16:52:06 OCA PAD INITIATION - PROJECT HEADER INFORMATION 06/14/93

Active

Project #: B-757 Cost share #: Rev #: 0
Center # : 24-6-Q0757-000 Center shr #: OCA file #:
Work type : RES
Contract#: AGREEMENT SIGNED 6/3/93 Mod #: Document : AGR
Prime #: Contract entity: GTRC

Subprojects ? : N CFDA:
Main project #: PE #:

Project unit: AERO Unit code: 01.021.341
Project director(s):
MICHELSON R C AERO (404)528-7568

Sponsor/division names: SOUTHRN COALIT ADV TRANSP INC / ATLANTA, GA
Sponsor/division codes: 500 / 253

Award period: 930510 to 930709 (performance) 930709 (reports)

Sponsor amount	New this change	Total to date
Contract value	38,400.00	38,400.00
Funded	38,400.00	38,400.00
Cost sharing amount		0.00

Does subcontracting plan apply ?: N

Title: ELECTRIC & HYBRID ELECTRIC VEHICLE TECHNOLOGY FOR MILITARY USE

PROJECT ADMINISTRATION DATA

JUN 1993 RECEIVED SUPPORT SERVICES OCA

OCA contact: William F. Brown 894-4820

Sponsor technical contact

ANNIE HUNT BURRIS
(404)526-2873

SOUTHERN COALITION FOR ADVANCED
TRANSPORTATION C/O GEORGIA POWER CO.
21ST FLOOR
333 PIEDMONT AVENUE, N.E.
ATLANTA, GEORGIA 30308

Sponsor issuing office

ANNIE HUNT BURRIS
(404)526-2873

SOUTHERN COALITION FOR ADVANCED
TRANSPORTATION C/O GEORGIA POWER CO.
21ST FLOOR
333 PIEDMONT AVENUE, N.E.
ATLANTA, GEORGIA 30308

Security class (U,C,S,TS) : U
Defense priority rating : NA
Equipment title vests with: Sponsor X GIT
NONE

ONR resident rep. is ACO (Y/N): N
NA supplemental sheet

Administrative comments -
INITIATION OF B-757. OVERHEAD WAIVED.

8R209-55

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

NOTICE OF PROJECT CLOSEOUT

Closeout Notice Date 05/25/94
Original Closeout Started 08/19/93

Project No. B-757 Center No. 24-6-Q0757-000

Project Director MICHELSON R C School/Lab AERO

Sponsor SOUTHRN COALIT ADV TRANSP INC/ATLANTA, GA

Contract/Grant No. AGREEMENT SIGNED 6/3/93 Contract Entity GTRC

Prime Contract No. ____

Title ELECTRIC & HYBRID ELECTRIC VEHICLE TECHNOLOGY FOR MILITARY USE

Effective Completion Date 931009 (Performance) 931009 (Reports)

Closeout Actions Required:	Y/N	Date Submitted
Final Invoice or Copy of Final Invoice	Y	
Final Report of Inventions and/or Subcontracts	N	
Government Property Inventory & Related Certificate	N	
Classified Material Certificate	N	
Release and Assignment	N	
Other ____	N	

Comments ____

Subproject Under Main Project No. ____

Continues Project No. ____

Distribution Required:

Project Director	Y
Administrative Network Representative	Y
GTRI Accounting/Grants and Contracts	Y
Procurement/Supply Services	Y
Research Property Managment	Y
Research Security Services	N
Reports Coordinator (OCA)	Y
GTRC	Y
Project File	Y
Other ____	N
____	N

Volume I
Technical and Management Proposal

SECTION 1

Innovative Electric Transportation Technology for Demonstration in the Military and Private Sectors

ARPA Electric and Electric Hybrid Vehicle Technology and Infrastructure Research Program

Points of Contract for this Proposal

	Technical	Administrative
	Robert C. Michelson	David A. Bridges
E-MAIL:	michelsn@prism.gatech.edu	david.bridges@oca.gatech.edu
Phone:	(404) 528-7568	(404) 894-4817
FAX:	(404) 528-3271	(404) 894-6956
Address:	GTRI-AERO-CCRF 7220 Richardson Road Smyrna, GA 30080	Georgia Tech Office of Contract Administration Atlanta, GA 30332

This proposal is being submitted by the Southern Coalition for Advanced Transportation (SCAT) which is comprised of numerous entities. SCAT members participating in the response to RA 93 - 23 have been organized into seven teams with interests spanning several electric transportation technology areas, with some SCAT members, for reasons of efficiency and economy, providing umbrella services to the entire effort of the consortium. The following list includes the names and telephone numbers for the various principal points of contact on each team that have been responsible for gathering input for use in this proposal:

Atlanta Team	Brad Worthington	(404) 913-9682
Florida East Team	Bob Suggs	(305) 552-4133
Florida West Team	George Moore	(813) 974-4771
Georgia Team	Curtis Pearson	(410) 765-3958
Georgia North Team	Terri Hobbs	(404) 229-5995
Tennessee Team	Joe Ferguson	(615) 821-3146
Texas Team	Mark Ehsani	(409) 854-7441

June 1993

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Southern Coalition for Advanced Transportation

June 8, 1993

ARPA/LSO
3701 N. Fairfax Drive
Arlington, VA 22203-1714
(ATTN: RA 93-23)

Dear Sirs,

Thank you for the opportunity to submit a proposal in response to Research Announcement 93-23. The attached proposal will detail the program that has been assembled by the Southern Coalition for Advanced Transportation (SCAT) to meet the stated goals of ARPA.

Please note that each of the five copies of the SCAT proposal that has been submitted, includes two sealed envelopes containing proprietary information about certain processes proposed for use by two of SCAT's seven participating teams. This information is being supplied to ARPA to strengthen the case being made by SCAT in the main body of the proposal and represents part of that main body in terms of page count. This information has not been made available to the proposal preparation team, nor has it undergone Red Team review by SCAT or its agents. The teams submitting this proprietary information warrant that the sealed envelopes accompanying this proposal, detail portions of their input to the technical section of this proposal (especially those portions dealing with the technologies to be employed by the submitter) and are of the page count written on the outside of their sealed envelopes. *Should the page count be found to exceed that written on the outside of the sealed envelopes, then the excess pages should be disregarded and should not count against the total page count of this proposal*).

The SCAT Board of Directors contact for this proposal is Ms. Annie Hunt Burriss, (404) 526-2873 or Joseph Ferguson, President - SCAT Board of Directors, (615) 821-3146.

Should you have any questions of a technical nature, please contact:

Robert C. Michelson (Proposal Manager)
Georgia Tech Research Institute
(404) 528-7568 [michelsn@prism.gatech.edu]

Administrative or legal questions should be directed to:

David Bridges
Georgia Tech Office of Contract Administration
(404) 894-4817 [david.bridges@oca.gatech.edu]

Sincerely,

Annie Hunt Burriss, Acting C.O.O.
and member, SCAT Board of Directors

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(not intended as part of page count)

SECTION II. SUMMARY OF PROPOSAL

A. DEFINITION OF THE PROBLEM AND THE PROPOSED SOLUTION

The various teams which are contributing to the proposed Southern Coalition for Advanced Transportation (SCAT) program (see Table 1) have offered various projects which address many of the issues associated with electric transportation. Seven proposed projects are summarized in this section. Each project is comprised of several tasks that address one or more of the goals set forth in the RA 93-23 statement of work. Taken in their entirety, the various projects create the proposed SCAT program which is fully compliant with the requirements of the statement of work, but goes beyond to provide a number of technology variants spread across enough vehicle platforms to yield a statistically significant sample for analysis.

Problem Identification

The need for mobility is a major source of air pollution in the United States, since all cars, vans, and buses currently rely on internal combustion engines burning fossil fuels. Our country's dependence on foreign oil is an Achilles heel to our status as *the* world superpower. As demonstrated in the past, foreign oil can be an unreliable, volatily priced source of fuel. This dependence must be recognized and addressed.

In the conventional design of the internal combustion engine (ICE) vehicle, the engine is sized to satisfy the peak power demand of the vehicle. However, the vehicle demands far less than this peak power, most of the time. This results in an engine that is oversized for the vehicle in the great majority of its operating duty. Furthermore, the engine operates away from its most efficient operating point, most of the time. The combination of this oversized and mismatched problem results in a vehicle that uses much more fuel than it needs, for the same performance. This inefficiency can be improved with electrically powered vehicles.

Electric vehicles are currently limited in performance and range characteristics, and climate control systems further compound the problem. The electric vehicle concept is severely limited by its battery, such that one cannot have both the range and the acceleration of a conventional ICE vehicle. A fundamental limitation imposed by physics is that any battery combined with an electric motor will fail to match a conventional ICE with a tank of gasoline, when comparing range and acceleration. Consequently, higher efficiency electric drive-train systems, as well as battery technology, climate control technology, and lightweight high strength bodies and frames, are needed to improve performance and range characteristics of electric vehicles. Reliable fast charging systems that will prolong battery life, improve battery capacity, and reduce battery maintenance will also improve electric vehicle functionality, usability, and desirability.

Proposed Solutions

Atlanta Team

The Atlanta team proposes to develop electric vehicles using off-the-shelf technology. They will apply an integrated, unified view of the electric vehicle which optimizes overall vehicle performance and operation. The systems integration approach presented in the Atlanta project defines a "plug-and-play" platform whereby different component technologies can be switched out with a minimum

TABLE 1. *MAJOR* TASKS COMPRISING THE SCAT PROGRAM

PROJECT	TEAM LEADER	MAJOR PRODUCT	#	IMPLEMENTATION	TECHNOLOGY	VENUE
Atlanta Team	ATR	Cars	12	Conversion	Pure Electric	Civilian
		Trucks	8	Conversion	Hybrid-Electric	Civilian
Florida East Team	FPL	S-10 Truck	5	Conversion	Pure Electric	Military
		Station Car	20	Conversion	Pure Electric	Civilian
		Bus	1	New Develpmnt.	Pure Electric	Civilian
		Pick-up Truck	5	Conversion	Pure Electric (DC Drive)	Civilian
		Pick-up Truck	5	Conversion	CNG Hybrid (AC Drive)	Civilian
		Van	4	New Development	Pure Electric (AC Drive)	Civilian
		Car	2	Impact (stock)	Pure Electric	Civilian
Florida West Team	USF	S-10 Truck	5	Conversion	Pure Electric	Military
		S-10 Truck	30	Conversion	Pure Electric	Civilian
Georgia Team	Westig-house	Pick-up Truck	5	Conversion	Pure Electric	Military
		Bus	3	Conversion	Hybrid-Electric	Military
		Bus	3	Conversion	Pure Electric	Civilian
Georgia North Team	Metro-trans	Bus	1	New Develpmnt.	Hybrid-Electric	Military
		Bus	2	New Develpmnt.	Pure Electric	Civilian
Tennessee Team	AVS	Bus	2	New Develpmnt.	Hybrid-Electric	Civilian
		Bus	2	New Develpmnt.	Pure Electric	Civilian
Texas Team	Texas A & M	S-10 Truck	2	Conversion	Hybrid-Electric	Military
		Car	1	Conversion	Hybrid-Electric	Civilian

of re-engineering (preferably none) as the opportunity arises. This approach will pay its greatest dividends in the early years of electric vehicle development while the nature of the accepted technology is still settling out. While some components (e.g. drive-trains) are less amenable to this retrofit philosophy than others, a great opportunity exists to demonstrate prototype battery technology, recharging technology (both while moving and stationary), and onboard energy management.

Florida East Team

The Florida East team intends to address the need for improved electric hybrid vehicle technology through tasks that include high efficiency AC drive-train systems, high efficiency battery systems and chargers, a solid polymer fuel cell, and newly-researched high efficiency climate control systems. They will also focus on public awareness and acceptance of electric vehicles used in conjunction with mass transit systems. To improve ridership on mass transit systems and appeal to upscale ridership, electric vehicles will be located at terminal points of existing mass transit systems. These vehicles will be available for use to subscribers to complete their daily commute. These "station cars" will provide terminal end flexibility for the mass transit systems user. Other testing will be performed with various vehicles including five government furnished S-10 trucks that will be converted to electric propulsion and operated at Patrick Air Force Base. Training courses will be developed for maintenance and support groups to ensure proper knowledge transfer of this newly emerging industry.

Market research will be performed to determined the optimal scope and timing of electric vehicle penetration into the market. Demographic and physchographic profiles of potential electric vehicle users will be generated and infrastructure needs assessment will be ascertained to help utilities develop a network of charging systems to accommodate electric vehicle user needs.

Florida West Team

The Florida West team will deploy up to 15 pick-up trucks and 2 light utility vehicles at a military base in order to assess the operational, logistical, and perceptual problems associated with operating electric fleet vehicles. Each vehicle will be supplied with an onboard battery charger and up to 15 AC outlets will be installed at 15 parking spaces in the base supplied electric vehicle parking area. One fast charger will also be installed on the military base. MacDill AFB is recommended for this task. Also, to provide a reasonable statistical sample, between 30 and 40 electric vehicles will be deployed, operated, and monitored over a two year period by Florida Power Corporation. Charging stations will be installed at the electric vehicle parking facilities and at key locations for opportunity charging. The deployed vehicles will be tested to determine the performance, reliability, range, necessary maintenance, human factors and operator comments, and infrastructure scheme required to enable these vehicles to perform their assigned functions in selected applications.

Several technologies will be tried during this project including: lead-acid battery state-of-charge indicators (electronic fuel gauge), rapid charging systems, advanced traction motors and controllers, nickel metal hydride batteries, onboard capacitive load management, efficient onboard HVAC units, and efficient electric vehicle lighting.

Georgia Team

The Georgia team is proposing a fully integrated effort that will evaluate electric and hybrid electric vehicle technologies from power generation, to infrastructure support, to vehicle performance, and to customer expectations and needs. The Georgia team proposes to place both electric and hybrid electric vehicles in military and commercial service, evaluate consumer expectations and requirements for vehicles, study the impact of these vehicles on the infrastructure and the environment, and collect operation data on all the vehicles for comparison among other SCAT team members as well as other consortia.

This program will develop and integrate vehicle components and technologies as well as the supporting infrastructure required to make them viable. The program will support armed forces vehicle needs by converting 5 (half ton) pick-ups to electric propulsion and three 30-passenger buses to hybrid electric propulsion for use on a military installation {RA Part 1}. The charging stations and natural gas infrastructure required to operate these vehicles will be installed on the military base and the Georgia team will provide training in the safety, maintenance, and operation of the vehicles for base personnel. The program will additionally evaluate the commercial applicability of electric vehicle technologies by developing three midsize electric buses that will be placed in shuttle service on the campus of the Georgia Institute of Technology {RA Part 2}. This will afford the opportunity to evaluate vehicle acceptability in a commercial environment.

