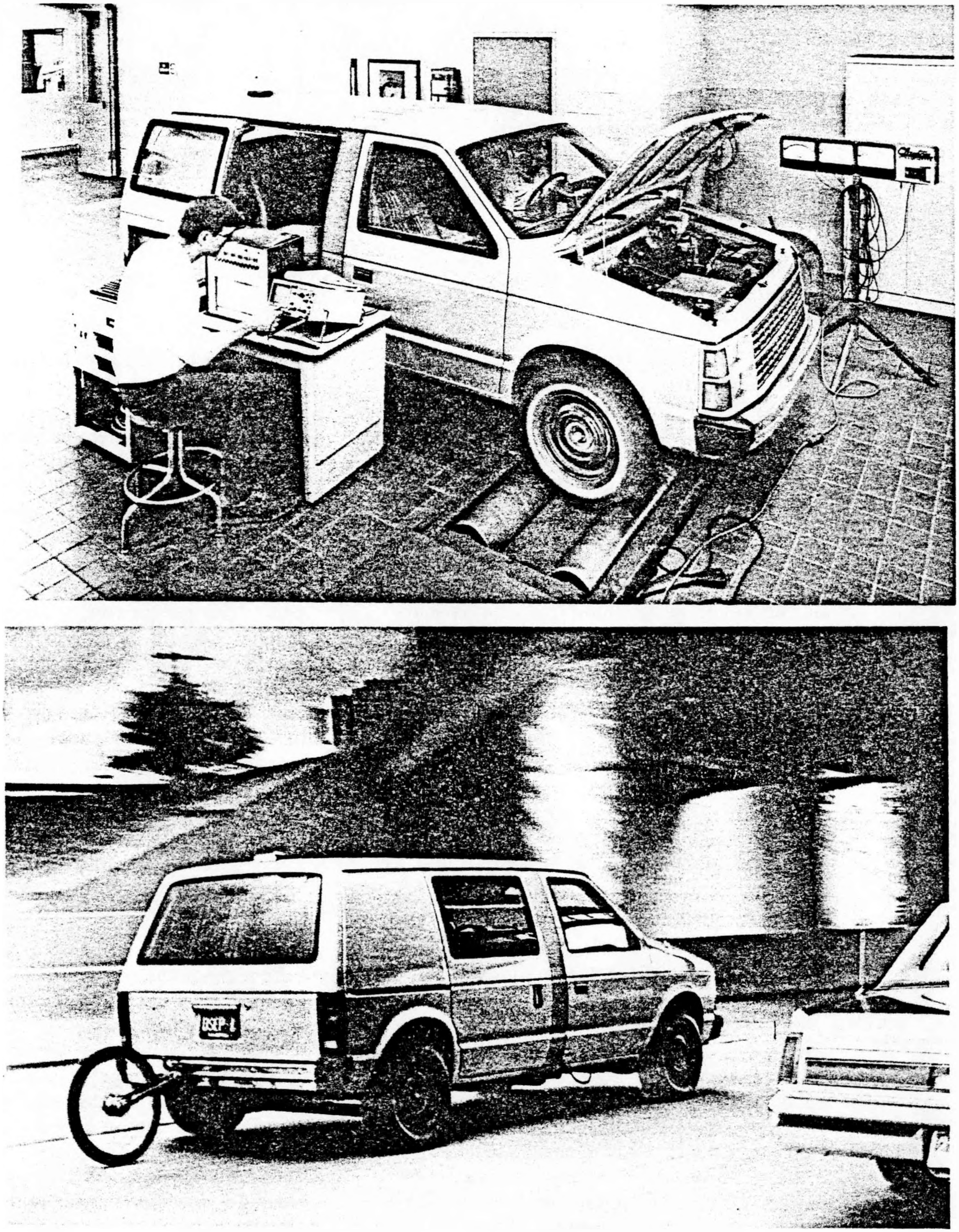


Figure 6. DSEP Vehicle Under Developmental Testing

without the need for any torsional dampers in the driveline. This feature is fully operational in the TB-1 vehicle powertrain.

The DSEP battery subsystem underwent extensive developmental and life cycle tests at Argonne National Laboratories, Eaton and Eagle-Picher. The subsystem appears capable of meeting all program goals which are among the most ambitious ever imposed on a vehicle battery. The testing of the 30 kWh DSEP nickel-iron battery on repeated cycling, which simulates a 50 mile daily operation in a fleet electric van on the Federal Urban Driving Schedule (FUDS), has accrued over 500 cycles (>25,000 miles) in an ongoing evaluation. A detailed analysis has indicated that the power capability of the battery is affected by the temperature variations which exist in the battery pack, with the coolest modules limiting the performance of the overall battery. This finding accentuates the need for careful thermal management of the battery, and modifications were implemented to solve this problem. The battery continues to exceed the 50 mile range requirement, while meeting the 52 kW power level required for acceleration from 0-50 mph in 20 seconds. However, an area of concern is the subsystem's ability to provide full vehicle acceleration power near the end of each simulated FUDS discharge cycle. An intensive effort is underway to fully diagnose and have the problem corrected in FY 1988.

2nd Generation Single-Shaft Electric Propulsion System Program (ETX-II)

The ETX-II Program is advancing overall propulsion system technology through the integrated advancement of sodium-sulfur battery subsystem technology and single-shaft alternating-current powertrain technology. This program is addressing several new, innovative technological advances over the state of the art reflected in the ETX-I Program. As in the ETX-I Program, the Ford Motor Company is the prime contractor and General Electric is a major subcontractor. General Electric is responsible for the electric subsystem, which includes the motor, its controls, and the inverter, including the power modules. Another subcontractor will be selected in FY 1988 for the sodium-sulfur battery. The program was carried at normal pace during FY 1987 after the slowed pace in FY 1986 due to the funding difficulties (i.e., lack of monies returned from the loan guarantee program); the program was extended to March 1989.

Many major technological advances will result from the ETX-II research program. Included among these are:

A new interior permanent magnet (IPM) motor for the transaxle assembly, which will be integrated into the rear axle of the test bed van;

Development of the control algorithms required for control of the interior permanent magnet motor;

Further development of the unique power modules;

Improvements to the inverter to reduce its size and weight; and

Integration of the vehicle controls and the electric subsystem controls to provide a system controller that is in command of the entire propulsion system.

In addition, specification and integration of an advanced sodium-sulfur battery is included in the program to assure that this important portion of the propulsion system is included in all of the system design trade-offs. Discussions have been held with Powerplex Technologies and Chloride Silent Power Limited on supply of traction battery subsystems for use in the ETX-II Program.

There were several major accomplishments and advances made during FY 1987 on the program:

All of the design work was completed and builds of all major subsystems were completed or near completion. The new interior permanent magnet motor was operated satisfactorily on the dynamometer. Preliminary results from this testing indicate that the ETX-II motor is 90% to 97% efficient in the normal operating ranges. This is an improvement of about 5% over the induction motor used in the ETX-I Program. The

ETX-II integrated interior permanent magnet motor and transaxle are pictured in Figure 7. The phase leg power modules were completed and tested; the inverter was built and preliminary testing accomplished; the inverter/motor controls were tested and most of the final circuitry completed; the transaxle design was completed, including the valve body, and fabrication of the parts initiated; and the system controller was built and preliminary integration tests done.

