NEW BATTERY FOR ELECTRIC CARS

U.S. PATENT 7,037,620 B2, May 2, 2006
MULTI-CELLULAR BATTERY WITH LEAD FOAM

A new battery has been developed especially for electric cars and is designed to replace Nickel-Metal Hydride and Lithium-Ion Batteries now being tested by major auto-makers.

The new **Tri-Polar Lead Cobalt Battery II** incorporates a number of improvements over its predecessor (the Tri-Polar Lead Cobalt Battery **I**), including a Lead Foam Substrate to replace hard lead grids, a Recirculating Electrolyte System, a Gas Purging System, an Automatic Watering System, an improved Tri-Polar Intracell and Intercell Connection System, and a Tongue and Groove Intercell Connection System. One hundred (100) claims were allowed on the patent for this sealed battery.

FIRST GENERATION BATTERY

Apollo's earlier battery, the Tri-Polar Lead Cobalt Battery **I**, was first produced in 1953 when it was made under the **ATLAS** brand for Esso Standard Oil of Puerto Rico. Shilstone Testing Laboratories of New Orleans, Louisiana tested the battery in 1966 in a MARS I Electric Car and found that it gave the car a range of 120 miles (a). A report for the Society of Automotive Engineers entitled "The MARS II Electric Car" showed that the MARS II, with these batteries, had a range of 70 to 120 miles (b). General Motors tested the battery in 1967 in a MARS II Electric Car and found that the Tri-Polar Lead Cobalt Batteries **I** gave it a maximum range of **146 miles** (c). Arizona Public Service drove a MARS II Electric Car 2,000 miles from Detroit, Michigan to Phoenix, Arizona in 1967 (d). In the two cross-country electric car races, the 1968 Great Transcontinental Electric Car Race (e) and the 1970 Clean Air Car Race (f), the winning vehicles were powered by Tri-Polar Lead Cobalt Batteries **I**, fast charging in 30 to 45-minutes between the California Institute of Technology in Pasadena, California and the Massachusetts Institute of Technology in Cambridge, Massachusetts. Over 100 full performance, highway electric vehicles were produced by Apollo's predecessor (Electric Fuel Propulsion Corporation—"**EFP**") (g), the first company since 1914 to offer electric cars for sale to the public.

SECOND GENERATION BATTERY

The new battery will have an energy density 2**.**946 times greater than the original battery and could easily replace Nickel-Metal Hydride and Lithium-Ion Batteries now being tested by some of the auto-makers. This means that the MARS II, tested by General Motors, would now have a maximum range of **430 miles** (146 miles x 2.846 = 430 miles).

A brief description of the improvements in the new battery follow:

Lead Foam Substrate.

The hard lead grids used in both positive and negative plates are now replaced with Lead Foam. This substantially increases the surface area of the hard lead grid and allows the active material of the plate (which chemically stores electricity) to reside in deep pores of the substrate and to produce electric current through thousands of lead conductors which allow the electrolyte free access to the active material. The contact between the active material and the lead conductors is over a thousand times greater than in the hard lead grid.

Recirculating Electrolyte System.

During the discharge of the battery, the sulfuric acid electrolyte begins to stratify, with highly concentrated acid migrating to the negative plate and water being formed on the positive plate, reducing conductivity and voltage between the plates, in accordance with the equation

$$PbO2 + H2 + H2SO4 = PbSO4 + 2H2O$$

During recharge of the battery, the reverse occurs. By circulating the electrolyte through the cell continuously, the density of the electrolyte remains constant at the positive and negatives plates, and stratification of electrolyte is virtually eliminated. This means that the battery can deliver maximum voltage to the electric motor of the car at all times.

Gas Purging System.

During operation of ordinary batteries, hydrogen and oxygen gases are formed and allowed to escape through vent caps on the battery cells. In VRLA (valve regulated lead-acid) sealed batteries, most of the hydrogen and oxygen are combined into water, but as cell pressure builds up, some of these gases are released through special valves. In either case, explosive gases escape from the battery which sometimes results in damaging explosions (4% hydrogen mixed with air is very explosive). This problem is solved with the new Tri-Polar Lead Cobalt Battery **II**. In this battery, the cells are sealed and gases are continuously removed from the cells and directed to a filter which disburses the gases into the air in a safe way without hydrogen concentration.