> NOTE: The body of the Georgia team project description is proprietary and is contained in one of the sealed envelopes attached to this proposal.

Georgia North Team

The Georgia North team proposes to build a safe, practical, affordable, high-performance hybrid-electric vehicle utilizing developing technologies. The Georgia North team plans to replace an existing bus at Warner Robins AFB with this new hybrid bus. They will provide the infrastructure necessary for recharging, servicing, and maintaining this vehicle. Training will be provided to base personnel along with continuing education classes. Vehicle onboard data collection will be provided to confirm performance and operational effectiveness. This minimal emission prototype hybrid-electric bus will pave the way for future replacement of current internal combustion engine medium-duty passenger buses on all military bases. The Georgia North team also plans to supply 2 all-electric airport shuttle buses at Atlanta's Hartsfield International Airport.

Tennessee Team

The Tennessee team proposes to develop four state-of-the-art 30-foot buses which will have advanced AC induction individual rear wheel propulsion systems. The batteries will be lead-acid. Two of the buses will have a natural gas auxiliary power unit (APU) range extender and two will be pure electric. Range extension on the pure electric will be accomplished with rapid recharging and quick battery change-outs. EPTI will provide a prototype rapid recharger under proprietary technology. The EPTI charging method to be used by the Tennessee team is unique in that it shortens the charging cycle while prolonging battery life. In addition to new electric technologies, the Tennessee team is focusing on composite materials which will be used in the construction of the bus as well as the natural gas fuel tanks. This project will prove that the Tennessee team approach to battery powered electric buses is more than adequate to meet today's requirements for power and range.

Two buses will be put into service in Chattanooga's "Living Laboratory" and operated by the Chattanooga Area Rapid Transit Authority (CARTA). Two will be put into service in downtown Atlanta and operated by the Georgia Power Company working closely with the Atlanta Metro Area Rapid Transit Authority (MARTA).

Texas Team

The Texas project team has solved the problems of ICE powered vehicles with a new concept of a hybrid ICE-electric propulsion system which avoids the battery limitations of a pure electric vehicle. The Electrically Peaking Hybrid (ELPH) system is a new and proprietary parallel internal combustion engine and electric drive technology. ELPH technology can make a typical sedan, for example, operate with up to four times better fuel economy with as little as $^{1}/_{16}$ the emissions, improved acceleration, and all without sacrificing vehicle range. Furthermore, the small size of the internal combustion engine used in the ELPH architecture can be economically and safely run on compressed gaseous fuels. This, along with other ELPH-specific innovations are responsible for this technology's low emission achievements. The ELPH car can be designed to use natural gas, propane, or gasoline, thus giving it the flexibility to replace imported oil with domestic gas. ELPH is based, entirely on existing component technologies and no new component research is needed for this demonstration.

NOTE: The body of the Texas team project description is proprietary and is contained in one of the sealed envelopes attached to this proposal.

B. DELIVERABLES ASSOCIATED WITH THE PROPOSED EFFORT

Table 1 describes the *major* tasks proposed by each team and the features which make the particular projects unique parts of the overall SCAT program. Note that this coalition offers a mixture of vehicle types (different kinds of buses, trucks, and cars), electric propulsion technologies, methods of implementation, and venues. In addition, as described in the body of this proposal, there are various subtasks which feed new support technology into these team projects.

Atlanta Team Deliverables

Atlanta team deliverables are as follows:

1. 12 automobiles
2. 8 trucks
3. Computer-based onboard intelligent vehicle management system (IVMS)
4. Empirical results from hybrid lead acid/zinc-air battery experiments
5. Empirical results from pulsed microwave roadbed-based recharger experiments
6. 20 program-controlled onboard rechargers
7. SCAT Standardized Data Acquisition Network data base and presentation software

Florida East Team Deliverables

The Florida East project shall deliver:

1. 5 S-10 trucks (from Patrick AFB)
2. 4 light weight vans
3. 10 pickup trucks
4. 2 General Motors (off-the-shelf) Impacts
5. 20 station cars
6. 1 bus (powered by an electric drive-train using a fuel cell/battery combination)

Florida West Team Deliverables

The Florida East project shall deliver:

1. Up to 13 trucks and 2 light utility vehicles (military)
2. 30 S-10 trucks (commercial)
3. State-of-charge (SOC) indicators for lead-acid, nickel metal hydride, nickel iron, and lead-acid gel cell batteries
4. Single rapid charging stations located on base, at the Florida Power Corporation, and at key locations for opportunity charging
5. Three 150 KW chargers
6. 6 nickel metal hydride batteries will be produced to equip up to 6 vehicles
7. A capacitor pack, designed to act as an auxiliary power supply to assist electric vehicles recover more energy during regeneration and reduce peak drain during acceleration, shall be built.

Georgia Team Deliverables

The Georgia Team shall deliver:

1. 5 half ton pick-up trucks converted to pure electric operation
2. 3 30-passenger buses converted to compressed natural gas (CNG) hybrid electric operation (military, Warner Robin AFB)
3. 3 buses converted to pure electric operation for shuttles on the Georgia Tech campus

NOTE: The body of the Georgia team project description is proprietary and is contained in one of the sealed envelopes attached to this proposal.

Georgia North Team Deliverables

The Georgia North team proposes to provide:

1. 1 hybrid bus to replace an existing bus at Warner Robins AFB
2. 2 all electric shuttle buses for operation at Atlanta's Hartsfield Airport
3. Data collection systems on all three buses
4. Maintenance instructions
5. 3 AC charging systems for buses
6. Spare parts
7. Technical and Cost Reports
8. Cost Reports

Tennessee Team Deliverables

The Tennessee Team proposes to deliver:

1. 2 Hybrid-Electric Buses
2. 2 Pure-Electric Buses
3. Rapid Recharge Stations

Texas Team Deliverables

The Texas Team proposes to deliver:

1. 2 S-10 Trucks (Military)
2. 1 Car (civilian)
3. 1 carbon fiber flywheel battery storage system (new development)
4. 1 fiber optic combustion pressure sensor (new development)

Proprietary Claims to Results and Prototypes

Results, prototypes, and intellectual property developed under this program are proprietary and should be considered the property of the contributing participants of SCAT, and therefore shall not be released without prior written authorization of the contributing participant. It is the intent of SCAT to make its findings as widely available as possible while not compromising the patentability or marketability of its constituents' developments.

C. COST AND SCHEDULE FOR *MAJOR* TASKS

Table 2 shows each of the major tasks for the SCAT teams and gives the cost to ARPA for each of these tasks. Note that cost sharing is not reflected in this table, only the cost to ARPA. Also, the tasks shown for each project are in some cases combinations of subtasks which are broken out individually in the cost volume to this proposal.

D. TECHNICAL RATIONALE AND APPROACH

Atlanta Team Rationale and Approach

The Atlanta team will develop an intelligent vehicle monitoring system (IVMS) and a fast battery recharging system as parts of the conversion development. Power will be supplied by a hybrid lead-acid/zinc-air battery system. Recharging will be accomplished through a non-contacting RF energy transfer from the roadway to the vehicle via a rectifying antenna onboard the vehicle.

Florida East Team Rationale and Approach

The Florida East team will undertake a number of conversions and new developments to create several pure electric and electric hybrid vehicles. Battery technology will center on lead-acid batteries used in conjunction with a rapid recharging system. Both DC and AC drive systems will be tested. The team will also develop a bus powered by a solid polymer hydrogen fuel cell and convert 5 vehicle to natural gas/electric hybrids. An important task will be to focus on improving the efficiency of the vehicles' climate control systems to reduce the drain on the electric power system.

Florida West Team Rationale and Approach

The Florida West team will conduct research and technology development for: high power quality fast chargers, highly efficient direct drive motors, EMF measurements, "fuel gauge" for advanced batteries, energy peaking capacitor storage, improved efficiency vehicle HVAC, testing of advanced nickel metal hydride batteries, development of battery monitoring and control, and application of efficient vehicle lighting. These technologies will be demonstrated by converting military base supplied pick-ups to electric, converting utility supplied pick-ups for fleet operation, and providing two light weight utility vehicles for military base fleet operation.

Georgia Team Rationale and Approach

The Georgia team will use demonstration vehicles to insert new technologies in propulsion and auxiliary systems developed during this program {RA Part 3}. An advanced high performance power train including an advanced AC induction motor will be common to both the trucks and buses. The electric and hybrid electric buses will be configured using a thirty-foot chassis. The hybrid configuration will use a compressed natural gas diesel generator as a secondary power source. The electric buses will use the same drive components as the hybrid (without the generator) but will carry

TABLE 2. HIGH-LEVEL SCHEDULE FOR INDIVIDUAL PROJECT TASKS

TEAM	TASK	COST	1993				1994				1995			
			1	2	3	4	1	2	3	4	1	2	3	4
Atlanta Team	Cars (12)	$436,300				■	■	■	■	■	■	■	■	■
	Trucks (8)	$246,700				■	■	■	■	■	■	■	■	■
Florida East	S-10 Trucks (5)	$133,600				■	■							
	GM Impact Program	$645,250				■	■	■	■					
	Broward Elec. Vehicles (5)	$102,475				■	■							
	Broward Hybrid Vehicles (5)	$153,625				■	■	■						
	Broward Passenger Composite Vans (2)	$82,185				■	■	■						
	Broward Cargo Composite Vans (2)	$88,585				■	■	■						
	Station Cars (20)	$360,000				■	■	■						
	Fuel Cell Bus	$462,500				■	■	■	■	■				
	Market Analyses & Policy	$225,662				■	■	■	■	■	■	■	■	■
	Training	$128,800				■	■	■	■	■				
	Demonstration & Support	$438,300				■	■	■	■	■				
Florida West	Convert Lead-Acid S-10 Truck	$50,000				■								
	Convert Nickel-Metal Hydride S-10 Truck	$180,000					■							
	Convert 2 Trucks (Lead acid) for Military	$42,000							■					
	Convert Trucks for Civilian sector (30)	$305,000				■	■	■	■	■	■	■	■	■
	Advanced Vehicle	$100,000											■	■
Georgia	Design	$1,220,562				■	■	■	■					
	Testing/ Evaluation	$451,399					■	■	■	■	■	■	■	
	Electric Pick-up Fab (5)	$191,546				■								
	Electric Bus Fab (5)	$443,859					■							
	Piston Electric Hybrid Fab (5)	$447,560					■							
	Sure Charge Station Fab	$194,088					■							
Georgia North	Buses (2)	$883,000												
	Design/ Build Bus 1					■	■	■	■	■				
	Bus 1 Evaluation	$539,000				■	■	■	■	■	■			
	Test 2 Buses	$483,000										■		
Tennessee	Buses (2) (Hybrid)	$1,269,000				■	■	■	■	■	■	■	■	
	Buses (2) (Pure Elec.)	$1,119,000				■	■	■	■	■	■	■	■	
Texas Team	Final ELPH Trucks (2)	$530,136				■	■	■	■	■	■	■	■	
	ELPH Mule Truck	$883,560				■	■	■	■					
	Final ELPH Car (1)	$530,136				■	■	■	■	■	■	■	■	
	ELPH Mule Car	$530,186				■	■	■	■					

a larger battery package to meet the range requirements. The Georgia team will minimize the effect of recharging on the vehicle availability by providing rapid charging stations. The quick charger will also extend the battery life by reducing the stresses during charging. The Georgia team will develop the infrastructure, training and maintenance programs to support integration of electric and hybrid-electric vehicles into fleet and consumer use. The team will also study the impact of electric vehicles on existing infrastructure, public awareness, and user requirements. The Georgia team will conduct EV demos through this program to promote public awareness {RA Part 4}.

Georgia North Team Rationale and Approach

The Georgia North team will pursue pure electric and electric hybrid bus designs. The power train will be identical for all the electric and hybrid vehicles and will utilize two high performance AC induction motors capable of regenerative operation mounted at the rear wheels. Off-the-shelf GNB battery type 12-EVG-1180 will be used in both designs. The chassis and body will incorporate an aerodynamic design promoting laminar air flow around body minimizing drag and rolling friction.

For the hybrid design several different power sources for the APU will be considered including internal combustion diesel engines and turbines. Candidate power sources will use diesel fuel. The APU will be packaged as a complete unit including an alternator, integrated controller, cooling system, and exhaust system. The vehicle control computer will provide traction /brake management based on operator inputs and will control the APU to maintain the proper battery charge and optimize emissions and fuel economy (hybrid unit only). It will also interface with the dashboard functions, control the battery charger, and provide diagnostics and fault management.

Tennessee Team Rationale and Approach

The four buses will be supplied by AVS and will be purpose-built as pure electric and electric hybrid vehicles. Motive power will be produced by a single liquid-cooled AC induction machine with an integrated transmission for each driving wheel. The buses will have innovative state-of-the-art battery change-out capability permitting the complete battery set to be changed out in under 5 minutes by one person. The proposed lead-acid battery modules incorporate a sealed, gas recombinant construction which makes them inherently safer and easier to handle than flooded batteries and are maintenance free. The battery packs, drive units, and inverters will together comprise the heart of the vehicle propulsion system. The DC-to-DC converter will draw from the propulsion energy storage to supply power to the nominal 12 VDC vehicle accessory loads. The propulsion system will also be capable of accepting electrical power from off-vehicle sources to replenish the battery pack. A rapid battery charging system will monitor the following information: starting charge time, present current, cumulative energy delivered to the batteries, voltage across the batteries, and time to charge completion.

A very low emission auxiliary power unit driving a generator will be used in the hybrid design as a range extender in order to keep the bus under electric propulsion at all times. Initially the Tennessee design will employ a very compact gasoline powered, vertical, four-stroke internal combustion engine coupled to an induction type generator. During year two of the Tennessee project, the APU will be converted to CNG with perhaps more advanced generator technology.

Tennessee's upgraded engine will likely be coupled to either a high efficiency, permanent magnet generator/starter, or improved AC induction machine. The machine will be more fully integrated with the engine and serve both as the APU generator and engine starter (cranking motor).

Texas Team Rationale and Approach

The Texas team will pursue its Electrically Peaking Hybrid (ELPH) system which is a parallel internal combustion engine and electric drive design. The demonstration will be done by retrofitting two S-10 military trucks and one Oldsmobile Cutlass passenger car with the ELPH drive system. Two primitive versions of the ELPH car will be built (ELPH "mules") within six months and twelve months, respectively, from contract award. These will be used to test and refine the final design plans which will be applied to the three ELPH vehicles delivered at the end of the project. In addition, they will perfect two other component technologies: a carbon fiber flywheel battery storage system and a fiber optic combustion pressure sensor. Finally, they will conduct and report studies related to the commercialization and introduction of the ELPH vehicles to market.