Design efforts on packaging the subsystems in the test bed vehicle were completed. All major components, with the exception of the traction battery, have been packaged in a location compatible with production considerations.

Considerable work was also done to improve the simulation programs that are used to evaluate the effects of design changes and to help design the subsystem control algorithms. These simulations have been expanded to include new features and have been used extensively to establish design criteria for transmission shifting as well as keeping track of subsystem design status. Operation of the simulation program indicates that the present component designs allow the system operation to be consistent with the program goals. In particular, the two important parameters of energy consumption and acceleration performance are within the targets set for the program.

This program, which is approximately two-thirds complete, will result in a propulsion system suitable for a light commercial van. This propulsion system will be the most advanced system built to date, and one whose features will enhance the probability of such a propulsion system being a viable commercial product.

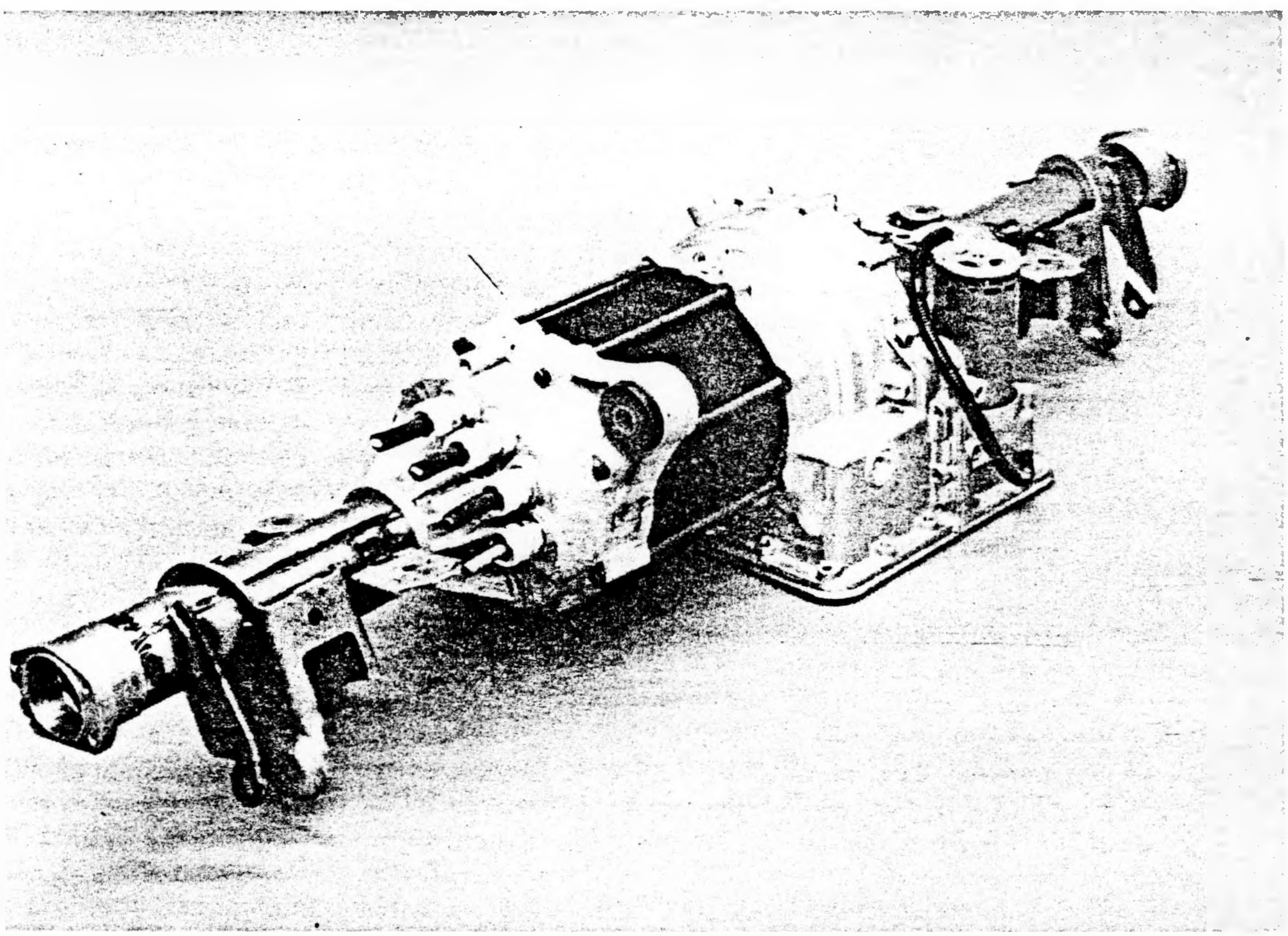


Figure 7. ETX-II Integrated Interior Permanent Magnet AC Motor and Automatic Transaxle

ADVANCED TECHNOLOGY

Hybrid Vehicle Evaluation

Although the hybrid vehicle program has not been funded since FY 1985, DOE is continuing a small in-house activity to keep abreast of current developments both foreign and domestic. In addition, a low level effort is underway to examine the performance and cost trade-offs with various battery options utilizing available computer models, such as MARVEL and HYVEC. DOE is also coordinating with the Electric Power Research Institute (EPRI) in their plan to develop and test a gasoline/electric range-extender hybrid vehicle concept.

Component Development

A variable-reluctance motor (VRM) has been constructed offering the potential to significantly reduce the parts count in the inverter with a comparable production induction motor while maintaining high efficiency and power density. The previous theoretical work by Massachusetts Institute of Technology has now been confirmed through testing of a 60 kW proof of concept motor. The 65 kg (168 lb.), 60 kW (80 h.p.) motor is 20 cm in diameter and 30 cm in length. It was high power tested at the General Electric Laboratories during the last quarter of FY 1987. It exceeded computer torque projections and reached efficiencies as high as 95%. Unique features of the VRM inverter include allowance of a high battery voltage (240V) and relatively low currents. The inverter drive utilizes high voltage GTO fast switching thyristors with only one high power switch per phase. Even though the motor has a high power to weight ratio, it runs at moderate speeds up to 12,500 rpm. Smaller versions of the VRM have already found applications in the robotics industry and are being tested in competition with permanent magnet motors for air conditioning compressors.

The VRM program has also generated a method of determining the motor-rotor position without a mechanical shaft encoder. The microprocessor method of observation and control has been tested by a permanent magnet motor manufacturer and found to work equally well in that application.

The VRM program will continue into FY 1988 with the objectives of completing Phase II with delivery of a final report for that Phase, improving the low speed motor-controller efficiency, integrating the observer position indicator software into the control algorithm and documenting and verifying the motor design loss model.