Automatic Watering System.

The Tri-Polar Lead Cobalt Battery **II** contains liquid electrolyte which is circulated throughout the cell to avoid stratification of the electrolyte. During the operation of the battery, hydrogen and oxygen gases are formed, which, in effect, removes some water (H2O) from the electrolyte (electrolyte consists of a mixture of sulfuric acid and water). As this water is removed, it is automatically replaced by an automatic watering system connected to all the cells in the battery.

Tri-Polar Intracell and Intercell Connection System.

In the Tri-Polar system, positive plates are connected to one another in three places, one at the top and two at the bottom of the cell. In a similar manner, the negative plates are connected to one another in the same way. Therefore, the plates contains six current collecting bus bars, two at the top of the cell and four at the bottom, thus a “Tri-Polar” construction within the cell.

At the bottom of the cell, the horizontal bus bars have vertical posts which protrude through the bottom floor of the cell. These posts are connected to a network of bus bars in such a way as to make an electrical connection from one cell to the other. The cells are also connected to one-another near the top of the cells with tongue and groove hardware (described below). Therefore, the “Tri-Polar” construction is effected between the cells.

The advantage of the Tri-Polar construction is that millions of current paths are opened up in and between the plates within the cell, and between adjacent cells, from cell to cell, resulting in maximum utilization of the active material in the cells, less voltage drop under high discharge and a flatter discharge curve under continuous high discharge. As a result, the cells are able to deliver more power and to accept high recharge currents. The Tri-Polar Lead Cobalt Battery **I** could be recharged to 80% of capacity in 22-minutes. With the added improvements, the recharge efficiency will be substantially improved in the second generation battery.

Another advantage of the Tri-Polar construction is that **vibration** of the plates and separators within the cell is virtually eliminated. This is why the Tri –Polar Lead Cobalt Battery **I** performed so well on tractors and other off-the-road equipment.

Tongue and Groove Intercell Connection.

A unique method for electrically connecting one cell to the other, near the top of the cell, is the development of tongue and groove hardware (silver plated lead). With this development, cells can be electrically connected to one-another without welding. A defective cell can be removed by hand, without tools, and replaced with another cell.

Cobalt

In 1953-1963, Tri-Polar Lead Cobalt Batteries **I** were sold extensively in Puerto Rico where temperatures are very high (80-100^{0}F) all year. This continuous heat resulted in a certain degree of self-discharge of the batteries. After a stand of 3 to 4 months, batteries would have to be recharged. By dissolving a small amount of cobalt sulfate in the sulfuric acid electrolyte, this problem virtually disappeared. Exide and Gould Batteries both obtained patents on this procedure at that time. The cobalt sulfate, after a few charge-discharge cycles, forms a protective layer on the surface of the positive plates, protecting the grids from oxidation. Even without using cobalt sulfate, self-discharge in Lead Foam Plates is lessened as sulfate crystals are much smaller when deposited in the small pores of the lead foam and are easier to convert back into the electrolyte in the charging process. Lead sulfate will always be used in second generation Tri-Polar Lead Cobalt Batteries **II.**

Battery Capacity and Cost

The battery capacity of the Tri-Polar Lead Cobalt Battery **I** is 37.2669 watt-hours per kilogram (WH/kg) (h). The theoretical capacity of a lead-acid battery is 170 WH/kg. It is reported that the capacity of Nickel-Metal Hydride Batteries is 90 WH/kg and the capacity of Lithium-Ion batteries is 110 WH/kg. Engineering calculations show that the Tri-Polar Lead Cobalt Battery **II** will have a capacity of 109.80 WH/kg, 2.945 times greater than the first generation battery. This means that the driving range of a car with the Tri-Polar Lead Cobalt Battery **II** should be greater than a car with a Nickel-Metal Hydride Battery and approximately the same as a car with a Lithium-Ion Battery.

However, the cost of the Tri-Polar Lead Cobalt Battery **II** is $75 per kilowatt-hour (kWh) vs. $360-$450/kWh for a Lithium-Ion Battery. A Lithium-Ion Battery weighing 450-pounds might cost $25,000, while a Tri-Polar Lead Cobalt Battery **II** of the same weight would cost $5,200 and take an electric car the same number of miles on a charge.