E. PROGRAM RISK REDUCTION

Each of the SCAT project teams will employ methods of risk reduction specific to their projects. Risk reduction at the consortium level will be derived through standardization of procedures and equipment that is common to all SCAT program team projects.

The first area of risk reduction through standardization will be data acquisition. As a service to all of the teams and in an effort to consolidate the output data from the entire SCAT program, this standard will be imposed upon the data acquisition, reduction, and presentation. Specifically, a standard data acquisition network and protocol has been defined which is based largely on off-the-shelf data manipulation hardware, software, and various existing network infrastructures (see Figure 1). In a similar fashion, risk will be reduced by the SCAT project teams' use of E-MAIL communication as a medium for information exchange and broadcast. The base line capability of each networked member of the SCAT consortium will be defined by the features and capabilities contained within the shareware pop-mail program *Eudora*.

Another high-level risk reduction measure is SCAT's overall product-neutral program management team (the Georgia Tech Research Institute (GTRI)). To effectively coordinate all efforts, GTRI will serve in the role of Program Director and act as "Contract Officer's Technical Representative (COTR)" for the SCAT Board of Directors. Functions which are global in nature (such as data acquisition, public education, etc.) will be organized and handled at the program level for the benefit of all team projects. Further risk reduction will be made placing much of the "soft science" activity at a high enough level to be of use by all of the SCAT projects. DeVry will be working closely with several of the SCAT project teams in the area of the soft sciences and the procedures that they develop will be made available to the other teams as well. This will serve two purposes, first, the work performed by DeVry can be leveraged for use throughout the SCAT consortium at little or no extra cost to SCAT or the government. Second, the methods and procedures for gathering information relative to the soft sciences will be standardized across SCAT, thereby increasing analysis efficiency and coordination of results.

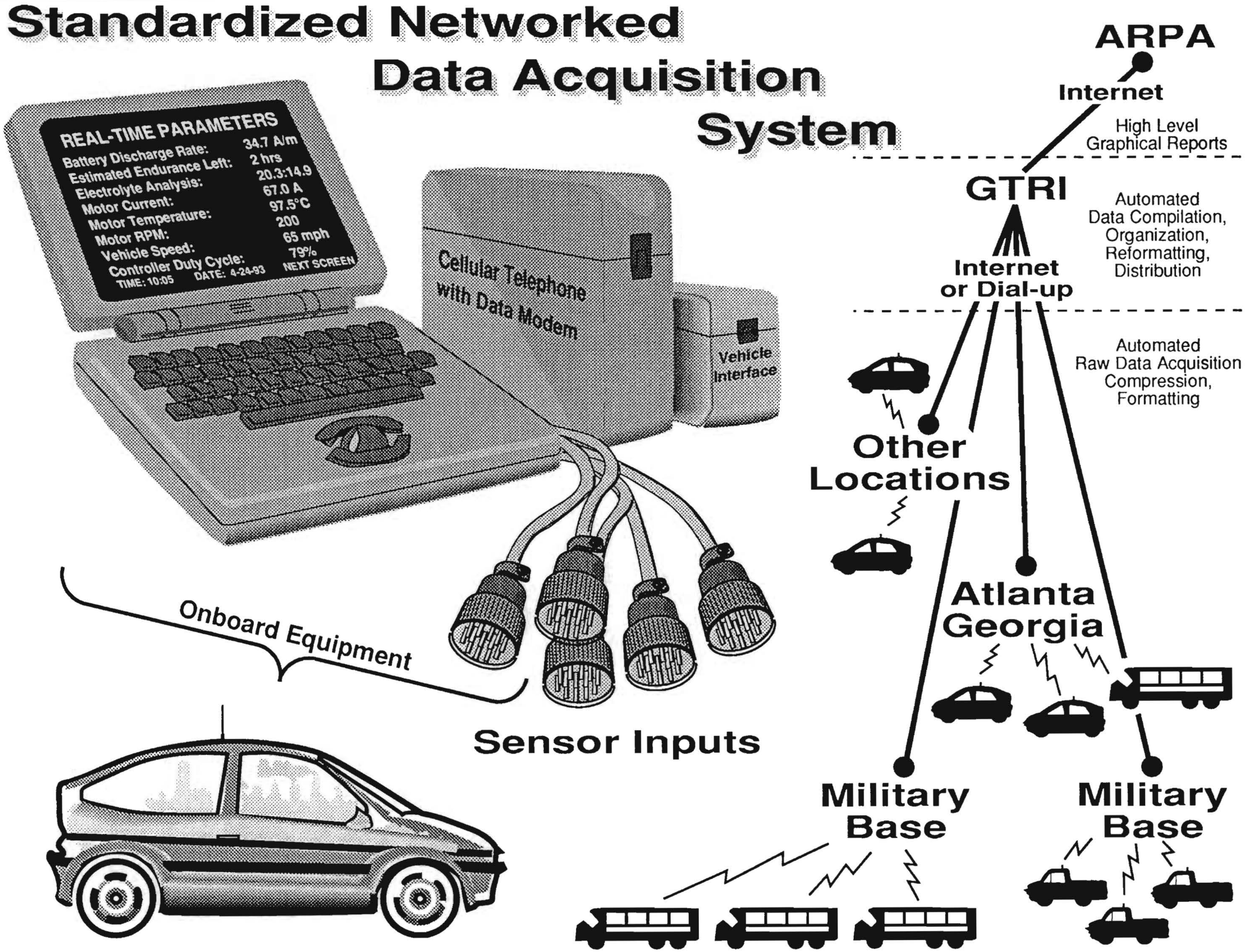

Figure 1. SCAT Standardized Data Acquisition Network.

F. LIST OF PARTICIPATING ORGANIZATIONS

Table 3 lists the participants in SCAT along with their shortened code names and team affiliations. Refer to Table 3 for definitions of acronyms used in subsequent tables.

TABLE 3. LIST OF SCAT ORGANIZATIONS PARTICIPATING IN THIS PROPOSAL

CODE	COMPANY NAME	TEAM
AAT	A.A. Technologies	Texas
ATEC	Advanced Transportation & Energy Concepts	Atlanta
ATR	Advanced Transportation Research	Atlanta, Florida East
AVS	Advanced Vehicle Systems	Tennessee
BBBC	Blue Bird Body Company	Georgia
DRAT	Delco Remy/Allison Transmission	Tennessee
DU	Duke University	Atlanta
DVRY	DeVry Insititute of Technology	Florida East
EPTI	Electronic Power Technology, Inc.	Florida East, Tennessee
ESI	Electrosource, Inc.	Texas
FPLC	Florida Power & Light Company	Florida East
GEC	General Electric Company	Georgia North, Texas
GNB	GNB Industrial Battery Company	Atlanta, Georgia North
GP	Georgia Power	Georgia, Georgia North, Tennessee
GT	Georgia Institute of Technology	Atlanta, Georgia
GTRI	Georgia Tech Research Institute	Atlanta, SCAT
LSG	Lone Star Gas Company	Texas
MATSI	MATSI, Inc.	Atlanta
ME	Micon Engineering	Texas
MTC	Metrotrans Corporation	Georgia North
SCC	Solar Car Corporation	Atlanta, Florida East
SMI	Spartan Motors, Inc.	Georgia North
T A&M	Texas A&M University	Texas
TBC	Trojan Battery Company	Florida West
TRW	TRW Corporation	Atlanta
UCF	University of Central Florida	Atlanta
USF	University of South Florida	Florida West
UTA	University of Texas Austin	Texas
WEC	Westinghouse Electric Company	Georgia

Effort to be Expended by Each Organization per Year

The effort to be expended by each project team within SCAT is shown in Table 2. The efforts shown cover each of the parts of the RA 93-23 RFP, military base experiments, commercial and private user experiments, advanced component and systems research, and public acceptance analyses/training.

Key Personnel

Key personnel associated with the SCAT consortium are listed in Table 4. Also shown are their roles or titles and their qualifications.

G. LIST OF EXISTING FACILITIES & EQUIPMENT, AND RESOURCES

Table 5 lists the facilities, equipment, and resources that will be made available by SCAT upon award of an electric or electric hybrid vehicle contract.

H. BUSINESS PLAN FOR SCAT

The Southern Coalition for Advanced Transportation, Inc. (SCAT) is a non-profit corporation of participating organizations who have an interest in electric transportation products and systems, and are representative of the southern region but inclusive of global markets. SCAT was initially created to capture ARPA grant funding and will pursue all public and private funding means to meet it's objectives. It will act as a catalyst to promote development, demonstration, and commercialization of clean fuel transportation fueled mainly by electricity.

SCAT seeks to link business, academia, and government to initiate technology transfer, particularly from the defense industries, that result in transportation that is energy efficient, environmentally sound, domestically fueled and economically beneficial. SCAT will serve as a conduit between donors and grantees, both public and private, so as to facilitate grants to companies or consortia of companies, academia and government, to further electric transportation products and systems. A SCAT goal is to serve as a prototype for efforts to transfer defense industry technology to civilian use. SCAT will provide opportunities for communication and cooperation between participating organizations and will facilitate the grant process on their behalf.

Due to the multi-faceted nature of the SCAT coalition, the total business plan for the coalition can best be described as umbrella in nature, expandable to encompass the ultimate commercialization of the technology by the participating organizations. The immediate coalition plan is to capture ARPA funding from the Electric and Electric Hybrid Vehicle Technology and Infrastructure Program for the Southern area. SCAT will also pursue all public and private funding means to meet similar objectives of development, demonstration and commercialization of clean fuel transportation fueled mainly by electricity. The long term business plan for the coalition will be to facilitate technology transfer that will result in marketable products that fill genuine needs and can be developed quickly (within two to three years).

The Proposals for these funds will be prepared for SCAT by the Georgia Tech Research Institute, GTRI, under the close supervision of both the Executive Committee and the Board of Directors of SCAT. GTRI will supply continuous contractual support to SCAT. This will include the primary functions of general management, program oversight, coordination, and performance analysis as the programs are funded.

TABLE 4. SCAT PROGRAM KEY PERSONNEL AND QUALIFICATIONS SUMMARY

CO.	KEY PERSONNEL	ROLE	QUALIFICATIONS
AAT	Anil Ananthakrisna Alan Rubenstein Walter Goodman	Technical Mgr. Program Mgr. Dir. Prototype Activity	19 yrs. in electric veh. devel. President of A.A. Technologies BS Mech. Engr. Technology
ATEC	Howard Ross	Consultant	
ATR	Brad Worthington	Project Manager	BSCh, Pres. of ATR, 24 yrs. R&D
AVS	Gerald Auchard Michael Howard Don Duffy L. Joe Ferguson Tom Dugan John Capell J. Hampton Barnett Gerald Whitehead A. Scott Keller Harshad S. Tataria	Engineering Mgr. Plant Manager Program Coordinator President, AVS Mgr. of Bus Operations Public Relations Program Director Principal Engineer Program Manager Sr. Engr., Battery	BSME, 8 yrs. in bus design Senior Designer and Plant Mgr. 24 yrs. of business experience BS, Exp. in Manu., Engr., & Sales 19 yrs. in transit management 23 yrs. in transit management MSEE, 35 yrs. experience BSEE, 33 yrs. experience MSEE, 13 yrs. experience MSChE, 20 yrs. experience
BBBC	Wilbur Rumph John Drawe Tom Turner	Technical Mgr. Project Mgr. Engineering services	45 yrs in bus R&D and manufac. BSME, 20 yrs auto. struc. design BSME, 24 yrs in veh. sys. & safety
DRAT	Fred Cartwright Jim Ordo Don Klemen Joe Hunter R.M. Bendert D.G. Boulware R.J. Krefta R.A. Martin S.R. McMullen	Project Mgr./Allison Technical Mgr./Allison Project Mgr./Allison Project Engr./Allison Principal Invest./Delco Manager/Delco Principal Invest./Delco Manager/Delco Project Engr./Delco	BSME, EV Prop. Proj. Mgr. BSME, EV Prop. Tech. Mgr. BSME, EV Prop. Sys. Proj. Mgr BSEE, EV Prop. Sys. Proj. Engr BSCh, Senior Proj. Scientist BSME, Mgr., EV Prod. Assurance BSEE, Senior Project Engineer BSIE, Mgr., Elec. Prop. Systems BSME, Senior Project Engineer
DU	Rhett George		PhD Electrical Engineering
DVRY	Paul Alcorn Gene Minor Raouf Ghattas Sandra McKee	Cultural Research Team Leader Project Management Consumer Research	General Studies Professor General Studies Professor Professor of Business Operations General Studies Professor
EPTI	Karen Robinson Yury Podrazhansky	President of EPTI Head of R&D	13 yrs. managerial experience 30 yrs. elect. design charging sys.
ESI	William Craven	VP, Business Devel	MBA, Dir of EV program (EPRI)
FPLC	Robert Suggs	Elec Trans. Mgr.	BS Environmental Design
GEC	Ralph A. Benson Richard W. Boothe Charles E. Konrad	Mgr., Elec. Veh. Eng. Senior Devel. Engr. Mgr., Elec. Veh. Sys.	MSEE, 20 yrs. in elec. drive devel. MSEE, 15 yrs. in ac drive design PhD, 30 yrs. in new product devel.
GNB	Sanjay Deshpande Joseph Szymbroski Joseph J. Jergl Paul Melichar	Program Mgr. Project Mgr. Battery Sys. Devel. Battery Sys. Devel.	MSChE, 16 yrs. in battery R&D MSCh, 28 yrs. in battery devel. MSCh, 20 yrs. in electrochemistry BSEE, Director of Product Devel.