Fuel Cell/Battery Powered Bus System Development

During FY 1987, DOE initiated a Congressionally mandated program to conduct research, development, and demonstration of a Fuel Cell/ Battery Powered Bus System Program.

The Departments of Energy (DOE) and Transportation (DOT) initiated a cooperative multiyear program in FY 1987 for the research, development, and demonstration of a fuel cell/ battery powered bus system for urban passenger transport. Argonne National Laboratory provides the technical management for these activities, and Georgetown University provides additional support under a cost-sharing (14%) contract with DOE.

Fuel cells potentially can provide the range advantages of an internal combustion engine, but with clean and quiet operation using non-petroleum based fuels. The objectives of this program are to develop, evaluate, and show the feasibility of a methanol-fueled phosphoric acid fuel cell/ battery technology aimed at proof-of-concept via a small urban test bed bus; to advance the fuel cell/battery and control technologies in an integrated fashion for urban bus applications; to show the technology viability/maturity for urban bus applications; and to advance the technology towards providing an alternative for diesel-powered buses.

The fuel cell/battery hybrid propulsion technology being developed in this program must satisfy the requirements of the urban bus application, many of which are unique and new for fuel cell power sources. Evaluation of the state-of-development of the various fuel cell types led to the selection of the phosphoric acid fuel cell as being the only viable candidate for the bus application in the next few years. Furthermore, the continuous start-stop operating mode of an urban bus imposes wide power demand swings (peak to average power ratios of 3 to 1 or more) on the power source, along with rapid transient response requirements. For maximum energy efficiency the recovery of the bus kinetic energy through use of efficient regenerative braking is desirable. These performance considerations led to the selection of a fuel cell/battery hybrid power source as being the most compact, efficient and cost effective. The fuel cell can be sized to provide the average power requirement with the additional power required during acceleration supplied by the battery, which can also readily accept the regenerative braking energy. This also eliminates the need to develop a fuel reformer with a rapid transient response. The battery must be capable of efficiently supplying the high acceleration power and accepting the high regenerative braking power while having an acceptable cost and life. Other technical considerations include a requirement for the use of methanol fuel, achievement of acceptable startup times, minimum power source size and weight, and meeting all safety and emission standards.

The first phase of the planned four-phase program is directed at showing the proof-of-feasibility of a phosphoric acid fuel cell/battery system as the prime source of power for an urban bus. Phase I is a system design and integration effort that encompasses systems definitions, trade-off analyses, and laboratory evaluation of a fuel cell/battery brassboard propulsion system. An RFP for the Phase I work was issued in FY 1987, and on the basis of this competetive procurement, it was determined technically that an evaluation of both air-cooled phosphoric acid fuel cells as well as liquid-cooled systems would provide the greatest probability of success in applying fuel cell technology to transportation needs. As a result of the competetive procurement process, a $2.5 million cost-shared (27%) contract was awarded to the R&D team of Energy Research Corporation, Bus Manufacturing USA, Inc., (BMI), and Los Alamos National Laboratory to develop an air-cooled phosphoric acid fuel cell/battery brassboard system; and a $2.1 million cost-shared (13%) contract was awarded to the R&D team of Booz-Allen & Hamilton, Chrysler, and Engelhard to develop a liquid-cooled phosphoric acid fuel cell/battery brassboard system. This approach will permit a full evaluation of each technology in a total systems environment. After completion of the brassboard evaluations in Phase I, a decision will be made to select one technology for the Phase II effort. Phase II encompasses the development of the proof-of-concept fuel cell/battery power source and the powertrain components, and the integration of these into a small test bed bus. Track testing and field evaluation of this test-bed bus with the proof-of-concept fuel cell/battery power source will be accomplished in Phase III. Phases I through III will provide the technology development and demonstration needed to proceed to Phase IV, which encompasses field testing of small fleets of prototype buses in various urban applications. The results of Phase IV will provide the data and experience needed by industry to make commercialization decisions.

4. TEST AND EVALUATION

Test and Evaluation (T&E) activities are performed on newly developed and existing technologies to characterize their performance potential in laboratory and field environments. The functions are carried out in three separate elements: Site Operations, Technology Engineering and Engineering Evaluation Testing. The activities conducted in FY 1987 within each of these T&E elements are described below.

Site Operations

During FY 1987, the emphasis of EV site operation activities was placed on continuing site operations, improving vehicle utilization through more careful performance and mission correlation and in analyzing field test data to obtain a more thorough understanding of the technical and economic issues associated with the current and projected EV technologies.

The number of site operators was reduced from 11 at the end of FY 1986 to the current 10 sites in 26 locations as inefficient vehicles were retired or phased out of the program. Included among the remaining sites are five private sector site operators and five public sector site operators including the U.S. Navy, which is now the largest user of EVs. The U.S. Navy with 14 active site locations and approximately 270 vehicles, receives most of its vehicles from other site operators that have completed their contractual obligations. Table 3 shows the sites that are currently in the program.

Significant strides were made in the field test and evaluation of product improvement technologies during the past year in the areas of advanced batteries, new vehicles, maintenance, and test and monitoring devices. A brief description of the test and evaluation programs that were conducted during FY 1987 is given below.

The major barrier confronting the acceptance of EVs is the development of a battery system with performance characteristics and an overall cost that are not clearly disadvantaged relative to internal combustion engine vehicles. Since the battery system is the critical technology, recent emphasis has been placed on the field testing of newly developed battery systems including:

Johnson Controls Inc.,
 Gel/Cell
Improved State of the Art (ISOA)
Delco nickel-zinc
Eagle-Picher nickel-iron

The Johnson Controls Inc., Phase III Gel/Cell batteries are being tested at ten different site locations including GTE, LILCO, APSC, DECO, the University of Alabama at Huntsville, the University of Hawaii, Sandia National Laboratories and the U.S. Navy. The major advantage of the battery is in its virtually maintenance free operation. No watering of the battery is required, which greatly reduces the operation cost. DECO estimated the savings at one hour of labor per 1600 km for each vehicle operated. Furthermore, because the battery is sealed and recombines the hydrogen and oxygen gases that are evolved during charging, hydrogen gas buildup outside of the battery is eliminated and there is little probability of a hydrogen detonation. No stirring of the electrolyte is required; therefore, the amount of overcharge is reduced and the energy consumption is lowered. The energy efficiency of the Gel/Cell was 28 and 35 percent better as measured by DECO and GTE, respectively, when compared to the conventional flooded, lead-acid battery.