Life

Over 100 full performance, highway electric vehicles were built by EFP, most of them sold to electric utility companies (MARS II Electric Cars). They all were equipped with Tri-Polar Lead Cobalt **I** Batteries. The average time between the date of sale of the vehicles and date of replacement battery orders was 42-months (i). Some batteries lasted 60-months (Arizona Public Service, Los Angeles Department of Water and Power) and others 36-months (Illinois Power & Light). Engineering studies have shown that the new Tri-Polar Lead Cobalt Battery **II** made with Lead Foam plates, will have a cycle life of 1,500. This should equate to 600,000 miles (1,500 cycles x 400-miles per cycle).

SUMMARY

The Second Generation Tri-Polar Lead Cobalt Battery **II** will make it possible **now** for auto-makers to build Pure Electric Cars operated by batteries only. These cars will have to be recharged at night or at Charge Stations located away from home. Coin-Operated Fast and Slow Charge Stations were set up in California in 1980-81-82 and extensive testing made (i). Silver Volt Electric Car batteries (292 Ah) could be fast charged to 75% of capacity in 30-minutes (240 volts a.c. @300 amps). Charging the <u>second generation battery</u> at home may take 7-hours to replace 700 amp hours in an 80% discharged battery in a large car (240 volts a.c. @100 amps). In a small “Neighborhood Electric Car”, recharge time would be much less.

The battery could be included in the cost of the car, or could be leased. A $5,200 Tri-Polar Lead Cobalt **II** battery could be leased over a 60-month period for $86.67 per month plus interest.

FUTURE

In the future, Pure Electric Cars may be equipped with Fuel Cells + Batteries. The Fuel Cell in a car will keep the Battery charged at all times (j). Hydrogen and oxygen must be continuously supplied to the Fuel Cell. Oxygen comes from the air (79% of air is oxygen) which is pumped into the Fuel Cell. Hydrogen could come from a tank of gaseous hydrogen stored in a high pressure tank under the car (dangerous), or from liquid ammonia stored in a low pressure tank under the car. Ammonia would be fed to an Ammonia Cracker which would produce pure hydrogen and nitrogen. Both gases would enter the Fuel Cell and nitrogen (which does not enter into the chemical reaction inside the Fuel Cell) would exit to atmosphere. Ammonia Fuel Stations could be established at Propane Stations and elsewhere throughout the country. Ammonia is the second largest chemical produced in the world and is used extensively for fertilizer and refrigeration. It is shipped by truck, rail, pipeline, ship and barge. Safety standards for shipping and handling have been established universally.

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References: (reference material available at Apollo Energy Systems, Inc. and elsewhere)