TABLE 4. SCAT PROGRAM KEY PERSONNEL AND QUALIFICATIONS SUMMARY (continued)

CO.	KEY PERSONNEL	ROLE	QUALIFICATIONS
GP	Annie Hunt Burriss Larry Coffeen Donald E. Francis II Ross Kist	Project Manager Technical Director Staff Engineer Technology Manager	Exp. in policy plan., legislation BSEE, 23 yrs in high volt. sys. BSME, 24 yrs in veh. devel. BSEM, 32 yrs indust. experience
GT	Mike Meyer	Technical Director	PhD, 20 yrs in transport. R&D
GTRI	Robert C. Michelson Bob McMillan	SCAT Tech./Data Mgt Project Engineer	MSEE, 20 yrs. in Mgt. & Engr. Microwave antenna/trans. design
LSG	Alan Tarrent	Mgr. Gas ICE System	BS, MBA 20 yrs. experience
MATSI	Glenn Woodruff	President of MATSI	BA, 3 battery related patents
ME	B.D. Russell	President of ME	PhD, 20 yrs. experience
MTC	Terri Hobbs Michael Walden O.G. Sims Chuck Herman	Exec. V.P. President/CEO V.P. Engineering Project Engineer	8 yrs. bus mfg., marketing, mgt. 20 yrs. specialty vehicle mfg. 13 yrs. coach body & sys. design MEEE, 31 yrs. veh. & prop. design
SCC	Douglas Cobb Robert Adams	Mech. & Elec. Design Program Management	20 yrs. in mech. & elec. design PhD, 30 yrs. project related exp.
SMI	Robert Closson Tim Williams	Electrical Engineer Chief Engineer	13 yrs. experience w/ Spartan 8 yrs. experience w/ Spartan
T A&M	M. Ehsani R.S. Martinez	Principal Investigator Project Engineer	PhD, Dir. TX App. Pwr. Elec. Cen. BSChE, MBA 29 yrs. indus. exp.
TBC	Jim Varian William Brecht	Mfg. Manager V.P. Technology	BABA, 11 yrs battery mfg. BSME, 22 yrs battery mfg.
TRW	Steve Rodgers		BSEE, 20 yrs in electronics
UCF	Charles Nuckolls		PhD Mechanical Engineering
USF	E.K. Stefanakos B. Krakow G.C. Moore E. Duffy Gene Fisher Y. Goswami E. Hughett J.R. Iurato W. McCracken M. McKeon D. Nowak G. Smith	Principal Investigator Project & Res. Coord. Project Man. & Coord. Training Consultant Principal Investigator Principal Investigator Principal Investigator Project Engineer Principal Investigator Liaison to Tampa Elec. Principal Investigator Principal Investigator	PhD, EE Department Chairman PhD, Electrochem. & Res. mgt. MIE, 35 yrs. util. mg't. and tech. PhD,VP for Development, YTC President, electric motor manufac. PhD, Dir. Energy Conservation,UF President, battery manufacturer BSME, 10 yrs util. market. & R&D PhD Materials, 15 yrs. Martin Mar. BSEE, 15 yrs w/ electric utility PhD Electrochem,12 yrs batt. R&D MSEE, 23 yrs. indust. electronics
UTA	John H. Gully William A. Walls Siddharth B. Pratap	Co-PI Co-PI/Program Mgr. Flywheel Battery	BSME, Dep Dir C for Electromech MSME, PM C. for Electromech. MSEE, PM C. for Electromech.
WEC	Curtis Pearson Tom Little Ted Lesster	Program Manager Sys. Engr. Director Veh. & Ener. Sys. Mgr	BSEE, DOD & civil prog. mgt. 30 yrs in energy sys & veh. devel. 30 yrs in power electronics

TABLE 5. FACILITIES & EQUIPMENT FOR SUPPORT OF THE SCAT PROGRAM

CO.	FACILITIES, EQUIPMENT, & RESOURCES
AAT	Custom vehicle fabrication facilities, CAT EV-1 electric pickup, 1 electric Yugo conversion, 2 electric 2 wheel scooters, battery monitoring equipment
ATEC	Tools, instrumentation, materials, power supply, misc. equipment
ATR	Database/networking software & custom R&D program mgt. software
AVS	Mfg. facility for 30 ft. bus, computer and CAD systems, full-service operating and maintenance facility for buses, Electronics Lab, Power Quality Lab, Battery Test Lab, Powertrain Test Center, Gas Evolution Garage, Test track, PC based equipment, Micro DAS equipment
BBBC	Vehicle production and system integration facilities
DRAT	Dynamometer test facilities, Noise & vibration lab, Precision gear machining equip., Therma test facility, Shock test facility, Battery test lab, Chemical and material test lab
DVRY	Computers and meeting facilities
EPTI	Computers, CAD machines, research facilities
ESI	Batteries, battery manufacturing facilities
FPLC	Various facilities including maintenance shops and offices
GEC	Drives design and manu. facility, AC & DC motor design and manu. facility, corp. R&D facility, pilot prod. facility, drive/system simulaton facility, test stands
GNB	Batteries, Battery manufacturing facilities with computer controlled test equipment
GP	Test facilities, System integration facility, Vehicle dynamometer
GT	Component and system level simulation, research and test facilities
GTRI	Mobile data acquisition system, microwave antenna fabriaction facilities
LSG	CNG refueling sys., ICE conv., dynamometer & emissions measuring instru.
MATSI	Batteries, Model shop, Bench scale test facility
ME	Microcomputer data acquisition and control development facilities
MTC	Mfg. facility, paint and molded parts facility, jig fixtures, AutoCad archives
SCC	Machine shop, sheet metal fabrication, R&D lab, elec. fabrication shop, computers
SMI	Dynamometer cell for heavy chassis, production area
TBC	Technology Center w/ computerized life-cycle and performance testers, CAD equip
T A&M	Power electronics & motor labs, rotating machinery and engine labs, battery test & development labs, highway research and vehicle safety test labs
TRW	Anechoic chamber for exhaustive free-space EMI testing
UCF	Engineerign and test facilities for electric vehicles
USF	Utility fleet services maintenance shops, utility power quality measurement, utility and univ. HVAC test lab, Martin Marietta Specialty Components lab facility, EV lab facility, 20KW Recharging station, Mobile data acquistion system, EV-Soft data analysis, Center for Urban Transportation
UTA	Computers, Machine shop, Filament winding facility, Rotating machinery test stand
WEC	Motor, controller production, test facilities, system integration facilities

SECTION III. DETAILED PROPOSAL INFORMATION

A. STATEMENT OF WORK

This proposal describes a twenty-four month effort to demonstrate the utility and efficiency of electric and hybrid-electric vehicle technology for military and civil use. The reduction in production costs for electric vehicle technology as a result of its introduction into private sector will accrue to the benefit of the military. For this reason, SCAT has put together a program that investigates various electric and hybrid-electric vehicle technologies as part of proof-of-principle demonstrations for both military base applications and civilian applications. In addition, a variety of vehicle types have been proposed for electrification including: large and medium sized buses, small and medium sized pickup trucks, automobiles, and communal use vehicles known as "station cars."

The teams contributing to the proposed SCAT program offer a range of projects which address many of the issues associated with electric transportation. The details of these proposed projects are provided in this section. Each project is comprised of several tasks that address one or more of the goals set forth in the RA 93-23 statement of work. Together, the various projects create a fully compliant SCAT electric/hybrid-electric vehicle technology program. A high-level description of the kind of work to be performed under each of the SCAT team projects is provided in Table 1.

The Atlanta Project

The Atlanta team will approach its project through the execution of ten tasks which address the various requirements of RA-93-23. A detailed explanation of the tasks which comprise the Atlanta project is given in the following paragraphs.

1. *Part 2— Task 1 CEVLE: Community-Based Electric Vehicle Laboratory Experiment:* This task is designed as an EV trial use/operations experiment where desired variables (both technical and user (customer) related variables) can be manipulated over the 18 month elapsed time of the experiment to yield a set of data from over 150 individual user experiences for analysis. The experiment will be conducted in a carefully designed "deployment lab" using Part 2 vehicles (vehicle details below). Recharging capability (infrastructure) will be installed at both the user's home and workplace. It is anticipated that ~ 150 users will each have a 2-4 weeks experience with an EV. Some users may be required to pay a usage fee to test consumer acceptance of cost structures. By using the number of vehicles specified, statistically significant samples of users (of varying profiles) can be generated to provide reliable and valid results.

Eighteen converted vehicles (14 cars and 4 S-10s) will be provided to the selected users (customers) in carefully chosen urban areas. A platform selection study will be conducted to select the cars for conversion based on the experience of the academic EV teams and the projected requirements for retrofit of advanced components in Part 3. Two additional conversions (vans) will be used as project support vehicles; for example, oncall (via cellular) roadside service will be provided to all Atlanta users. All of these vehicles will include DOD specified data acquisition capabilities, onboard or offboard fast recharge systems (will allow a vehicle to recharge from a 22VAC power source in about half the normal time or less; 220VAC will be installed as infrastructure in users homes), and some will include an intelligent vehicle management system which will provide integrated computer-based management of all vehicular functions. In addition, 5 Ranger trucks from the State of Georgia Department of Transportation will be converted; these vehicles will be used to conduct field testing of the vehicles under actual work conditions. With team support, DOT will maintain their own vehicles, maintenance records, and provide recharging stations. At least one of the conversions will have an auxillary power unit; this vehicle will be designed for normal over-the-road ranges equivalent to gasoline powered ranges. Part 3 components will undergo subsystem test and optimization in single subsystem test platforms prior to integration into fully integrated vehicle (all subsystems) with IVMS.

2. *Part 3— Task 1 Zinc-Air/Lead-Acid Hybrid Battery Development:* A development group comprised of GNB Industrial Battery Company, MATSI, and Advanced Transportation Research will design, develop and fabricate the hybrid lead-acid/zinc-air batteries. Integration of this battery hybrid into a platform will result in a "zero emissions" hybrid-electric vehicle where one battery (zinc-air) provids the energy for vehicle range and the other battery provides the power needed for acceleration, passing, and hill climbing. This battery system will be installed and tested in CEVLE fleet vehicles (see supporting materials section).

3. *Part 3—Task 2 Onboard Microwave Recharging & Highway Datalink:* A microwave recharging system will be used to recharge the batteries of the vehicle without plugging in or unplugging the unit or other driver intervention to control the operation. A prototype microwave antenna will designed, developed, and fabricated for integration onto a variant and microwave power transmission units for testing in the roadbed; the transmitters will send RF energy to the onboard antenna where it will be converted to electricity. The group will conduct experiments to provide proof-of-concept data for both stationary opportunity charging (to simulate vehicles stopped at a intersection/traffic light or at a corporate parking lot) and mobile charging (vehicles passing over an row of power units at a simulated intersection/ traffic light.) The microwave recharging effort will be limited to proof-of-concept.

4. *Part 3—Task 3 Regenerative Braking System:* The feasibility of paired counter-rotating flywheels will be explored as a means to overcome gyroscopic effects. Also various flywheel materials will be investigated.

5. *Part 3— Task 4 Driver-Friendly Dashboard Data Display:* A dashboard data presentation subsystem will be designed and prototyped which will present essential real-time vehicle data in a clear, nonconfusing format. Data to be addressed include energy level (state of charge indicator or "battery gasoline gauge"), low energy warning, and chimed reminders which call the driver's attention to various vehicle states.

6. *Part 4—Task 1 Deployment and User Evaluation Study; Concept/Product-Market Test:* Two studies will be done in concert to plan, analyze and evaluate the CEVLE from combined transportation research and marketing perspectives.

7. *Part 4—Task 2 Electric Vehicle Policy Decision Model:* A system dynamics model of the impact of electric vehicles will be constructed. A systemic approach will be used to identify the various sectors impacted and their relationships.

8. *Part 4—Task 3 Comprehensive Training Model and Tools:* Classroom science/EV technology teaching materials (partially computer-based) will be developed for use in schools.

9. *Part 4— Task 4 Public Education/Public Acceptance Activities and Events:* Advanced Transportation Research in coordination with other team participants will conduct various public education/public acceptance activities over the 24 month period of the project. These will include small local "EV Fairs", newsletters, direct mail, "infodisks" (interactive software that includes on-disk video clips) on floppies, videotapes, newspaper and trade journal advertising, and press releases. In addition, "electric vehicle wagon trains" will be run between various participants to generate public interest in electric vehicles.

10. *Part 4— Task 5 International Scholastic Clean Air Grand Prix:* The Clean Air Vehicle Association and Advanced Transportation Research, as part of the ARPA program, will conduct an expanded International Academic Clean Air Grand Prix in Atlanta as part of its 1994 Clean Air Vehicle Conference, Exposition & Grand Prix.

The Florida East Project

The Florida East Project is made up of nine major tasks as follows:

1. Station Car Program: A pool of small EVs will be placed at the "terminal end" station for use by the mass transit rider/subscriber to provide end of trip flexibility. The EVs provided under this project are intended to travel only up to speeds of 45 mph, with maximum trip lengths of 45 miles/day and use the secondary road system. This project develops and prototypes systems to manage networked pools of vehicles, including those used in conjunction with military base needs. The use of these vehicles would represent another level of service provided by the mass transit and would reduce the number of vehicles on main commuter routes.

2. Fuel Cell Powered Bus: This project is to build a "ground-up" 40 passenger electric bus. The bus body and frame would be built from lightweight composite materials. The power for this bus will be supplied by a Solid Polymer Hydrogen Fuel Cell.

3. Five AC Drive Pickups for Patrick AFB: Five pickups will be converted to electric using in advanced AC power train. An onboard computer based system will be used to collect telemetry and use data. Battery power will be provided by GNB advanced lead-acid batteries. The pickups will also be equipped with advanced climate control systems developed under another project identified in this program. Charging will be accomplished by an advanced rapid charging system design by EPTI developed under another project identified in this program.

4. General Motors Impact: Two GM Impacts will be placed in the Florida Power and Light fleet. FPL will use them in a variety of public appearances and in an aggressive loaner program to determine public use and acceptance of an ultra-high tech, ground-up electric vehicle.

5. High Efficiency Climate Control System: This task is the development of a high efficiency climate control system. This project will provide adequate climate control for only 20% of the energy needed for conventional systems.

6. Rapid Battery Charging Systems: This project will take currently patented technology which is being used on the small battery market (computers, etc) and develop it for use with the larger battery systems used with EVs. This technology has improved battery life by up to 60%, has operated up to 1100 charging cycles, and will reduce charging time.

7. Advanced Lead-acid Battery Development: GNB is proposing to develop an advanced, maintenance free, sealed lead-acid battery for use on various vehicles that will be delivered under this proposal.

8. Broward County Vehicle Experiments Parts 1, 2, &3: There are three projects; 1) to convert 5 vehicles to DC electric drive systems, 2) to convert 5 vehicles to natural gas/electric hybrids, and 3) to build 2 lightweight composite body vehicles with AC drive systems.

9. Market acceptance and Training Programs: This task will focus on research into the perceptions and needs of potential customers. From the findings, the necessary marketing communication, customer and technical support, and training can be developed and made available. SCAT's contribution, through Devry Institute and the private sector, to the customer acceptance and information/ training area falls into three categories: Marketing/cultural research, technical and consumer information gathering and training, and project management.