The Johnson Controls, Inc., ISOA (EV-2300) battery system is an approach for combining major battery subsystems for electrolyte destratification, single point watering, thermal management and charging into a single integrated unit. At DECO, the ISOA battery powered SCT Rabbits proved superior in many respects to the conventional, lead-acid battery vehicle including

Table 3

Electric and Hybrid Vehicle Program Site Operators

Private Site Operators

GTE Service Company Honolulu, Hawaii Pomona, California Tampa, Florida GTE Laboratories Waltham, Massachusetts	Long Island Lighting Company (LILCO) Northrop Corporation Philadelphia Electric Company (PECO)* Arizona Public Service Company (APSC) Detroit Edison Company (DECO)

Public Site Operators

Alexandria, Virginia Huntsville, Alabama	Sandia National Laboratories University of Hawaii

U.S. Navy

Naval Weapons Station Concord, California Naval Air Station Moffett Field, California Pacific Missile Test Center Point Mugu, California Naval Facilities Engineering Command Pearl Harbor, Hawaii Mare Island Naval Shipyard Vallejo, California Naval Weapons Center, China Lake, California* Navy Public Works Center Norfolk, Virginia Naval Ordnance Station Louisville, Kentucky	Naval Weapons Support Center Crane, Indiana Naval Air Station Bermuda Naval Underwater Systems Center Autec, Bahamas Naval Supply Center Pearl Harbor, Hawaii Naval Academy Annapolis, Maryland Puget Sound Naval Shipyard Bremerton, Washingon Naval Construction Battalion Port Hueneme, California

*Operations completed or terminated in FY 1987.

range (16% better), acceleration (roughly 8% better), energy consumption (10% better), water consumption (54% better) and improved low temperature performance. However, further engineering of the subsystem integration is needed to improve the reliability and remove some of the deficiencies of the battery.

The Delco Design 5 nickel-zinc battery system was tested in two SCT VW Rabbits at DECO. The vehicles powered with nickel-zinc batteries had an average 25% better acceleration over the life of the battery compared to conventional lead-acid battery driven vehicles. In addition, energy consumption was 28% lower, which is attributable to the reduced amount of overcharge required for the nickel-zinc battery. Finally, the battery is much less temperature sensitive than the lead-acid battery. At −18°C the capacity of the nickel-zinc battery is only reduced to 80% of rated capacity compared to 50% for lead-acid batteries. The rapid drop-off in capacity with cycle life is the most serious problem confronting the introduction of the nickel-zinc battery. The shorter cycle life (less than 200 cycles to 60% rated capacity as measured by DECO) is attributable primarily to the electrode degradation, but also to the higher sensitivity of the nickel-zinc battery to uneven charging and discharging.

Eagle-Picher nickel-iron batteries were installed in 12 electric vehicles in 1982 and tested at Northrop and GTE. The principal advantages of the nickel-iron battery are in its excellent ruggedness, good cycle life and vehicle range. Over 40,000 test miles have been driven with nickel-iron powered vehicles. Both Northrop and GTE report little or no unscheduled maintenance and a range that is on average 20% greater than vehicles driven by lead-acid batteries. However, the nickel-iron battery exhibits high energy and water consumption as well as excessive gassing due to the high overcharge that is required to fully charge the battery. The major disadvantage though, still remains the high initial cost of the battery. In other activities, the reliability and long life of nickel-iron batteries in EV applications continued to be demonstrated in actual EV operation with over 44,000 miles achieved to date in an electric van being operated at the Tennessee Valley Authority's EV Test Facility.

The second area of new products in which testing continued during FY 1987 is in new vehicles. The GM Griffon van entered its fifth year of on the road testing at DECO. The results of the tests at DECO show that the GM Griffon van is a sturdy, dependable vehicle with adequate accessories and performance characteristics for the short haul service for which it was designed. Furthermore, the van demonstrated that an EV is possible at a price that is competitive with that of an internal combustion engine driven vehicle and yielding performance characteristics that are acceptable for certain applications. Several of the important results that were determined during the DECO test program include a maximum range of 200 km at a constant 32 kph; energy consumption of between 0.2 and 0.6 kWh/km and a maximum speed of 85 kph. Testing of the Grumman Kubvan continued at LILCO. The Kubvans are excellent on-site security vehicles as well as being well suited for light duty delivery applications.

The last area of new product technology that was tested during the year is maintenance, test and monitoring devices. Included among these products are:

- Aachen range prediction device
- Propel on-board battery monitor
- Propel and Alber off-board battery capacity tester
- Turbo-Electric battery cell watering unit
- Lester "smart" chargers
- Eaton and Soleq dc/dc converters

The Aachen range prediction device (RPD), which was developed under an Electric Power Research Institute (EPRI) contract, was installed in two SCT VW Rabbits and a GM Griffon van and tested at GTE, PECO and DECO. Testing at these sites determined that the Aachen RPD has overcome some of the accuracy problems that have been associated with RPD systems. However, in order for the RPD to be practical as a standard EV component, more development work is needed. In particular, work is required to improve the reliability, user friendliness, and to reduce the cost of the unit.

PECO and LILCO evaluated the Propel on-board battery monitors in seven vehicles, including the Electrica Escort and SCT VW Rabbits, to identify and diagnose vehicle operating problems. The monitor provides an indication of the relative state of discharge of each traction battery module. Testing at the sites determined that the device in spite of numerous modifications and repairs failed to meet the specifications over the two year period that the device was tested.

Off-board battery capacity measurement systems continued to be tested during the current year. APSC, which is testing and evaluating a Propel offboard battery capacity tester, reports that improvements to operating efficiency have been realized due to the units faster and more accurate troubleshooting of problems. The Alber battery capacity tester, which has been routinely used by DECO since 1983, was also evaluated by GTE during FY 1987. GTE claims that the Alber system performs well and is highly effective in isolating weak or bad modules and bad interconnections in battery systems. DECO is the most reliable EV operation of all monitored sites because of its policy of regularly scheduled battery capacity checks with the Alber tester. Battery pack life has been extended by over 1000 miles by properly matching the age and capacity of the modules within a pack.

The Turbo-Electric battery cell watering unit, which is composed of an electric watering wand, a sonic alarm that indicates a full battery cell and a deionizer filter and pressure regulator, was tested at various sites during the year including the Navy, GTE, DECO, PECO, APSC and LILCO. The overall conclusion from all test sites is that the watering unit is very effective in terms of cost savings, reliability and performance. The watering unit reduced the labor time for watering conventional lead-acid batteries by up to 50%. Furthermore, the unit assures that the cells are filled to a correct level and prevents overfilling since the probe of the wand contains a sensor set to the proper cell fill level.

Advanced microprocessor controlled "smart" chargers have been developed by Lester Manufacturing. The improved chargers that have been used primarily with Gel/Cell batteries provide a programmable temperature compensated charging profile and a system of internal diagnostics for problem identification. The charger is well accepted by sites and has been found to minimize overcharging as well as contribute to improved energy efficiency. The charger technology can also be adapted to any future EV battery.

Work is continuing in the development and testing of improved auxiliary power systems. New dc/dc converters are available which offer larger power limits and better reliability than previous converters. Two such converters by Eaton and Soleq were tested at DECO and LILCO. These converters with higher 12V current outputs alleviate the winter load problem. At DECO, three Eaton prototype dc/dc converters and three production Soleq converters were installed in VW Rabbits; whereas, LILCO evaluated four Soleq dc/dc converters in Eagle-Picher Escorts that were used primarily for commuting. Minor problems were encountered and corrected with the Eaton converters. The Soleq converters have been operating without problems since November 1986.