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b. Society of Automotive Engineers, The MARS II Electric Car, number 680420, May 20-24, 1968
c. General Motors/Cornell Aeronautical Laboratory, CAL No. VJ-2623-K-1, February 1969
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g. Website: www.apolloenergysystems.com Click "Index Guide" go to Customers
h. Detroit Testing Laboratories, Test Report 007020 I, September 5, 1980
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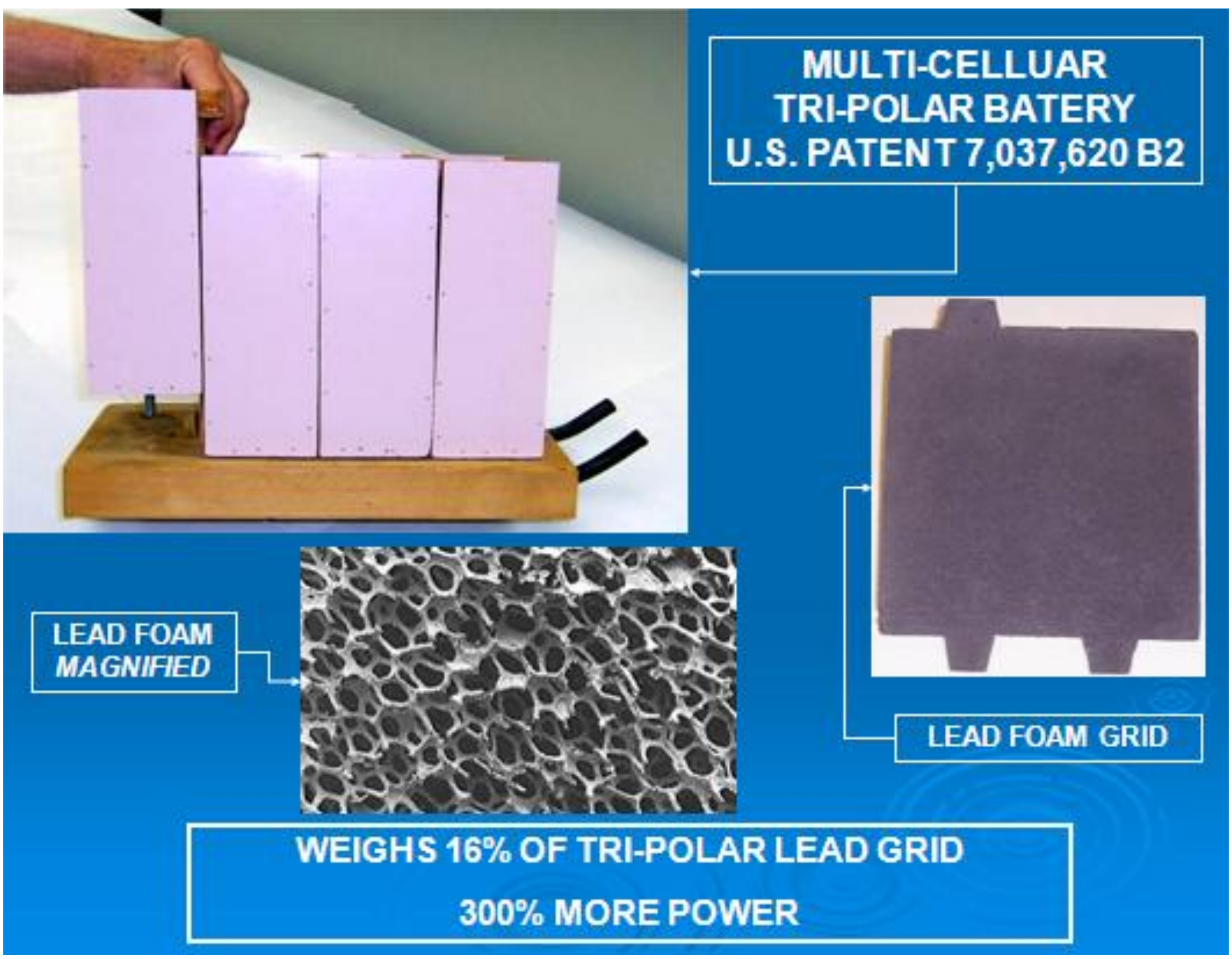
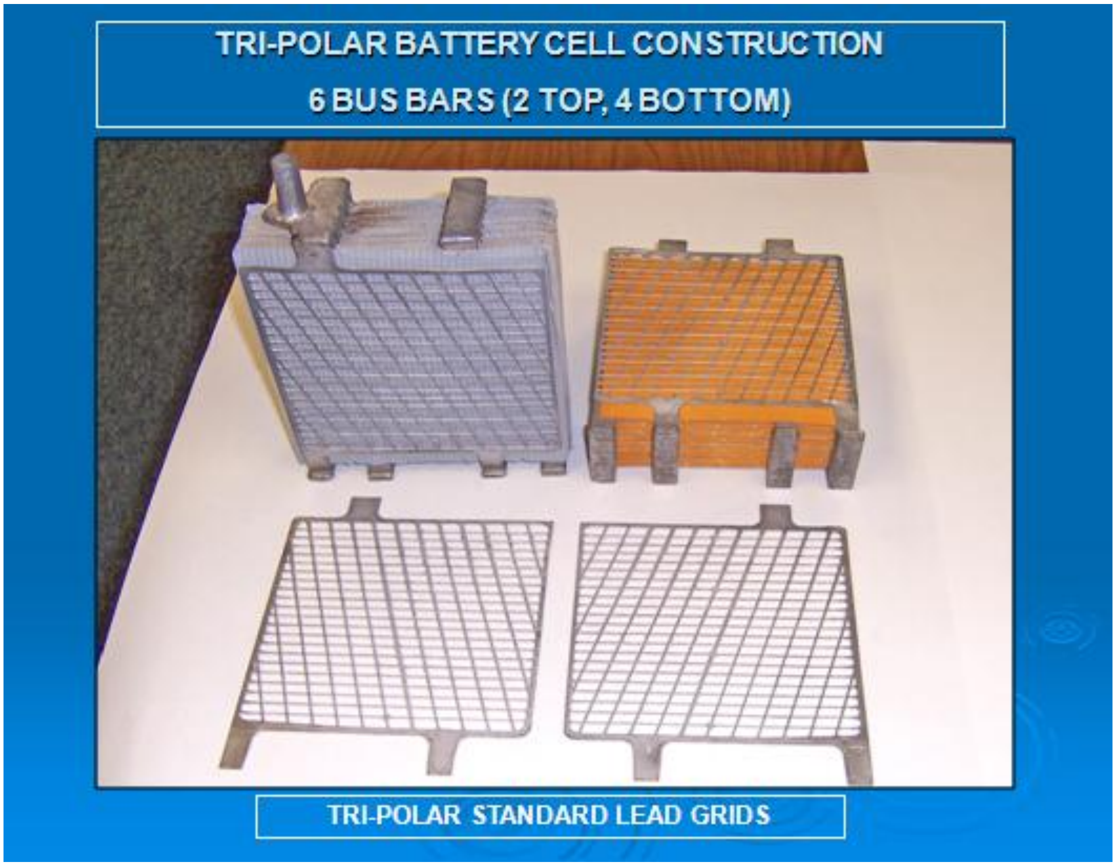
j. Fourth Annual Ammonia Conference, Hydrogen from Cracked Ammonia for Alkaline Fuel Cell, Rechargeable Battery Hybrids and ICE Vehicles, San Francisco, Oct. 15-16, 2007