The Florida West Project

Up to 15 pickup trucks and 2 light utility vehicles shall be deployed on an ARPA specified military base. Each will be supplied with an onboard battery charger and up to 15 AC outlets will be installed at 15 parking spaces in the base supplied electric vehicle parking area. One fast charger will also be installed on the military base. The choice of MacDill AFB is recommended for this task. To provide a reasonable statistical sample, between 30 and 40 electric vehicles shall be deployed, operated and monitored over a two year period by Florida Power Corporation. Charging stations will be installed at the electric vehicle parking facilities and at key locations for opportunity charging. Deployed vehicles will be tested to determine the performance, reliability, range, necessary maintenance, human factors and operator comments, and infrastructure scheme required to enable these vehicles to perform their assigned functions in selected applications.

All the lead-acid battery-powered electric vehicles will be provided with a lead-acid battery state-of-charge indicator (SOC) developed at USF. The principle of the lead-acid SOC shall be applied to other types of batteries such as nickel metal hydride, nickel iron and lead-acid gel cells with a view to establishing a "fuel gauge" capability for such batteries.

A charger will be designed to charge both flooded and valve regulated batteries in less than 15 minutes to 80% of the discharge capacity. The charger will employ a patented MAGNESTAT™ converter which makes input power line current harmonic distortion extraordinarily low. Three 150 KW chargers shall be fabricated.

An advanced design traction motor by Fisher Electric Motor Technology Inc. will be combined with a new controller designed by the University of South Florida (USF) to achieve an electric vehicle power drive that will provide the best combination of starting torque, high velocity cruising, and regenerative braking.

The following tasks will also be performed:

- Nickel metal hydride batteries shall be produced to equip up to 6 vehicles.
- A capacitor pack, designed to act as an auxiliary power supply to assist electric vehicles recover more energy during regeneration and reduce peak drain during acceleration, shall be built and tested.

- Techniques shall be investigated and implemented for minimizing the impact of air conditioning on vehicle range.
- An advanced battery monitoring and control system shall be investigated.
- Measurements will establish baseline levels for electromagnetic fields (EMF) in conventional and electric vehicles for comparison and mitigation (if necessary) action.
- More efficient electric vehicle lighting shall be sought through investigation of Ultra Bright LED technology.
- A training program for electric vehicle technicians shall be implemented to support the Florida West team vehicles.
- An awareness and promotional program will be implemented with the public school system, museums, and utilities.

The Georgia Project

The Georgia team will convert 5 pickup trucks to pure electric, 3 buses to pure electric, and 3 buses to hybrid-electric.

NOTE: The body of the Georgia team project description is proprietary and is contained in one of the sealed envelopes attached to this proposal.

The Georgia North Project

The Georgia North team proposes to replace an existing bus at Warner Robins AFB with a hybrid-electric bus, along with the infrastructure necessary to recharge, service and maintain the vehicle. This hybrid vehicle will use a diesel cycle Auxiliary Power Unit (APU) to take advantage of the availability of diesel fuel on all military bases worldwide. In addition, the Georgia North Team will provide two all-electric vehicles to be operational at Atlanta's Hartsfield International Airport during the 1996 Summer Olympics providing international exposure and resulting public acceptance of these technologies.

The following tasks make up the Georgia North project:

1. System Design: All team members will participate in the preliminary systems design to optimize the performance and cost of the all-electric and hybrid vehicles. The items to be determined during this phase include: vehicle size and weight, battery size and weight, APU technology and rating, and battery charger technology and rating. Design specifications for the system components will be generated for use during the detailed design.

2. Detailed Design: This task will cover the detailed design and laboratory testing (where appropriate) of the following items: chassis, APU, battery system, power train, battery charging system, and vehicle system computer.

3. Battery Performance Verification: Using preliminary estimates of the power required by each of the vehicle types, GNB will perform battery performance verification testing to the planned driving cycles for the vehicles. The testing will develop a baseline for vehicle performance and range. Tests will be conducted to identify the optimum state of charge of the battery for operation in the hybrid mode and will provide direction in the selection of the appropriate size of the heat engine.

Once the hybrid power train has been defined, GNB will conduct performance simulations and life testing of the battery modules using the operating scenario determined for the hybrid bus. Testing will focus on the identification of optimum recharge capabilities for the battery at various states of charge and charging techniques which allow rapid recharging while controlling the gassing and temperature of the battery pack.

4. *Auxiliary Power Unit Evaluation (APU):* The APU will be operated over its full range on a dynamometer. Emissions and fuel economy will be documented and mapped for control optimization. The vehicles will be checked-out and road tested at Metrotrans.

5. *Dynamometer Test:* One hybrid and one all-electric bus will be dynamometer tested at Georgia Power.

6. *Delivery and Performance Monitoring:* The hybrid will be delivered to the Warner Robins AFB. The performance will be monitored by a data collection system as specified by ARPA for the duration of the program and the information gathered will be merged with the data base in the SCAT standardized data acquisition network. The two all-electric buses will be delivered to customers for operation at the Atlanta Airport. A subset of the military bus data will be monitored.

7. *Infrastructure:* GNB will identify the requirements of the opportunity charger as part of the development effort. Working with the Georgia Power Company, GNB will specify the equipment requirements to complete the demonstration installations.

8. *Public Acceptance and Public Perceptions:* The Georgia North team will ensure global public awareness of this project via team-sponsored trade journal advertising, international press releases, newsletters to public utilities and direct mail to users in a network for which Metrotrans currently supplies internal combustion coaches. Public acceptance will be enhanced by utilization of the commercial vehicles by high-profile end users at Atlanta's Hartsfield International Airport allowing millions of people worldwide to experience the practical application of these technologies. In addition, Georgia Power Company proposes to monitor and evaluate evolving public perceptions of electric vehicles and transportation opportunities based on public exposure to two new major exhibits on electric vehicles and transportation systems. It is proposed that an adjunct interactive tracking system be used in conjunction with a national 4,000 sq ft. road show exhibit sponsored by the Electric Power Research Institute (EPRI) and 14 utilities across the United States.. The second system, developed from the first, would monitor a 6,000 sq ft. science center exhibit featuring a working Electric Vehicle Research Center (EVRC) behind glass. ARPA support would be applied specifically to interactive perception tracking. Systems for both exhibits and the information developed through ARPA's support and guidelines would be available for both public and private sector use. The two major exhibits coming on line in 1993 and 1994 will be at SciTrek, Atlanta's science and technology museum.

9. *Support:* Training will be provided to end-users by all team members to ensure correct preventive maintenance, accurate diagnostic procedures along with proper operating procedures for the vehicle and its related systems. Upon delivery, a five-day operation and maintenance seminar will be conducted for appropriate user personnel. Ongoing training in the form of service bulletins, systems updates and recurrent training will be provided to ensure minimum down time of the electric vehicles.

The Tennessee Project

The Tennessee team proposes to develop four state-of-the-art 30-foot buses which will have advanced AC induction individual rear wheel propulsion systems. Two buses will be placed into service in Chattanooga's "Living Laboratory" and operated by the Chattanooga Area Rapid Transit Authority (CARTA). Two will be placed into service in downtown Atlanta and operated by the Georgia Power Company working closely with the Atlanta Metro Area Rapid Transit Authority (MARTA).

Other tasks will focus on the development on advance electric vehicle component technologies, including:

1. composite materials
2. electric drive
3. auxiliary power unit
4. DC-to-DC converter
5. flywheel technology
   battery pack
6. inverter
7. rapid charging technology

Validation Test Plans: A Drive Unit Validation and Inverter and DC-to-DC Validation Test Plan will be used to confirm product conformance to the customer's requirements. Validation test parameters will be customized to duplicate the customer's operating environment. *Typical validation tests are included in Attachment C of the Supporting Information section at the end of this proposal.*

Tennessee Training Programs: These will include vehicle maintenance and safety, driver training and general employee orientation programs. The vehicle maintenance and safety programs will identify the skills and maintenance techniques to properly and safely diagnose and maintain electric buses. A complete electric bus maintenance program will be developed and documented. Maintenance manuals will be written and a formal maintenance and safety program completed. This program will be able to be presented on site for operators of electric buses.

Public Acceptance: Base line surveys will be conducted in Chattanooga and Atlanta. Strategy will be developed to most effectively advance the public acceptance of electric vehicles. Near the end of this ARPA program, a follow-up survey will be done to determine if the public attitudes had changed.

ETUI Electric Bus Promotional Vehicle: ETUI is preparing a video promoting electric buses. This video focuses on the benefits of electric vehicles and encourages support for electric bus development. (This is already paid for by ETUI and is therefore an in-kind match for purposes of cost sharing).

The Texas Project

The Texas team proposes to design, build, test and demonstrate the new Electrically Peaking Hybrid (ELPH) drive system for land vehicles. The demonstration will be done by retrofitting two S-10 military trucks and one Oldsmobile Cutlass passenger car with the ELPH drive system. The trucks will be delivered to ARPA at one of the designated military bases and the passenger car will be delivered to Texas A&M University System, as one of their fleet cars, all within 24 months of the start of the project. In addition, the Texas team will conduct extensive studies on ELPH vehicle safety, total cycle emissions, mass produced product acceptance, natural gas fuel infrastructure economics, and personnel training issues. Finally, the Texas team will develop two new component technologies which, although not part of the ELPH system design, can have a positive impact on the future generations of ELPH. This project is aimed, mainly, to fulfill parts 3 and 4 of the ARPA RA-93-23. However, the delivered vehicles also qualify under parts 1 and 2.

NOTE: The body of the Texas team project description is proprietary and is contained in one of the sealed envelopes attached to this proposal.

Parallel Component Technology Development: The Texas team has agreed to cooperate with the development of the following two component technologies:

Flywheel Battery Storage - In this task the technical objective is to explore and demonstrate whether flywheel batteries are more suitable for certain applications of ELPH drive systems, such as military vehicles.

Fiber Optic Combustion Pressure Sensor Development - This system would seek to monitor the performance of the individual cylinders and adjust the fuel-air ratio and ignition timing to obtain optimum operation.

Description of Tasks: A detailed project management schedule will be developed by the management staff and shared with ARPA at the beginning of the project. However, as is shown elsewhere in this proposal, the work leading to the tests and delivery of ELPH vehicles is divided into several tasks, each of which is undertaken by a specialist university center or industrial company. The major milestones of the project are the building of a preliminary ELPH S-10 truck (ELPH "mule") in six months, a better version ELPH Cutlass (ELPH work horse) in one year, and the final three ELPH vehicles in two years.

The project tasks are of four basic types: theoretical (design, simulation, soft sciences), done by university centers; future new components development (flywheel battery, fiber optic combustion sensor), done by university centers; hardware engineering, manufacture and vehicle integration (vehicle conversion, electric motor drive, instrumentation, microcomputer controllers, data acquisition, engine conversion to natural gas, lead-acid batteries, infrastructure), done by industry; and project oversight (scheduling, trouble-shooting, information coordination, quality control, financial control), done by a dedicated staff at Texas A&M University. The individual task subcontractors, their qualifications and facilities are listed elsewhere in this proposal.

The GTRI and SCAT Management

GTRI will provide project management to SCAT team members by coordinating efforts among the teams and by serving as a clearing house for information distribution. It will be the responsibility of GTRI and SCAT to insure that the consortium and participating organizations are responsive to the ARPA's needs and the objectives for Research Announcement 93-23. This will include proposed task content, required time lines, deliverables, and budget limitations.

In addition, GTRI will institute the SCAT standardized data acquisition network. As a service to all of the teams and in an effort to consolidate the output data from the entire SCAT program, a standard will be imposed upon the acquisition of data, its reduction, and presentation. Specifically, a standard data acquisition protocol has been defined which is based largely on off-the-shelf data manipulation hardware, software, and various existing network infrastructures.

B. DESCRIPTION OF ANTICIPATED RESULTS

Expected Results from the Atlanta Team

The Atlanta team expects to quantify the special needs that the electric vehicle user will encounter during operations with different kinds of vehicles and in different travel scenarios. Conclusions which are expected to be drawn from the data gathered by the Atlanta team will define recharging needs and preferences, emerging electric vehicle usage habits which might differ from those of conventional fossil fuel vehicles, and driving patterns. In particular, the Atlanta team project is expected to show that pure electric vehicles are cost effective for commuter use and can function in that role more economically than hybrid-electric vehicles with only moderate impact on the present electrical distribution infrastructure. Also, the Atlanta project will show that many off-the-shelf technologies can be incorporated into electric vehicle conversions to achieve an operationally satisfactory, consumer acceptable electric vehicle without the need for extensive re-engineering.

Expected Results from the Florida East Team

The Florida East team project will demonstrate that electric station cars are a publicly acceptable approach to intermodal end-of-line commuting, and that an extrapolation of the proposed project will clearly show the potential for traffic congestion and inner city air pollution mitigation. Results expected to be leveragable from this project are the successful demonstration of a solid polymer hydrogen fuel cell-powered bus, an effective low power onboard climate control system, and a rapid battery charging system for small vehicles. Acquired data are expected to show that the use of lightweight high strength bodies and frames will result in improved performance and range characteristics.

Expected Results from the Florida West Project

The improved accuracy and dependability of the new state-of-charge indicator that is to be deployed is expected to make drivers more comfortable and confident so they can make better use of the range capability of the electric vehicles by requiring a smaller margin of error. Nickel metal hydride batteries are expected to double the vehicle range and the experiments using them will indicate the extent of perceived viability of the electric vehicles with this capability.

Expected Results from the Georgia Team

For a discussion of the results expected to be derived from the Georgia project, see the sealed proprietary Georgia Team information accompanying this proposal.

Expected Results from the Georgia North Team

The Georgia North team estimates that their all-electric bus will be capable of carrying a battery with a maximum weight of approximately 4,000 pounds. Using GNB's 12-EVB- 1180 battery modules, a battery pack of this weight would have an energy storage capacity of approximately 65 KWh. With an estimated energy usage of 1.5 KWh per mile for traction and an accessory load of 15 KW, the vehicle would have a range of only 25 miles at an average speed of 20 miles per hour. Therefore, "opportunity charging" will be a critical element in the success of this vehicle demonstration.

The minimum vehicle performance requirements for the North Georgia team hybrid bus are expected to be as follows:

1. Acceleration 0-15 mph in 4 sec, 0-30 mph in 10 sec, 0-50 mph in 25 sec
2. High Speed Test: <2% Grade — 55 mph min
3. High Speed Grade Ability — 45 mph @ 6% grade
4. Low Gear Grade ability — Ascend 20% grade @10 mph
5. Driving Pattern Cycle FUDS Range — 200 miles
6. Range @50 mph Steady Speed — 200 miles-continuous @ <2% grade
7. Minimum Battery Charge Remaining following tests: — 20% charge
8. Recharge Time from 80% DOD to Full Charge: — 8 hrs. max.