Additional Booz, Allen & Hamilton activities that occurred in FY 1987 include:

1. Development of a life cycle cost model that compares EV life cycle costs to competitive alternative fuel technologies, such as gasoline, methanol and CNG.
2. Expanding the technology trend analysis to compare EV and ICE fleet performance, the results of which will serve as inputs to EV performance goals and to assess what technology improvements will be needed to achieve these goals.
3. Completion and distribution of the EV Maintenance Report, the highlights of which included:
   a. Description of the DOE EV data base.
   b. Overview of the four sites selected for detailed analysis.
   c. Discussion of preventive maintenance, corrective maintenance labor, component maintenance times and parts replacement.
4. Preparation of a data base for the EV Technology Information System which documents current experience on various EVs and components that have been tested or are under development that could be field tested by User Task Force members.
5. Updating the EV data base management system which contains critical performance parameters and mission characteristics for effectively defining the EV duty cycle.
6. Analysis of the Versatile Data Acquisition System (VDAS) data. A GM Griffon van at DECO and a VW pickup at Northrop equipped with VDAS have completed their special drive cycles and runs. The purpose of the data collection was to define mission and performance requirements of several EV operations including service runs, delivery operation and commuter duty cycles to aid in the understanding of field related influences on EV performance and battery life.

Technology Engineering

Technology Engineering activities undertake the evaluation of improved-technology components that are likely to enhance the capabilities of early state of the art EVs in site-operated fleets. These components are evaluated in laboratories; on test tracks in vehicles; and in sheltered (outdoor laboratory) on-the-road vehicles to verify their suitability for incorporation in site-operated EVs. Factors, such as temperature, road shock, moisture, electromagnetic interferences, durability and safety, are evaluated along with the actual performance measurements for the component under test. Battery technology improvements discovered through integrated independent testing of new process components offer the greatest opportunity for enhancing EV performance. The chart in Figure 8 provides the current status of electric vehicle battery technologies under this activity with battery goals shown for those batteries still under development. Improved controllers, battery chargers, battery monitoring instrumentation and EV safety issues also are evaluated when enhanced EV capabilities may result from incorporation of these technologies. Battery evaluation was conducted at the University of Alabama in Huntsville, Soleq Corporation in Chicago, Illinois, and Sandia National Laboratories, Albuquerque, New Mexico.

The University of Alabama, continued to characterize gelled electrolyte lead-acid batteries over a wide temperature range resulting in a temperature independent charge algorithm for gelled electrolyte batteries. The algorithm, requires a small microprocessor but charges all modules in a battery pack uniformly. Here-tofore some modules would overcharge while some would remain undercharged. The new algorithm also requires less overcharge for a complete recharge; therefore, it is expected that this will extend battery life. The algorithm is currently being used in a vehicle to determine how well it adapts to battery needs as the battery ages and what effect it has on vehicle range-reliability with battery age. This testing is being done in a vehicle that incorporates Phase IV Gel/Cell lead-acid batteries.

Soleq Corporation continued on-the-road evaluation of Gel/Cell technology and was responsible for the retrofit design and fabrication of vehicle battery compartments for two passenger vehicle types to accommodate the Phase IV Gel/Cell battery. Regenerative braking on the brake pedal only became standard on Soleq powertrains and the DC/DC converters were modified to protect auxiliary batteries from overcharging.

Sandia National Laboratories continued outdoor laboratory testing of several battery types including Gel/Cell batteries. The Laboratory was also reponsible for retrofiting the battery compartment of one passenger vehicle type and a small size pickup truck to accommodate the new Phase IV Gel/Cell battery.

The Gel/Cell battery technology adaptation to a traction battery type of sufficient size to power a commercially useful electric vehicle was completed in FY 1987. Phase IV of the government/industry cost-shared program has resulted in a family of battery models: a 6V-200, a 12V-100 and and a 2V-600. The 6V-200 and 12V-100 models are inventoried by the Industrial Prod-

ELECTRIC VEHICLE BATTERY TECHNOLOGY ENGINEERING STATUS

Battery	Company	Type/Model 6 Volt Module	Status	Specific Energy (Wh/kg)	Specific Pk Pwr @ 50% (DoD) (W/kg)	Projected OEM Cost (1987$/kWh)	Cycle Life (Cycles to 80% DoD)	Cost/Cycle /kWh (1987 $)
Gel/Cell Lead Acid	JCI, Globe Battery	GC-6V-200 Traction	M	22	80	124	500	0.32
Nickel/Iron	Eagle-Picher (EPI)	NIF 225	M	53	110		500	
			BG	56	79	125	1125	0.13
Nickel/ Cadium	Energy Research (ERC)	EV 180	M	44	110		243	
			BG	53	79	125	500	0.12

OEM = Original Equipment Manufacturer

DoD = Depth of Discharge

BG = Battery Goals

M = Battery Modules

Figure 8. EV Battery Engineering Status

ucts Unit of Johnson Controls, Milwaukee, Wisconsin, but the 2V-600 is a special order item. The success of this maintenance free technology in large size has caused Exide Battery and Sonnenschein Battery to form a joint venture and build a tubular type gelled electrolyte battery for railroad signal blocks. The Veterans Administration of California funded Concorde Battery of California to develop a golf car size immobolized electrolyte (sealed) battery for wheel chair and handicap applications. Fortunately, the Concorde battery with its golf car size case retrofits well into passenger car type electric vehicles. DOE Site Operators now have two sealed maintenance free batteries to choose from to replace flooded lead-acid batteries in their electric vehicles. The tubular type Exide-Sonnenschein battery is a full industrial design; while the Johnson Controls Gel/Cell family is a semi-industrial and the Concorde battery is more of a light duty commercial type. Therefore, the applications spectrum is nicely covered by the new maintenance free products.

Technology engineering and research programs to develop the nickel-iron (Ni/Fe) and nickel-cadmium (Ni/Cd) battery types to a higher state of the art were restructured to include an independent analysis and test program. Cells and modules incorporating new processes and/or materials are being delivered to Argonne National Laboratories and the University of Alabama, respectively for Ni/Fe and Ni/Cd. Eagle-Picher Ni/Fe modules incorporating National Standard Fibrex® nickel material in the nickel electrode have been very encouraging in performance and in potential for cost reduction. A comparative evaluation of the data is in progress to determine if further research on the old sintered technology should be dropped in favor of a concentrated effort using the Fibrex® material. Energy Research Corporation delivered Ni/Cd modules to the University of Alabama wherein it was found that high rate discharge substantially affected module storage capacity. It was also learned that the capacity could be restored by increasing the overcharge factor. Pierced nickel foil is used as the electrode conductor in this technology at present and there is speculation that the active nickel electrode material is developing a high resistance interface at the conductor when operated at high rate due to temperature effects. It is therefore planned to evaluate the possible benefits of switching to nickel Fibrex® for a conductor and structural member.