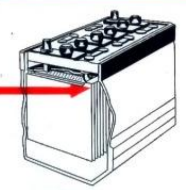



TRI-POLAR BATTERY CELL CONSTRUCTION
6 BUS BARS (2 TOP, 4 BOTTOM)
TRI-POLAR STANDARD LEAD GRIDS


ORDINARY BATTERY CELL CONSTRUCTION
2 BUS BARS AT TOP ONLY
ORDINARY LEAD GRIDS

LAS BATERIAS CORRIENTES TIENEN UN SOLO PUNTO DE SUJECION . . . .

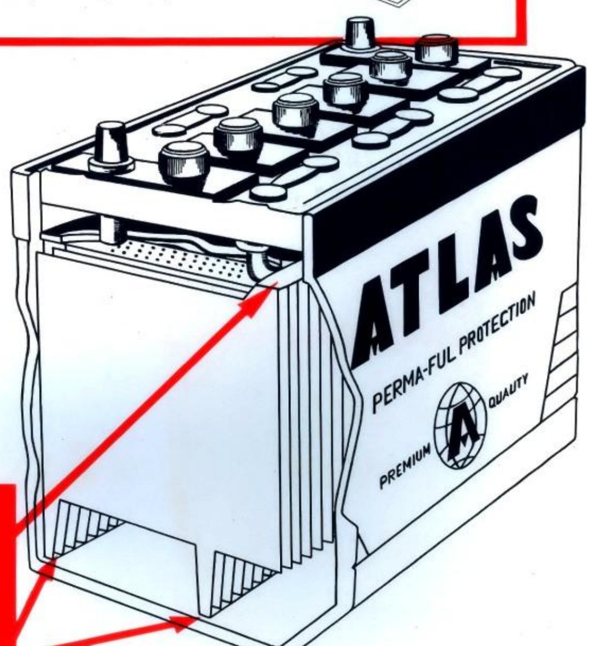
Es este el punto más débil, donde las baterías comunes sufren las consecuencias de las vibraciones del carro. En este único punto de sujeción es donde las placas internas se quiebran y desprenden, provocando corto-circuitos que restan potencia y duración a la batería.



LA NUEVA BATERIA

ATLAS

fue diseñada gracias al ensayo de miles de sistemas de fabricación entre los cuales fue seleccionado su nuevo, exclusivo y revolucionario procedimiento de . . .