Expected Results from the Tennessee Team

The Tennessee team will demonstrate the feasibility of a CNG auxiliary power unit for use in their hybrid-electric bus and show that the efficiency of the induction machine/inverted combination exceeds 90% and results in DC power levels from between 30 to 35 KW. These expected performance results will be based on CNG, though ethanol, M80, and propane could also be used to achieve this type of result. The DC-to-DC converter used in this project is expected to exhibit efficiencies greater than 90% under nominal loads. The rapid charging units to be used in conjunction with the pure electric buses are expected to produce eight times less battery gassing than conventional units while only increasing the ambient temperature by 15° F.

Expected Results from the Texas Team

The outcome of the Texas project will be a conclusive demonstration that present internal combustion engine technologies coupled with an adjustable speed electric motor and lead-acid battery can be used in a new architecture of hybrid propulsion that is not only simpler than the conventional internal combustion engine car, but actually outperforms it as well. Adjunct tasks will demonstrate that a 4,000 lb vehicle can accelerate with 200 hp on a 10% duty cycle by using a flywheel battery. Also, it will be demonstrated that engine performance can be monitored on a cylinder by cylinder basis with an inexpensive fiber optic combustion pressure sensor that could be produced in quantity for on the order of $25 per engine.

C. DETAILED TECHNICAL RATIONALE

Rationale and Technologies Employed in Support of the Atlanta Project

Electric cars (and light trucks) for the consumer market can be built today with current off-the-shelf technology and these vehicles, *if* properly supported in the field by the manufacturer, can meet the transportation needs of certain well-defined segments of the transportation market. Meanwhile, high tech companies, including technically savvy defense corporations, are constantly refining and offering improved component subsystems (drive-trains, batteries, materials for bodies, etc.). This process continues unabated.

What is missing is an integrated, unified view of the electric vehicle which optimizes overall vehicle performance and operation. The systems integration approach presented in the Atlanta project defines a "plug-and-play" platform whereby different component technologies can be switched out with a minimum of re-engineering (preferably none) as the opportunity arises. This approach will pay its greatest dividends in the early years of electric vehicle development while the nature of the accepted technology is still settling out. While some components (e.g. drive-trains) are less amenable to this retrofit philosophy than others, a great opportunity exists to demonstrate prototype battery technology, recharging technology (both while moving and stationary), and onboard energy management.

Rationale and Technologies Employed in Support of the Florida East Project

Station Car Program and Fuel Cell Powered Bus: Traffic congestion continues to plague American cities while vehicle miles traveled continues to soar. Attempts to increase ridership on mass transit systems have been thwarted by the lack of cleanliness, dependability, and flexibility. To improve ridership on mass transit systems and appeal to upscale ridership, electric vehicles could be located at terminal points of existing mass transit systems. These vehicles would be available for use to subscribers to complete their daily commute. These "station cars" would provide terminal end flexibility for the mass transit systems user. Additionally, alternate methods for providing zero emission transportation, such as fuel cells, must be researched.

Fleet Operations: The integration of electric vehicles into fleet applications will be one of their early uses. Broward County Division of Transportation has been conducting a compressed natural gas program and would like to add several electric vehicles to their fleet to compare to natural gas vehicles. Of particular interest to ARPA is the practicality, usability, and acceptance level of electric vehicles on board military installations. Patrick AFB is very interested in becoming a platform to test these issues.

Public Acceptance: The success of the electric vehicle industry is directly related to the willingness of people to purchase and use them. One electric vehicle, the GM Impact, has done more to capture the public imagination and break the old "golf cart" image of EVs than any other. Florida has the second largest auto market in the U.S. and, based on research, has a significantly high population of potential buyers of electric vehicles, and has the geography and climate most conducive to early EVs. Given that changes in technology are often resisted by the general buying public, any facilitation of electric vehicle acceptance must grow out of research into the perceptions and needs of potential customers.

Component Technology Improvements: After traction power, climate control is one of the highest energy users on any vehicle. Estimates have indicated that the range of an EV is reduced by 25% to 50% when conventional air conditioning and heating systems are in use. Therefore, development of a high efficiency climate control system is one of the early development programs that is needed. FMVSS standards require certain performance levels from heaters/defrosters and most customers will not consider a vehicle that is not adequately heated/air conditioned. Also, current market research indicates that potential users of electric vehicles are concerned over low range capability, but agree that a method of quick charging, would improve their willingness to use them. Further, in the near term, lead-acid batteries will continue to be the battery of choice for EVs and it is projected that significant improvement of these batteries is possible.

Rationale and Technologies Employed in Support of the Florida West Project

The technologies listed below support the development efforts in fulfillment of the goals set forth in the RA 93-23 statement of work.

1. *State-of-Charge Indicator*: A state of charge indicator (SOC) is the gas gauge equivalent for electric vehicles (EVs). The University of South Florida has developed a very accurate SOC for an EV powered by lead-acid batteries. Some results, using this prototype SOC in a Chevy S-10 pickup truck EV powered by US 2300 flooded lead-acid batteries show outstanding correlation between these results and the actual state of charge in the vehicle, and were much better than the gauge supplied with the vehicle. Application of the SOC at this time to lead-acid powered vehicles is in order as is development of its applicability to more advanced batteries.

2. *Fast Battery Charger with Low Distortion*: The development of a fast charger for electric vehicles (EVs) will have a major impact on the acceptance of EVs by the public, because it will drastically reduce the present shortcoming of EVs, that is, the short mile range EVs can travel before recharging.

One of the major issues with Power companies providing power for electric vehicle chargers is the influence of many chargers, operating simultaneously, on the quality of power in the electric grid. The MAGNESTAT™ addresses this problem. This is a new way to convert AC to DC power and employs a three phase rotating magnetic field to produce generator action in a static device. Continuous loading of all three phases results in minimal input current distortion.

A model 9 coil 10 KW MAGNESTAT™ set up at the University of South Florida (USF) has been tested by Florida Power Corporation (FPC). The Total Harmonic Distortion (THD) was 0.98%. THD for a commercial HP 600 DC Power Supply was 43%. The IEEE standard of 5% which will be in effect in 1995. A paper describing the MAGNESTAT™ and its capabilities has been submitted for publication in IEEE Transactions on Power Electronics and is included in Section IV of this proposal.

Based on results obtained at the Johnson Research Center, a special pulse modulated charge procedure can be used to accelerate charging, particularly during the finishing charge phase where the charge acceptance of the battery is very low. The charge algorithm is expected to reduce the amount of gassing normally associate with charging while at the same time allowing an accelerated rate of charge this is stored in the battery.

3. *Mobil Data Acquisition System (MDAS)*: An automated onboard mobile data acquisition system (MDAS) has been designed at USF specifically to acquire the needed EV information with minimal human error and labor. An interface will be provided to convert from the existing MDAS format to the protocol and physical standard necessary for communication with one of the SCAT Standardized Network Data Acquisition System nodes. This will allow the Florida West team data to integrate compatibly and automatically with the rest of the SCAT data for presentation to ARPA.

4. *Nickel Metal Hydride Batteries*: Nickel metal hydride batteries are finding a growing market for small (AA and sub C) cells for portable applications such as computers and electronic devices. They have attractive prospects for electric vehicles because of their high energy density, high specific energy and freedom from maintenance requirements.

5. *Capacitors*: Controlling the rapid drain or rapid charging of batteries is one of the prime areas for improvement in electric vehicles. Martin Marietta Specialty Components, Inc. (MMSC) has developed capacitors with energy densities comparable to lead-acid batteries that might help resolve this problem.

6. *Advanced Electric Motor-Controller (AEMC)*: Brushless DC (BLDC) motors can deliver more horsepower per pound (up to 4 hp/lb) at a higher efficiency (96%) than an induction motor. The BLDC has higher starting torque and high overall efficiency, whereas in an induction motor high efficiency and high starting torque are mutually exclusive. To achieve regenerative braking, a more complicated controller is required for an induction motor than the BLDC. This means that a BLDC motor and controller combination can be designed which clearly outperforms either induction motor drives or conventional dc motor drives. Fisher Electric Motor Technology has a patented flux management system which optimizes motor efficiency, horsepower/pound, horsepower/cubic inch, and torque/amp. The variable field rotor characteristic of the AEMC system can be used to generate the correct voltage for efficient regenerative braking. The AEMC drive-train completely eliminates the need for a transmission and a right angle drive into the differential. Therefore, in addition to being the most efficient motor and controller, the new drive eliminates wasted energy and weight characteristic of conventional drive-train components.

7. *EMF*: The question of health effects from exposure to electric and magnetic fields (EMF) from utilization of electrical energy is a growing concern for manufacturers and utilities.

8. *Climate Control*

On electric vehicles, air conditioning demands burden the small energy supply severely and have a large impact on vehicle range. This is particularly important in hot and humid climates such as the Southeast U.S. Studies on maintaining passenger comfort conditions in electric vehicles have been completed in the past two years by both the Department of Energy and the Electric Power Research Institute. Implementation of these suggested improvements shall be pursued.

9. *LED Lighting*: Dual Use of SDI Ultra-Bright LED technology to improve head lights, tail lamps, and turn signals may provide brighter, longer life, and lower cost signaling and instrument lighting with less battery drain.

Rationale and Technologies Employed in Support of the Georgia Project

NOTE: The body of the Georgia team project description is proprietary and is contained in one of the sealed envelopes attached to this proposal.

Rationale and Technologies Employed in Support of the Georgia North Project

The implementation of the pure electric bus has distinct and measurable advantages, namely lower cost of operation and zero-emissions. However, there are applications in which the pure electric has limitations due to present battery capacity. For this reason, this program, will also incorporate a hybrid bus which will provide extended range. For versatility, a common design will be employed for both the all-electric and hybrid bus. This common design provides flexibility for different applications by allowing a portion of the batteries to be replaced with an auxiliary power unit.

1. *The All-Electric Bus:* The all-electric bus will depend upon the battery pack entirely for the power it requires to complete its assigned route. Although the total distance traveled by the type of shuttle bus is relatively low (as envisioned by the Georgia North team), it is likely to operate for extended periods of time, and will require significant amounts of energy to operate auxiliary equipment such as air conditioning, lighting, and other loads. These auxiliary loads consume a considerable amount of energy and a battery sized to provide adequate energy for a full day of operation would be unacceptably large for the size vehicle under consideration. However, because the vehicle has a fixed route and spends a significant amount of time "parked" at both ends of the vehicle's route, the operational scenario will take advantage of the time that the vehicle is parked to recharge the battery.

2. *The Hybrid Bus:* The hybrid-electric bus will utilize both an internal combustion engine and a battery to provide the power required for vehicle operation. Initial estimates require that the battery have an energy storage capacity of approximately 30 kilowatt-hours and operate at a nominal system voltage of 336 volts. A battery pack sized to meet these requirements will consist of twenty-eight GNB 12-EVG-1180 battery modules connected in series. The bus powered by the hybrid-electric propulsion system will be capable of extended vehicle range since the battery pack will be charged during vehicle operation by the installed internal combustion engine system. The rating of the auxiliary power unit is estimated at 36 KW.

3. *Chassis and Coach Body Technologies Employed:* The coach body will utilize a unique low-floor design making it totally compatible with provisions of the Americans with Disabilities Act. Chassis and body construction will optimize strength-to-weight ratios by utilizing light-weight ferrous metals, aluminum, fiberglass and other advanced composites as available.

4. *Battery Technology Employed:* GNB has developed an electric vehicle battery design using its patented ABSOLYTE Valve Regulated Lead-acid (VRLA) technology which GNB feels is ideally suited for EV applications. The VRLA technology provides the vehicle owner a "user friendly" battery which operates essentially as a sealed system and requires no watering and only a minimum of maintenance over its lifetime. In addition, the VRLA battery avoids the nuisance and safety issues associated with electrolyte spills, gas emissions, and corrosion of hardware and vehicle components.

5. *Power train Technology Employed:* The power train will be based on the AC drive developed by GE on the DOE Modular Electric Vehicle Program and supplied to the Ford Ecostar demonstration fleet. The use of this drive designed for the high volume automotive market takes advantage of a proven, high performance, highly efficient design. The integrated wheel motors are based on developments from the Federal Transit Administration's hybrid transit bus development program. Many of the control algorithms developed on this program will also be used for the hybrid shuttle.

Rationale and Technologies Employed in Support of the Tennessee Project

Vehicle System Specifications: Specifications for the propulsion system components and interrelationships described in the Tennessee team's project are best estimates based on existing equipment, experience, and engineering judgment and may be modified based on results of mission analysis activities. *The specifications are included in Attachment B of the Supporting Information section at the end of this proposal.*

Challenges in Achieving Specification and Performance Goals: The technological issues described in the Tennessee team's project are leveraged in part from numerous electric propulsion programs in which Delco Remy/Allison has had significant involvement. The application of these technologies to electric propulsion has been demonstrated and is well understood. The remaining substantial hurdles include battery pack thermal management, manufacturing, packaging, safety, and reliability. *Complete discussion of the risk is included in Attachment E of the Supporting Information section at the end of this proposal.*

Rationale and Technologies Employed in Support of the Texas Project

It is well known that the lack of a suitable electric storage battery is the greatest obstacle on the path to an all electric vehicle that is price and performance competitive with the internal combustion engine (ICE) automobile. While the progress has been remarkable, it should be more clear than ever that chemical electrical storage batteries will probably never approach the energy storage density and convenience of today's petroleum based fuels. This conclusion can be based on basic chemical principles. Therefore, the design of an all electric vehicle is driven by the need to minimize the load on the limited battery energy. This has forced extreme designs to reduce road friction, aerodynamic drag, vehicle weight and power level of the various auxiliary systems. Since the Texas team expects no significant improvement in battery performance in the near future, the above design constraints could force the introduction of undesirable vehicle trade offs. This, in turn, can lead to potential user dissatisfaction which can adversely affect the long term commercial acceptability of the electric vehicle concept.

It is now widely known that to have both suitable range and performance the electric vehicle needs to incorporate some form of power plant. The hybrid ICE-electric vehicle is presently the best solution with existing technology. In the hybrid architectures suggested up to now the engine alternately drives the vehicle in place of the electric drive. In other architectures, the engine drives a generator. The output of the generator is used to power the vehicle's electric drive or to charge the storage batteries. This latter system is similar to that used in the diesel electric locomotives. However, all of these hybrid concepts are more complex, heavier and inherently more costly than the conventional ICE automobile.