Eagle-Picher's R&D effort is focussed on the development of thick nickel electrodes having the desired porosity and strength required for good performance and long life. During FY 1987, an advanced NIF-225 design was developed using thick sintered-powder technology, which provided 30% greater energy in the same size and weight than the NIF-170 nickel/iron battery developed for the DSEP Program. A parallel technology development effort successfully fabricated and evaluated nickel-iron battery modules constructed with fiber-type nickel cathodes. The fiber-plate technology has reduced the nickel requirements by 15% compared to conventional sintered-powder electrode technology. Because nickel metal is the major cost driver in the manufacture of nickel-iron batteries, the fiber-plate technology provides a reduction in the initial cost of the battery.

In support of the EV Battery R&D Activities, laboratory evaluations of developmental EV batteries were conducted at Argonne National Laboratory to assess the functional capability of these batteries to perform the mission requirements of electric vehicles. Battery performance and life characteristics were evaluated under uniform test conditions that simulate driving cycle load profiles. Tests were conducted on full-size nickel-iron, zinc-bromine, sodium-sulfur, and lithium/metal-sulfide batteries. Developmental hardware from flow-through lead-acid, nickel-iron, and nickel-cadmium battery R&D programs were also evaluated. The evaluation results provided a measure of the success of the battery development efforts and provided insights into the direction the research programs should take.

Testing of the 30 kWh DSEP nickel-iron battery on repeated cycling, which simulates a 50-mile daily operation in a fleet electric van on the Federal Urban Driving Schedule, has accrued over 500 cycles (>25,000 miles) in an ongoing evaluation. A detailed analysis has indicated that the power capability of the battery is affected by the temperature variations, which exist in the battery pack, with the coolest modules limiting the performance of the overall battery. This finding accentuates the need for careful thermal management of the battery, and modifications were implemented to solve this problem. The battery continues to exceed the 50-mile range requirement, while meeting the 52 kW power level required for acceleration from 0-50 mph in 20 seconds.

Engineering Evaluation Testing

Under the Engineering Evaluation Testing Activity dynamometer and laboratory tests are conducted to evaluate technology outputs in circumstances that duplicate or simulate actual EV operation and environments under repeatable and well defined conditions. For this reason, test and evaluation programs are in process that (1) subject batteries to the actual electrical loads of high-technology EVs on a dynamometer and in test bed vehicles; (2) integrate advanced EV drive systems in vehicles and test them on the track, road and dynamometer; (3) test and characterize auxiliary systems, such as battery chargers, state-of-charge indicators, and battery monitoring and thermal management systems in a realistic EV environment; and (4) test advanced batteries by electrically loading them with complex driving cycle power profiles in a controlled laboratory environment.

DOE selected the Idaho National Engineering Laboratory (INEL) in FY 1984 to perform these testing activities, and dynamometer and battery test laboratories were established for this purpose. The present laboratory facilities permit the testing of vehicles and complete battery subsystems under simulated load conditions which closely approximate the demands of EV operation, including the performance of the Federal Urban Driving Schedule (FUDS). Battery laboratory capabilities were enhanced during FY 1987 to permit the testing of battery packs over a range of operating temperatures from −20°C to +80°C.

INEL dynamometer testing during FY 1987 focused on performance testing of electric propulsion systems developed under previous DOE-sponsored programs. A limited series of dynamometer and road tests were performed on a DC powertrain packaged in a test bed vehicle by the Eaton Corporation. This powertrain was found to have higher energy consumption (about 240 Wh/km on the SAE Schedule D cycle) than either the previously tested Eaton AC-3 (182 Wh/km) powertrain or the reference General Electric ETV-1 (155 Wh/km) vehicle, due to a combination of lower efficiencies and higher tire rolling resistance. An extensive series of dynamometer tests was initiated by INEL on the ETX-I AC powertrain packaged in a test bed vehicle developed by the Ford Motor Company. These tests will be completed in FY 1988, along with additional track and road testing. Figure 9 is a photograph showing the ETX-I/Mercury LN7 vehicle on the INEL dynamometer in the foreground with the ETV-1 General Electric Corp./Chrysler Corp. reference vehicle in the background.

As part of a systematic effort to identify and quantify the causes of differences between laboratory testing and actual field operation results, INEL conducted a series of dynamometer, road and track tests using a single electric vehicle instrumented with two types of on-board data acquisition systems. Comparison of the results of these tests, which were matched against the best currently available vehicle simulation models, showed that controlled track and road tests can match laboratory results within 5% to 7% for basic parameters, such as energy consumption. This study will continue in FY 1988 to identify the causes of the significant differences between laboratory testing and uncontrolled road use, which are expected to include driver behavior, road surfaces, and a number of environmental factors.

Dynamometer testing was also performed on an improved nickel-cadmium battery system incorporating roll-bonded electrodes, a thermal management system, and a "fuel gauge" intended to control recharge automatically. This testing was conducted to provide baseline performance for an ongoing multi-year development program at the Energy Research Corporation (ERC). The measured peak power capability of this battery was above 100 W/kg at 50% depth-of-discharge. The battery provided about 28% more range than the Phase III Gel/Cells for the ETV-1 reference vehicle (161 vs 125 km) at a steady speed of 72 km/hr, but the ranges obtained for the stop-and-go cycles (Schedule D and FUDS) were about the same for the two batteries. Acceleration performance of the test

Figure 9. Dynamometer Testing of ETX-I
(ETV-I in Background)

vehicle was improved 15% to 20% for a fully charged nickel-cadmium battery (compared to the Phase III Gel/Cells), but it degraded severely at low states of charge. The capacity of the battery declined about 10% during the first 100 cycles of life. The ongoing battery development program at ERC is intended to improve the baseline performance of this battery significantly.

Basic performance tests were performed on two sealed, lead-acid batteries which are now commercially available. The Phase IV Gel/Cell is a gelled electrolyte battery developed by Johnson Controls, Inc., (JCI) under DOE sponsorship, while the Concorde GP 6180 is an absorbed electrolyte battery produced independently by the Concorde Battery Company. Both batteries were found to have low internal resistance and similar energy storage capability (about 25 Wh/kg at a 3 hour discharge rate for the Concorde battery), with the Concorde having the advantage of a standard golf cart package.

DOE and the Electric Power Research Institute (EPRI) agreed to continue their joint sponsorship of the design and fabrication of a half-ton van, intended to produce two operational prototype vehicles. EPRI contracted with Acustar Inc., (a Chrysler subsidiary) to build the vehicles, and DOE arranged through INEL for the FY 1988 purchase of nickel-iron batteries to power the vehicles.

During FY 1987, JCI completed the development of flame attenuation devices intended to inhibit or mitigate the severity of a hydrogen ignition in nickel-iron and lead-acid batteries. Prototype hardware was successfully fabricated by JCI and independent functional and safety testing was started at INEL. This testing will culminate in FY 1988 with operational testing in a full-size battery system under actual electric vehicle use conditions.

Field performance data continued to be collected with the Versatile Data Acquisition System (VDAS) installed in vehicles at cost-shared private sector site operations.

5. INCENTIVES

The major incentives-related activities included the Corporate Average Fuel Economy (CAFE) and Loan Guarantee activities.