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PUNTOS DE SUJECION

Con el que usted obtiene

2 AÑOS Y MEDIO DE GARANTIA.

La nueva patente de producción de ATLAS contempla y provee uno de los factores más importantes en el mantenimiento de una buena batería "LA VIDA INTERIOR". Igual que en los humanos el buen mantenimiento interior del cuerpo es fundamental para alargar la vida de una batería. Con los tres puntos de suspensión, la Batería ATLAS, evita los corto-circuitos y el desgaste de las placas (ionizadas) alargando indefinidamente la vida interior de la batería, dándole una POTENCIA SELLADA sin precedentes.

General Motors Test of Lead Cobalt Battery and MARS II Electric Car

On October 31, 1967, just after Arizona Public Service and completed a 2,000 mile trip from Detroit to Phoenix in a **MARS II** Electric Car on October 6, 1967, EFP received an order for a **MARS II** from General Motors. The Car was picked up from EFP's shop in Ferndale Michigan (a Detroit suburb) and taken to Buffalo, New York for over six months of testing by Cornell Aeronautical Laboratory, Inc. Cornell issued its 138-page report in February, 1969. Excerpts from that report are on the next pages.

The remarkable thing about this test was that the Lead Cobalt Battery drove the MARS II 146 miles on a charge - on pure battery power.

THE MARS II ELECTRIC CAR
146 miles range powered by patented Lead Cobalt Batteries

TECHNICAL REPORT

AN EXPERIMENTAL EVALUATION OF THE MARS II ELECTRIC AUTOMOBILE

by: James E. Greene

CAL No. VJ-2623-K-1

Prepared For:

GENERAL MOTORS CORPORATION
GENERAL MOTORS ENGINEERING STAFF
GENERAL MOTORS TECHNICAL CENTER
WARREN, MICHIGAN 48090

CONTRACT NO. CC-140

FEBRUARY 1969

CORNELL AERONAUTICAL LABORATORY, INC.

OF CORNELL UNIVERSITY, BUFFALO, N. Y. 14221

MARS II ELECTRIC CAR

WITH

120 VOLT, 27-kWh TRI-POLAR LEAD-COBALT BATTERY

General Motors/Cornell Aeronautical Laboratory test report VJ-2623-K-1, Feb. 1969

Table 2

FIXED-THROTTLE RANGE TEST RESULTS

GEAR	THROTTLE STEP	LOCATION	RANGE (MILES)	DURATION (HOURS)	AVE. SPEED (MPH)	AMBIENT TEMP (°F)	BANK 3 DISCHARGE AMP-HRS	AVE.[1] BANK CURRENT (AMP)	NOMINAL SPEED VARIATION	NOMINAL BANK CURRENT VARIATION
3	4	OVAL TRACK	146.8	6.74	21.8	66-73	226	33.6	18-24	32-44
2	6	OVAL TRACK	94.1	3.22	29.3	65-68	189	58.7	23-32	58-78
2	6	ON-ROAD	125.1	3.98	31.3	84-85	220	55.3	23-36	44-66
3	6	ON-ROAD	91.0	2.45	37.2	58-62	195	79.6	34-43	65-95
4	6	ON-ROAD	83.9	1.88	44.5	73-74	192	102.0	40-51	90-122

(CONTINUATION)

INITIAL SPECIFIC GRAVITY @ 77 °F	DISCHARGE SPECIFIC GRAVITY @ 77 °F	RECHARGE SPECIFIC GRAVITY @ 77 °F	BANK 3 RECHARGE AMP-HRS	RECHARGE A.C. KWH	RECHARGE DURATION (HOURS)	MILES/AH [2]	MILES/Δ SG [3]	MILES/KWH [4]	COST/MILE (¢) [5]
1.286 (80)*	1.060 (80)	1.285	235	49.1	19.0	.650	650	2.99	.67
1.282 (80)	1.097 (83)	1.284	-	44.8	18.0	.498	509	2.10	.95
1.286 (83)	1.082 (94)	1.287	-	~50	-	.569	614	2.5	.80
1.278 (80)	1.102 (83)	1.284	206	42.9	17.0	.467	517	2.12	.94
1.282 (90)	1.113 (96)	1.285	-	42.2	16.5	.436	496	1.99	1.00