In this proposal, the Texas team shows that the presently available technologies in the ICE, adjustable speed electric motor, lead-acid battery and microcomputer based controls, can be directly used in a new architecture of a hybrid vehicle propulsion system that is actually simpler and better performing than the conventional ICE car. The job of producing demonstration ELPH vehicles and their associated tests and study results is broken down to several tasks. These tasks are to be carried out by some the leading specialists in universities and industry in this country.

D. DETAILED TECHNICAL APPROACH

Technical Approach to Accomplish the Atlanta Team Project

1. *Part 2—Task 1 Cevle: Community-Based Electric Vehicle Laboratory Experiment:* A number of studies will be executed to optimize the experimental design of the CEVLE. A detailed deployment study to select the best "boxes" (deployment areas) , both from a projected vehicle use/trip analysis perspective and a customer profile perspective will be conducted. The deployment study

will also investigate the influence of demographic factors in selection of the best deployment areas. This study will address questions such as: Where can we find sufficient residential density in close enough proximity to a handful of high-density employment areas to allow aggregation of the vehicles at a small number of workplaces during the day while maintaining commute distances supportable with the envisioned technology/operations support plan? The concept study will also be used as a decision tool in selection of the deployment areas.

A detailed platform selection and analysis study will be conducted to select the passenger car platforms for conversion and also which electric motor solutions to employ given specific platforms. Conversion teams will compare ideas and approaches so as to identify the best engineering solutions. The IVMS and the fast battery recharging system will be developed as essential parts of conversion development. The IVMS will be an outgrowth from the required data acquisition system to be installed on the vehicles. IVMS functionality planned for development includes: vehicle performance monitoring, "flight recorder" functions, speed measurement; potential IVMS functionality to be investigated will include: driver performance and energy usage (driving) efficiency, self diagnosis, onboard energy/recharging management. Control/management systems for individual subsystems (e.g., battery hybrid, regenerative braking system), will be developed and tested at the time that the subsystem is tested alone in its own onboard subsystem test. After subsystem optimization, the subsystem will be integrated onto the "full system" test vehicle.

2. *Part 3—Task 1 Zinc-Air/Lead-Acid Hybrid Battery Development*: The energy density of the zinc-air system is more than 2.5 times that of a lead-acid battery and zinc-air batteries have already been demonstrated in experimental electric vehicles. The electrochemistry of the zinc-air system, however, does not allow the battery to operate efficiently over a wide range of discharge rates, and optimum performance is achieved by operating the battery at a constant discharge rate. This characteristic is acceptable for longer constant speed trips. Further, because of its high energy density, the projected ranges for zinc-air batteries are attractive. To overcome the shortcomings of the zinc-air battery system to provide responsive acceleration which requires rapid changes in the rate at which the battery is discharged, the hybrid design will include a small lead-acid battery which would be used to provide the power required by the vehicle for freeway merging, passing, and hill climbing. The lead-acid battery couple has excellent power density capabilities. It may even be possible to provide some recharge to the lead-acid battery from the zinc-air battery to optimize the size of each of the battery types for optimum vehicle operation; this will be investigated. Although the zinc-air battery is a primary system, the objective is that all components of the battery stack be reusable a minimum of ten times (mechanical recharges), except the zinc anode which is replaced each time the battery is "recharged". The cost of the zinc needed to "recharge" the battery stack is estimated at $2.64 per KWh for battery grade materials. In the long run a method to reprocess the spent anode materials could reduce the materials cost for recharging to $0.36/KWh.

3. *Part 3—Task 2 Onboard Microwave Recharging & Highway Datalink:* The technical principal entails a non-contacting RF energy transfer from the roadway to the vehicle and a rectifying antenna onboard the vehicle. With such a system, the vehicle would simply be positioned over a unit in the roadway that is flush with the surface; an enabling signal from the vehicle would turn on the transmitter in the roadway to start energy transfer which would cease when the battery was recharged. The nominal power rating or the roadway transmitter would be 10 KW, yielding an antenna output

onboard of about 30 KW-HR. It is proposed that the transmitter be of the magnetron type with active cooling, sealed in a cylindrical enclosure with integral power supply, equipped with a horn type feed, roadway antenna and a triggering circuit enabled by a low watt RF signal from the vehicle. A nominal air gap of 15 CM is proposed. The antenna would be rated at approximately 1.5 watts/cm^2 of incident energy and would have an area of approxiimately 1.5 square meters. Power control and energy management would be provided by onboard electronics. The prototype would be extensively tested with special emphasis on the health safety aspect; EMI/EMC tests will be conducted at the PRIMES (Preflight Integration of Munitions and Electronic Systems) operated by the 3246th Test Wing at Eglin AFB, FL.

4. *Part 3—Task 3 Regenerative Braking System*: A regenerative braking system will be designed and prototyped for integration and testing on test platforms. Previously used designs and approaches will be reviewed and a system will be designed that will work well in tandem with the other energy-related subsystems being developed in this project. Special attention will be paid to the ease and cost of fabrication as design issues are encountered; concurrent engineering techniques will be applied.

5. *Part 3—Task 4 Driver-Friendly Dashboard Data Display*: The dashboard data display will be a peripheral to the IVMS which will be based on a Macintosh computer As such it will operate either on the CPU bus (extended) or as a SCSI device. The use of touch screen displays will be investigated.

6. *Part 4— Tasks:* TREC will conduct an ongoing study, primarily from a transportation research perspective, aimed at defining issues for research during the Community-based Electric Vehicle Laboratory Experiment and also at evaluating the results of the CEVLE at its conclusion. Issues addressed will include effect of EVs on "normal" (non-EV) patterns of vehicle use, effect of type and convenience of infrastructure (recharging) on normal patterns of vehicle use, effect of user profile on EV acceptance, etc. Research quality statistical techniques will be applied in the reduction and analysis of data. The Marketing Department of the Emory Business School will conduct a study comprised of two parts: a concept test in 1993-94 and a product-market test in 1994-95. The concept test will involve an evaluation of perceived utilities of alternative product features to be included in the deployed models and a test of the product concept and its basic positioning. The product-market test will evaluate and study people's reactions to the actual product and their use response. Issues relating to what users feel about their product-use experiences and their purchase intentions will be measured. A combination of focus group interviews and experimental design techniques will be used for this part of the study.

Continuous and discrete simulation will be used to develop computer models to simulate different scenarios. The models will serve as powerful tools to examine alternative policies that will impact the propagation of electric vehicles. The software model will be made available for use on microcomputers so government and business planners can use it as a tool in their own policy situations.

Multimedia and intelligent computer aided instruction will be combined to provide a state of the art training tool. The tool will provide for flexibility in pedagogical philosophies and student background and will be supplemented with conventional training materials and approaches. The package will focus on the underlying scientific principles that are used in electric vehicles, but will also address policy, environmental, and social issues inherent in the propagation of electric vehicles. In addition, training materials, some computer-based, will be developed for use by vehicle users and for use in team staff training in the CEVLE.

Technical Approach to Accomplish the Florida East Team Project

The Florida East team will undertake a number of conversions and new developments to create several pure electric and electric hybrid vehicles. Battery technology will center on lead-acid batteries used in conjunction with a rapid recharging system. Both DC and AC drive systems will be tested. The team will also develop a bus powered by a solid polymer hydrogen fuel cell and convert 5 vehicle to natural gas/electric hybrids. An important task will be to focus on improving the efficiency of the vehicles' climate control systems to reduce the drain on the electrical power system. This approach is intended to demonstrate electric vehicles, test early market niches for EVs, develop technologies for EVs, determine the sufficiency, adequacy, and scope of the needs of electrical infrastructure to support EVs, develop training programs for a variety of EV user groups, identify barriers to market entry of EVs, and determine the scope, timing and pace of electric vehicle acceptance in the market.

Technical Approach to Accomplish the Florida West Team Project

1. *SOC*: The program will utilize a lead-acid battery gauge developed at USF. Tests have suggested that the gauge will indicate the energy remaining in a flooded lead-acid battery with a conservative accuracy of 7% or better. These gauges will be provided for all the flooded lead-acid battery powered electric vehicles on the military base and a similar number in the private sector.

2. *Fast Battery Charger with Low Distortion*: It is proposed to develop a universal fast charger that can handle battery packs with different voltage and power requirements (0-240 VDC, 0-650 Amp, 0-150KW). The charger will be designed so that the level of harmonic distortion it produces in the AC input line current is lower than the standards of IEEE 519. The charger will be programmable and contain unique features that will facilitate fast charging even at the upper end of the charge cycle where most of the gassing problems occur.

3. *Mobil Data Acquisition System (MDAS)*: MDAS's shall be installed on 6 vehicles on the military base and on a similar number in the private sector. The MDAS would be available for other trucks as well as buses and light weight vehicles. On each of these vehicles the MDAS shall record the array of parameters specified in Attachment 6, Part II of RA93-23 Information Material. The data from the MDAS shall be transmitted to USF, processed using EV-SOFT to establish performance parameters of the vehicles and the supplied to ARPA by means of the SCAT Standardized Data Acquisition Network.

4. *Nickel Metal Hydride Batteries*: To help examine the nickel metal hydride battery potential, EV Cell, Inc. will scale up its cell size capability for small scale production of large nickel metal hydride cells that would be suitable for powering electric vehicles. The large cells will employ the same $LaNi_5$ hydride alloy that is used in small cells and has proven to have low operating pressures and good charge retention. EV Cell, Inc. proposes to produce nickel metal hydride batteries to equip 6 electric vehicles. It is anticipated that three of the six electric vehicles equipped with metal hydride batteries will be military. The batteries for these will be available within six months of the award of contract. The other three will be deployed in the private sector.

5. *Capacitors*: Martin Marietta Specialty Components, Inc. (MMSC) proposes to design, build and test a capacitor pack to act as an auxiliary power supply to assist electric vehicles recover more energy during regeneration and reduce peak drain during acceleration. As a part of this design effort, the development and characterization of some materials will be required to meet the system and environmental needs of the electric vehicle for a capacitor pack.

6. *Advanced Electric Motor Controller (AEMC)*: In the AEMC drive-train and implementation, the flux management system will be combined with a novel and proprietary (Fisher Electric Motor Technology) electro-mechanical field weakening technique. To keep the motor size to a minimum, the AEMC drive-train would follow GM's example and use a total gear reduction from the motor output to the wheels of 10:1. The drive-train efficiency is improved by approximately 10% when the losses from a right angle drive into the differential are eliminated. The design of the controller will be pressed to secure a system that combines efficiency with good performance.

7. *EMF*: Measurements will be made with Electric Power Research Institute (EPRI) developed field measuring equipment by Florida Power Corporation (FPC).

8. *Climate Control*: A state-of-the-art vapor compression cycle system will be evaluated and tested. Special attention will be given to the design of the air duct to reduce the air velocities and increase the air flow. Strategies to reduce the air conditioning load including exterior and interior vehicle improvements that can be implemented in converted vehicles such as the radiative properties of the interior and exterior of the vehicle, glass area and glazing, insulation and active and passive ventilation will be tested and evaluated.

9. *LED Lighting*: This effort is proposed to transfer SDI and other Ultra Bright LED technology into the electric car industry. The effort will mainly be that of identifying the available "dies" and die manufacturing techniques, and establishing a firm to produce them for commercial products.

10. *Vehicle Deployment*: Initially, the vehicle conversions shall employ readily available technology. Private sector vehicle deployment will continue throughout the 2 year project period as opposed to the military base deployment which is all in the first 6 months for pickup trucks and the first year for all vehicles. This provides time to benefit from research progress and advanced technology will be employed when it is developed. Near the end of the program, at least one vehicle will be built that will employ many technology improvements developed under this program such as: advanced motor and controls, more efficient lighting and climate control, light bodies, advanced batteries, and capacitors.

Technical Approach to Accomplish the Georgia Team Project

The Georgia team will use its vehicles to insert new technologies in propulsion and auxiliary systems developed during this program. They will develop training and maintenance programs to support integration of electric and hybrid-electric vehicles into fleet and consumer use. The team will also study the impact of electric vehicles on existing infrastructure, public awareness, and user requirements. The Georgia team will conduct EV demos through this program to promote public awareness {RA Part 4}.

The pickups used in this program will be Ford Ranger mid-sized trucks, supplied by the Georgia Power Company. The advanced high performance power train including an advanced AC induction motor will be supplied by Westinghouse Vehicle & Energy Systems and will be common to both the trucks and buses. The trucks will be fully configured to meet all requirements set forth in the research announcement in both performance and information collection and will be in place at the ARPA selected military site within six months of program start.

The electric and hybrid-electric buses will be configured using a thirty-foot Blue Bird Q-bus chassis driven by the Westinghouse power train. The hybrid configuration will use a compressed natural gas diesel generator as a secondary power source. The electric buses will use the same drive components as the hybrid (without the generator) but will carry a larger battery package to meet the range requirements.

The infrastructure that the Georgia team will put in place to support these vehicles will minimize vehicle down time. The Georgia team will minimize the effect of recharging on the vehicle availability by providing rapid charging stations. The quick charger will also extend the battery life by reducing the stresses during charging.

NOTE: The body of the Georgia team project description is proprietary and is contained in one of the sealed envelopes attached to this proposal.

Technical Approach to Accomplish the Georgia North Team Project

1. *Chassis and Body:* Chassis and body design will be integrated by Spartan and Metrotrans to incorporate numerous exclusivives: power steering (electric assisted hydraulic, torque/speed sensors for inputs for on demand steering, reducing energy requirements), four-wheel independent coil-spring suspension with independent wheel drives commanded by an on-board vehicle computer, hydraulic power brakes, integral design of battery tray and APU on hybrid vehicle, extensive use of aluminum and light-weight composites for external body panels to provide high strength-to-weight ratios and lower rolling friction, and aerodynamic design promoting laminar air flow around body minimizing drag and rolling friction.

2. *Auxiliary Power Unit (APU):* Several different power sources will be considered during the system design phase including internal combustion diesel engines and turbines. Since ARPA strongly requested operation on diesel fuel, which is widely available around the world, candidate power sources will be limited to diesel powered. In addition to the engine, the APU will contain an alternator and integrated control. The APU will be designed to respond to a "power command" from the vehicle control computer to optimize the vehicle emissions and fuel economy. The APU will be packaged as a complete unit, including cooling system, exhaust system. This package will be mounted to minimize noise and vibration.