CAFE Regulations

Section 18 of the Chrysler Corporation Loan Guarantee Act of 1979 (Public Law 96-185) directed the Department of Energy (DOE)

> ... to conduct a 7 year evaluation program of the inclusion of EVs in the calculation of average fuel economy... to determine the value and implications of such inclusion as an incentive engineering development and initial commercialization of electric vehicles in the United States.

This 7 year evaulation program was conducted by DOE and a final assessment report on this activity was completed in February 1987.

The key concern of this mandated report was to determine if the EV CAFE provision provided an "incentive for the early initiation of industrial engineering development" and/or provided an incentive for "initial commercialization of electric vehicles in the United States."

In order to determine a response to the first issue DOE had to obtain information from the automobile manufacturers. The extent of "industrial development" is difficult for observers outside the industry to determine. Letters were sent to the auto manufacturers requesting information on whether industrial engineering development on electric vehicle technologies had been stimulated by the EV CAFE provision. According to the responses received from the automobile manufacturers, the provision has not provided an incentive for the early initiation of industrial engineering development for electric vehicles.

Answer to the second issue was settled from considering offerings in the marketplace. No electric vehicles are offered for sale by the automobile manufacturers which are subject to the CAFE legislation. Therefore, it must be concluded that the EV CAFE provision has not yet provided the desired incentive to assist in the commercialization of electric vehicles.

Although the EV CAFE provision (Federal Regulations 10 CFR Part 474) has not had its intended effect, the consensus by both DOE and the auto industry was that the EV CAFE credit regulations should be retained since there is a possibility that the petroleum price will increase and import dependence of the past that stimulated this provision in the first place could return again in the future. There are no administrative costs to the Government or to industry to keep this provision in force. The import share of U.S. oil supply is on the way up again after several years of decline. Therefore, the concern for reliance on imported oil that was influential in causing Congress to enact this legislation is likely to remain a concern.

DOE's final recommendation was that the EV CAFE provision be continued, to the extent that the CAFE regulation remains intact, in the average fuel economy calculations under the Motor Vehicle Information and Cost Savings Act.

Planning Grants

There was no activity in this incentive program during FY 1987.

Loan Guarantees

During FY 1987, no new authority was sought by, or provided to, DOE for the provision of loan guarantees for the development of electric and hybrid vehicle technology. (The time for making principal and interest assistance contracts under the Electric and Hybrid Vehicle Loan

Guaranty Program expired on September 17, 1983, as provided for by the notice of final rulemaking published in the Federal Register on May 31, 1979 (44 FR 31510)).

Since inception of this program in FY 1979, ten formal applications were provided to DOE and two loan guarantees were issued, both of which were terminated due to default. The assets of one company were liquidated in 1982 recovering approximately $83,000, which resulted in a loss of $2,363,000. A workout agreement was negotiated in January 1983 with the second company providing for full payment of the $2,170,000 principal outstanding pending liquidation of real estate and other assets.

During FY 1987, DOE agreed to convey title to the land that was obtained under the terms of the workout agreement back to Jet Industries Inc., upon full payment of the outstanding principal and interest. If the land is not sold and the debt paid in full by September 1, 1990, DOE will turn the property over to the General Services Administration for liquidation.

6. OTHER ACTIVITIES

STUDIES AND ASSESSMENTS

Impact Studies

Public Law 94-413, Section 13, requires a continuing assessment of material demand and pollution effects from electric and hybrid vehicles (EHVs). No new studies of material demand were conducted in FY 1987 because earlier studies indicated that the availability and production of materials for EHV production could be readily increased to meet any plausible level of EHV production during this century.

Section 13 of the Act also requires a statement of activities related to research on incentives to promote broader consumer acceptance of EHVs. No new activities were initiated in this area during FY 1987.

Program Reviews

The DOE's multi-year planning process requires that formal program reviews be conducted periodically to relate major programs to their stated objectives and to ensure that the objectives are still valid. The process recognizes that while many major programs are Congressionally mandated, it is incumbent upon DOE to report on program progress and to recommend the extent and appropriateness of future Government involvement. Every year the Assistant Secretary for Conservation and Renewable Energy and the Deputy Assistant Secretary for Conservation select major programs for this independent review process. The overall Electric and Hybrid Vehicles (EHV) Program was selected for review. Also, the EV propulsion system R&D part of the overall EHV Program, which includes the advanced Dual-Shaft Electric Propulsion System Technology Development Program (DSEP) and the advanced Single-Shaft Electric Propulsion System Technology Development Program (ETX-II), was one of the programs selected for review in FY 1987.

Electric and Hybrid Vehicles Program Review

During FY 1987, a two-day review on November 19-20, 1986, of the overall Transportation Energy Conservation Program was held at Oak Ridge National Laboratory and was attended by a cross section of over 50 industrial executives, academia, and National laboratory personnel. The Electric and Hybrid Vehicles Program constituted only a small portion of that overall review.

The electric vehicle review panel concluded that there is a potential for reducing the usage of liquid fuel, including imported oil, with the introduction of electric vehicles in the marketplace. The panel also felt that there was definitely a role for the Government in electric vehicle technology development since the market is unclear and this is clearly a high-risk R&D activity. It was determined that battery development was still the critical, key element to making electric vehicles a viable alternative. Therefore, it was recommended that DOE concentrate its resources on fewer battery types with the leading candidates being determined by an independent assessment performed by electrochemical and end user experts. This recommendation is being addressed by a Battery Assessment Study underway at INEL with assistance from outside experts in the field, as described under the Battery R&D Program Plan activity.

EV Propulsion System R&D Review

A distinguished panel of independent electric vehicle experts met on December 9-10, 1986, to conduct a critical review of the Electric and

Hybrid Vehicles Propulsion System R&D Program. The six person panel represented a cross-section of industry, government and academic expertise with prior experience in the development of electric and hybrid vehicle technology. The mission of the panel was twofold: (1) to conduct an objective, independent assessment of the DSEP and ETX-II programs; and (2) to assess the contribution of these two programs to the overall Electric and Hybrid Vehicles Program.

The Panel found the DSEP and the ETX-II programs to be of value and DOE's involvement in electric vehicle R&D appropriate. Without DOE involvement the advances in EV technology would be severely limited. EV technology development is clearly in the national interest in the long term. Both the DSEP and ETX-II programs are sound and justified since they are addressing different technologies with different time scales.

The Panel found the the DSEP program is well managed, on schedule and major milestones are well defined and attainable. Eaton is conducting production cost projections which are essential to EV commercialization. Eaton's involvement is very beneficial because they are a major supplier to the automotive industry.

The Panel strongly endorsed the involvement of Ford as a major automotive manufacturer in the ETX-II program. This involvement helps to address problems from the industry's viewpoint. For the ETX-II battery subsystem, the Panel recommended that Ford be given total responsibility for battery selection, development and integration into the vehicle. The ETX-II program must include the development of meaningful production cost estimates. The Panel emphasized that to move a technology from research and development to production in the auto industry, stringent criteria are used. In this industry, proposed hardware is installed by the potential supplier in one or more concept vehicles to enable management decisionmakers to inspect and drive the vehicle. This vehicle must be a reliable, drivable, finished vehicle. Otherwise, the decision to commercialize will not materialize. Therefore, DOE's standard technology readiness criteria must be modified for the automotive industry toward the goals of reliability, durability and safety, rather than just the performance goals of the DSEP and ETX-II propulsion systems.