1 DISCHARGE AMP-HOURS ÷ DURATION

2 RANGE ÷ DISCHARGE AMP-HOURS

3 RANGE ÷ (INITIAL SPECIFIC GRAVITY - DISCHARGE SPECIFIC GRAVITY)

4 RANGE ÷ CHARGER INPUT A.C. KILOWATT-HOURS

5 BASED ON 2¢ PER KWH

NOTE - SPECIFIC GRAVITY MEASURED IN CENTER CELL OF BATTERY NO. 15

*NOMINAL ELECTROLYTE TEMPERATURE (°F)

Utility vps watt rod it to Arizona

Arizona Public Service's electric car zips into Phoenix after crossing the country. Car, a Mars II, received "tremendous reaction" from public

You've heard the story . . .

About the electric car that has that extension cord . . . Goes like mad until it outruns its electric umbilicus.

Big joke.

Arizona Public Service heard the story, too, and today they are really laughing. Because October 6, APS finished driving an electric car—a Mars II—2,000 miles cross-country. And without an extension cord.

The 2,000 mile jaunt began in Detroit Sept 20, after APS purchased the second production model 1967 Mars II (first production Mars II was sold to Wisconsin P&L).

Developed by Electric Fuel Propulsion Inc, Ferndale, Mich., the Mars II—a much-modified Renault R-10—is the brain child of Robert Aronson, president of EFP, and Donald Swanson, a Ferndale Renault dealer and vice president of EFP.

Motorists wouldn't bat an eye at the utility's new car—unless they noticed a missing exhaust system, an absolute lack of engine noise, or the fact that the car had been trusted to the man who runs the substation.

By the time Mars II reached Phoenix, its final destination, it had passed through nine states, and made 36 planned stops about every 60 miles to recharge the car's 20 six-volt, lead-cobalt batteries.

"Refueling" was carried out at utility substations and garages and at restaurants along the route—preselected spots where APS drivers could plug their Mars watt-rod into a 240-w, 3-phase system. Jubilant APS personnel say that throughout the trip the car had received "tremendous reaction" from the public.

The drivers included, at various stages: Vice Presidents M. C. Titus, research & development, and Don Willis, marketing; Ted Dando, APS publicity manager; Bob Jones, project engineer; Paul Escen, APS photographer; and Robert Aronson, EFP's president. They reported that at normal cruising speeds of 45 to 55 mph, the car "worked perfectly." In St. Louis, however, the car was delayed a day due to mechanical, not electrical failure. The blame was put on a coupling that joins the motor to the drive shaft. It was quickly replaced.

Between a beefed-up suspension system and 1,700 lbs of batteries, the weight of a Mars II is 3,640 lbs compared to the usual R-10's 1,950 lbs. The car features a regenerative braking system that provides dynamic braking as it automatically recharges the batteries at currents that range from 165 amps at 60 mph to 30 amps at 10 mph. In addition, the APS electric carries a 12-v auxiliary battery that powers the magnetic control panel, lights, radio, and horn.

The differences between Mars II and the electrics of 50 years ago are great. Early electrics used conventional lead-acid batteries and, because the cars were slow and had extremely short ranges, they were strictly for in-town use (Grandma's Baker never made a 2,000-mile trip). On the other hand, Mars II, powered by a 15-hp direct current motor, can accelerate from 0 to 40 mph in ten seconds, can hit a top speed of 60 mph, and will run from 70 to 120 miles before the lead-cobalt batteries must be recharged.

Aronson claims that the batteries in his cars can be recharged 800 times, which would be equivalent to driving from between 56,000 to 90,000 miles. The batteries will accept a high recharge rate without damage to the cells. An 80% recharge on a completely discharged battery can be attained in 30 minutes; a 100% recharge in 90 minutes.

Once in Phoenix, the Mars II, which was named by Aronson's 9-year-old son Douglas, will be the center of an intensive promotion and publicity campaign to get the public interested in electric cars.

"We have purchased this car and have made the trip to stimulate public interest in the vehicle and at the same time give APS people first-hand experience with electric transportation vehicles," said Walter Lucking, Arizona Public Service chairman and chief executive officer.

Plug-in Battery + Fuel Cell Electric Vehicle
with 42 kWh Lead Cobalt Battery and 30 kW Apollo Fuel Cell