The Panel strongly recommended that the two programs be oriented toward the propulsion systems integration for roadworthy concept vehicles. The Panel also recommended that DOE EHV program resources be concentrated on fewer battery types as did the overall program review panel. The Panel felt that DOE should develop in-house capabilities for computer modeling. The Panel also recommended that communication of program achievements be improved with wider dissemination of technical reports, press conferences and announcements by the contractors, and by the entry of first class concept vehicles in trade shows.

Eighth International Electric Vehicle Symposium

The United States was the host to the VIII International Electric Vehicle Symposium held in Washington, D.C. on October 20-23, 1986. Twenty-one different countries were represented in the symposium for the exchange of technical information on the development of electric vehicle technologies throughout the world. The Department of Energy participated in the conference by serving on the Executive and Scientific Committees, and in presentation of technical papers on the technology developments in the Department's program.

Battery R&D Program Plan

A project to develop a technology-based five-year program plan for guiding DOE's development of EV power source technologies was initiated at DOE's Idaho National Engineering Laboratory (INEL). This project is intended to assist DOE in exercising technology-based decisions in the development of competitive power source technologies to levels of maturity which will allow industry to make quality decisions regarding commercial product development. This will be accomplished by the identification and prioritization of the most promising technologies for meeting the fleet-van mission as part of an advanced-technology propulsion system, e.g., the Eaton Corporation's Improved Dual-Shaft Electric Propulsion (IDSEP) van.

This project is building on prior DOE-sponsored EV battery and fuel-cell assessments in order to conduct an IDSEP-van mission-directed power source assessment, pursuant to the recommendations of DOE's 1986 Task Force on refined EV battery goals. Prior assessments have been reviewed with regard to the relative capabilities of competing power sources to satisfy the requirements of this urban fleet-van mission. Additional mission-specific fully-integrated hardware design information is being obtained for the purpose of conducting more comprehensive analyses of the practical limitations of each technology in this mission. Technical data on each power source will be assembled in a common format and evaluated using a consistent and objective assessment methodology to arrive at a prioritization of competing technologies. These results will be employed in the development of a five-year R&D program plan for DOE sponsorship of selective EV power sources.

In May 1987, INEL awarded an 18-month subcontract to Sheladia Associates, Inc., of Rockville, Maryland, to provide management, coordination, and technical support for this project. Sheladia's team of ten power source and EV experts are working in cooperation with representatives from six National Laboratories (ANL, INEL, LANL, LBL, PNL, and SNL) to conduct the power source assessment. The technical assessment is scheduled for completion in mid-FY 1988, while the power source R&D program plan is scheduled to be undergoing independent review at the end of FY 1988.

Battery Goals Task Force

The DOE Task Force completed its review of EV battery research and development goals and finalized the Battery R&D Goals Report. This report recommended R&D goals for ten candidate EV battery technologies, based on meeting specific vehicle mission requirements throughout battery life. Eaton Corporation's Improved Dual-Shaft Electric Propulsion (IDSEP) van, with mission ranges of 50, 75, and 100 miles under the modified FUDS, was used as the basis for developing the battery goals. Comments on the preliminary report received from the EV and battery industry and government reviewers were incorporated into the final report. The new set of goals, which are based more on real-world conditions than previous goals, will provide better bases for industry to make quality decisions for future technologies.

Battery Test Working Task Force

The EHP Battery Test Working Task Force was formed in 1983 to coordinate the battery evaluation work at several DOE-funded laboratories. Present member laboratories are ANL, INEL, SNL, and TVA. The group has met twice each year since then to discuss testing procedures, results, reporting methods, and special techniques. Several new evaluation procedures have been developed, tested and implemented. The Task Force has recommended improvements in testing procedures used at each represented laboratory, and most have been accepted.

During FY 1987, a key accomplishment of the Task Force was the development and adoption of test termination criteria for the simplified Federal Urban Driving Schedule test procedure. This procedure was developed by the group in prior years to provide a realistic EV battery test regime. Final laboratory tests of the new termination criteria and preparation of a final report for the test procedure were in progress at year's end.

In other areas, a glossary of battery testing terms developed by the Task Force was reviewed by experts in industry and DOE. It provides a set of carefully written definitions for use by all who need to understand and interpret battery test results. A final revised edition of the glossary will be distributed early next year.

A standard test procedure for measuring battery capacity, issued by the Task Force last year, was revised to improve its clarity and applicability. These revisions were based on experiences within the group and comments from other organizations.

Finally, the Task Force considered several possible concepts for developing a computerized data base for battery test results. Various options for a data base design were reviewed. Several possible scenarios were presented to DOE for comment.

Future activities include developing additional standard testing procedures and further work on a testing data base. Also, the group will continue its important task of coordinating the diverse battery testing activities of member laboratories to insure accurate results and avoid duplication of effort.

Battery Computer Modeling

In support of the DOE Electric and Hybrid Propulsion Program, Argonne National Laboratory (ANL) developed computer-based systems for technical analysis and modeling of electric and hybrid vehicles. During FY 1987, the capabilties of a software package named MARVEL were extended to increase its effectiveness as an analytical tool. MARVEL enables the design and least-cost optimization of the characteristics of an EV battery for a specified electric or hybrid vehicle and for a specified mission. Datasets were developed for 18 different battery systems, various vehicle types (urban vans, passenger cars), and several driving missions (Federal Urban Driving Schedule, SAE driving profiles). MARVEL is a user-friendly system available for the IBM-PC and other microcomputers.

Simulation Modeling

During FY 1987, DOE focused responsibility for electric and hybrid vehicle simulation modeling at INEL. Previously developed performance modeling codes including ELVEC, HYVEC and HEAVY were transferred from various inactive sites to INEL and made operational on a common computer system, and a number of test calculations were performed for subsequent verification against actual vehicle test results. Work was started on identification of tools for support of future DOE needs for technology forecasting, impact assessment and other analytical activities.

Use of Foreign Components

Section 14 (2) of Public Law 94-413 requires the Department to examine "the extent to which imported automobile chassis or components are being used, or are desirable, for the production of vehicles under Section 7.0, and of the extent to which restrictions imposed by law or regulation upon the importation or use of such chassis or components are impeding the achievement of the purpose of the Act."

No further vehicle purchases are being made under the provisions of Section 7.0 of the Act. Activities following the development progress of foreign made batteries, drivetrain components and vehicle systems are continuing.

7. RECOMMENDATIONS FOR INITIATIVES

The Department of Energy is not considering any new legislative initiatives to further the purpose of the Act. The current legislation is sufficient to stimulate the advancement of EHV technologies to the point where the private sector can determine their viability as transportation options and continue their development into marketable products.

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