3. *Vehicle Control Computer:* The vehicle control computer will communicate with the wheel drives and the APU over a serial data link which will minimize vehicle wiring and simplify diagnostics. The vehicle control computer provides the following functions:

- Traction /brake management based on operator inputs
- Control of the Auxiliary Power Unit to maintain the proper battery charge and to optimize emissions and fuel economy (hybrid unit only)
- Interface with the dashboard functions
- Control of the battery charger
- Diagnostics and fault management

4. *Power train:* The power train will be identical for all the electric and hybrid vehicles and will utilize two high performance AC induction motors mounted at the rear wheels. The motors will be directly connected through a two stage planetary gear system to the wheels. A preliminary analysis indicates that two motors rated at 100 horsepower each will be required to achieve the desired performance. The wheel motor concept will allow for the elimination of the differential and rear axles and will allow a true "low floor" design. The motors will be controlled through two microprocessors based inverters using Insulated Gate Bipolar Transistors (IGBT). The inverters and motors are capable of full rating in both the motoring and regeneration modes of operation. The regenerative capability will result in increased range and economy as well as reduced brake wear.

5. *Battery Module and Tray Design:* The GNB design, identified as the 12-EVB-1180 offers an energy density of 39 Wh/kg at the C/3 discharge rate and a projected cycle life of 700-750 cycles to an 80% depth of discharge. Each of the 12-EVB-1180 battery modules measures 12.1 X 6.9 X 8.7 inches (l x w x h) and weighs 66 pounds.

6. *Battery Charger:* GNB will define the charger specifications which will include output voltage and current requirements, the quality of the output power including voltage regulation and ripple, and methods to control and terminate the opportunity charge based on monitored measurements of the vehicle battery. The input power requirements, harmonic isolation and physical construction will be determined in conjunction with Georgia Power. Three of these chargers will be required to complete the demonstration. GNB has worked with several charger manufacturers on the development of charging systems for commercial applications and will select one of these firms to provide the chargers required for the demonstration.

Technical Approach to Accomplish the Tennessee Team Project

The four buses will be supplied by AVS and will be purpose-built. They will have a unique monocoque steel chassis for strength and will utilize composite materials to minimize weight. The buses will have an innovative state-of-the-art battery changeout capability for which a patent is being sought. The complete battery set can be changed out in under 5 minutes by one person. This capability will open up an entirely new focus for zero-emission buses due to increasing their range through rapid battery changeouts on an economical basis.

Delco Remy/Allison proposes to develop, test, and supply an electric drive system for a transit bus application consisting of battery packs, two drive units, two inverters, and a DC-to-DC converter as described herein. A range extender will be supplied with two buses, and the other two will be pure electric. The battery packs, drive units, and inverters will together comprise the heart of the vehicle propulsion system to store electrical energy and convert that energy into mechanical torque to propel the vehicle based on inputs from the driver. The DC-to-DC converter will draw from the propulsion energy storage to supply power to the nominal 12 VDC vehicle accessory loads. The propulsion system shall also be capable of accepting electrical power from off-vehicle sources to replenish the battery pack.

The proposed lead-acid battery modules incorporate a sealed, gas recombinant construction which makes them inherently safer and easier to handle than flooded batteries and are maintenance free. The pure electric buses will have four battery packs and the buses with the range extender will likely have two battery packs, each with 26 individual propulsion battery modules, a battery pack control module (BPM), and high power disconnect capability.

Motive power is produced by a single liquid-cooled AC induction machine with an integrated transmission for each driving wheel. The motor is composed of a wye-wound, three-phase stator, brazed, short-circuited copper bar, squirrel-cage rotor, bi-directional encoder, temperature sensor, and three-phase power connector. Since induction machines are capable of higher speed operation than other electric motor technologies, higher operating efficiencies can be achieved while reducing the physical motor size. One advantage of induction machines is their suitability for both motoring and regenerative operation.

Initially the Tennessee design shall employ a very compact gasoline powered, vertical, four-stroke internal combustion engine coupled to an induction type generator. During year two of the Tennessee project, the APU will be converted to CNG with perhaps more advanced generator technology. Mercury Marine and AC Rochester will be involved in taking the engine to CNG fuel use. Tennessee's upgraded engine will likely be coupled to either a high efficiency, permanent magnet generator/starter, or improved AC induction machine. The machine will be more fully integrated with the engine and serve both as the APU generator and engine starter (cranking motor).

The three-phase induction machine is fed by a pulse-width-modulated (PWM) inverter incorporating current and slip frequency control techniques, and isolated gate bipolar transistor (IGBT) power switches. The inverter converts DC battery power to variable frequency, variable voltage, three-phase power. Vehicle acceleration and brake commands are converted to the desired torque input signal. Accessory power is produced by a liquid-cooled DC-to-DC converter incorporating a PWM topology to convert high voltage battery pack power into regulated low voltage power for low voltage accessory loads.

EPTI will provide a prototype rapid recharger under proprietary technology covered by U.S. Patent No. 4,829,225 with additional patents pending. The EPTI charging method is unique in that it shortens the charging cycle while prolonging battery life. This is accomplished by substantially improving the efficiency with which energy is delivered to the battery. Specifically, this improved efficiency allows for the introduction of energy to the battery at substantially higher rates without battery overheating and results in dramatic reductions in the time required for recharging the battery. Further, this improvement in the efficiency of the charging process is accomplished by a method which significantly reduces the internal resistance of the battery to the flow of the charging current throughout the charging cycle. In addition, the EPTI charging system has been demonstrated to reduce gassing by more than 8 times, while only increasing the ambient temperature by less than 15 degrees when compared with pulse or conventional charging technology. EPTI will provide the design, engineering, and fabrication of a prototype battery charging system for the rapid charging of electric vehicles at a central charging station. The system microprocessor will be capable of independently controlling the duration, amplitude and number of charge/discharge pulses as well as the rest period for each circuit. The system will monitor the following information: starting charge time, present current, cumulative energy delivered to the batteries, voltage across the batteries, and time to charge completion.

EPTI will utilize the service of Electrotek Concepts, Inc.'s Electric Vehicle Test Facility (EVTF) for the testing and evaluation of the EPTI charger with regard to power efficiency, level of harmonics, and battery life testing. In addition, they will be utilized as an additional resource during the overall design review. *Preliminary technical specifications for the battery charging system are included in Attachment D of the Supporting Information section at the end of this proposal.*

Technical Approach to Accomplish the Texas Team Project

This project is divided into several tasks that will be accomplished under the supervision of a small management staff. Each task has been assumed by a company or group, with a specific budget. The participants in the various tasks constitute the Texas Team. The university components of the Texas Team are mainly responsible for basic concept and design development, simulation, and performance specifications. The industrial groups are responsible for actual component engineering, manufacturing, and system integration. The two ancillary groups will develop new components which are off the critical path of ELPH vehicle development, but if successful, will be tested on the ELPH platform. The Texas Applied Power Electronics Center at Texas A&M University is the lead establishment for this project, and is where the Texas project management team staff will reside.

Two primitive versions of the ELPH car will be built (ELPH "mules") within six months and twelve months, respectively, from contract award. These will be used to test and refine the final design plans which will be applied to the three ELPH vehicles delivered at the end of the project.

NOTE: The body of the Texas team project description is proprietary and is contained in one of the sealed envelopes attached to this proposal.

GTRI Technical Approach to Data Acquisition Management

Figure 1 shows the hardware to be supplied to each of the SCAT team vehicles having a requirement for data logging. Every instrumented vehicle will carry the SCAT standardized data acquisition network interface, or be able to interface by other means with the network. This system will communicate with the suite of sensors contained on each instrumented vehicle through a standardized interface. The parameters of this interface will be provided to each of the SCAT teams to assure that the various instrumented vehicles present their sensor outputs in the pre-defined conditioned format (e.g. digital voltage swings, fan-out, minimum bandwidth/refresh rate, word size, etc.). This will facilitate "apples-to-apples" comparisons that are more statistically significant.

As shown in Figure 1, a network of internet or dial-up nodes is envisioned. The master node will be located at GTRI since it has direct access to the internet network (as well as others). The master node will periodically and automatically contact the various test sites around the SCAT region to query the nodes. Compressed and formatted data that has been acquired from each vehicle operating within the influence of a given node will be automatically uploaded to the GTRI master upon request. This data will have been gathered in a similar manner by the node computer as it automatically dials up each vehicle onboard system via a cellular telephone link. All of the node computers will be programmed using the commercially available database scripting language "Fourth Dimension." Except for the interrogation schedule for each node, all node computers will run the same software. By standardizing the data formats and protocols at each level of interrogation, even data bases generated by other sources, but converted to the SCAT protocol, can be queried as part of the overall network data acquisition concept.

The GTRI master computer will decompress the data it receives from each node, compile it, organize it, and reformat it for distribution and analysis. One distribution point will be located at ARPA. Information will be automatically uploaded to the ARPA computer on a daily basis via internet. ARPA will be able to monitor SCAT activities from its Washington D.C. offices at a high level (pre-generated performance graphs, usage charts, digitized video, etc.), or alternately, it can directly view the activity of a given node in terms of low-level raw data by linking directly to that node through the GTRI master computer. Other users can also avail themselves of the SCAT information in a similar manner, as the GTRI master computer can be made to upload the same information that ARPA receives.

(As desired by ARPA, this data acquisition scheme can be made available to all of the participants of the RA 93-23 program so that ARPA can obtain a national look at all of its funded electric vehicle projects on a daily basis, and with a commonality of format. This has not been priced in the scope of the SCAT program, but can be a matter of negotiation after award.)

E. ROLE AND RESPONSIBILITIES OF EACH SCAT TEAM MEMBER

The Southern Coalition for Advanced Transportation (SCAT) is a consortium of companies joined together to pursue parallel technologies in different geographical areas under ARPA's Hybrid-Electric Vehicle Program. Seven teams have been organized within SCAT and each will manage complete, stand-alone projects coordinated through SCAT. SCAT will ensure standard data acquisition and reporting formats for all teams and provide data transfer between teams. The Georgia Tech Research Institute (GTRI) will serve as the overall technical coordinator for SCAT.

SCAT seeks to improve the success of the Hybrid-Electric Vehicle Program by developing parallel technologies in different geographic areas. Among the technologies to be pursued are: lead-acid and nickel metal hydride batteries, solid polymer hydrogen fuel cells, gasoline and compressed natural gas auxiliary power units, high efficiency HVAC, advanced AC induction drive motors, and a mobile microwave recharging system. SCAT teams will cover the southern region of the United States with operations in Georgia, Florida, Tennessee, and Texas.

Roles within the Atlanta Team

Advanced Transportation Research will serve as team leader with Brad Worthington as the overall project manager and R&D director. GNB Industrial Battery and MATSI will develop a zinc-air/lead-acid battery hybrid. TRW, ATEC, GTRI and Flat Antenna Corp. will prototype a microwave recharging system. The Atlanta Team has obtained over 90,000 hours of task related committed EV experienced student participation (and over 8,000 hours of faculty participation); the schools participating in conversion and component specific development have each successfully converted their own electric vehicle in the past year. Georgia Tech TREC will conduct a deployment study and an evaluation study. Southern College of Technology will work on software. Solar Car Corporation will supply conversion kits and training. The University of Central Florida will work on vehicle conversion and develop a regenerative braking system (working with Clemson). Georgia Tech, Fort Valley State College, Kentucky Tech/Ashland, Daytona Beach Community College, and Clemson will work on vehicle conversion. Emory University will conduct a concept test and a product-market test. Morris Brown College will develop a EV policy decision tool, and EV teaching materials. ATR will develop, as an essential part of conversion development, an Intelligent Vehicle Management System (IVMS) and an onboard/offboard fast recharging system, will conduct various public awareness/education activities, and will manage infrastructure installation. Clean Air Vehicle Assn. will conduct an International Scholastic Clean Air Grand Prix. Georgia Dot will provide trucks for conversion.

Roles within the Florida East Team

The Florida East team will pursue a combined solid polymer hydrogen fuel cell/battery technology as part of the SCAT consortium. They will focus on the eastern region of Florida including the Miami area. Florida Power & Light (FPL) Company will provide team leadership for the Florida East team. FPL will also be responsible for the infrastructure development, consumer research and publicity. GNB Industrial Battery Company will develop advanced, maintenance free, sealed lead-acid batteries for use on various team vehicles. Hughes Power Control Systems (HPCS) will provide AC drive systems for S-10 pickup trucks. HPCS will also provide engineering support to assist in the application of the end product. Electronic Power Technology, Inc. (EPTI) will develop and build stand-alone charging stations that will charge electric vehicle batteries in less than one hour. EPTI will be responsible for the installation and testing of the rapid charge stations as well as all related training and support. Solar Car Corporation will be responsible for systems integration and vehicle retrofit, quality control and final testing before release of vehicles to demonstration and program sites. DeVry Institute and Florida Power and Light will conduct marketing/cultural research, gather technical and consumer information, and conduct training.

Roles within the Florida West Team

The Florida West team will explore the use of lead-acid and nickel metal hydride battery technology in the west Florida region. They will also address the environmental conditions (heat) associated with this region by developing high efficiency air conditioning systems. The University of South Florida (USF) will serve as the team leader with George Moore as the project manager and utility coordinator. USF brings an experienced, highly motivated team of utilities, private companies, and research capability together to address the issues of infrastructure, technology development, and deployment management for electric vehicles. The Florida West team will convert pickup trucks supplied by a military base (recommended location is MacDill AFB), to electric operation. The Florida West team will also convert utility-supplied pickups for utility fleet operation and provide two "light weight" utility vehicles for military base fleet operation. Existing USF-developed mobile acquisition systems, configured to interface with the SCAT data acquisition network at the node level, will be installed in these vehicles. The Florida West team will conduct research and technology development for: high power fast chargers, highly efficient direct motor drive and optimized control, EMF measurements, "fuel gauge" for advanced batteries, energy peaking capacitor storage, human factor evaluation for electric vehicles, improved efficiency vehicle HVAC, fabrication, installation and operational testing of advanced nickel metal hydride batteries, development of battery monitoring and control, application of efficient vehicle lighting, maintenance and safety personnel training, and publicity/information dissemination. The Trojan Battery Company is in a position to supply battery technology to the Florida West team.

Roles within the Georgia Team

The Georgia team will pursue electric and hybrid-electric vehicle technology using advanced AC induction drive motors and compressed natural gas diesel generators. Their operations will take place throughout Georgia. Westinghouse Electric Corporation (WEC) will provide overall project management for the Georgia Team. Their experience in power electronics, conversion, and transmission will ensure that the power trains developed under this project will be highly efficient and capable of meeting a wide variety of vehicle needs. Westinghouse will be responsible for the power train development, including system design, production, and system integration. Blue Bird Body Company is the number one bus manufacturer in the United States with over 65 years of experience. They will be responsible for the vehicle development and fabrication. Georgia Power Company, one of the nation's largest investor-owned utilities, has extensive experience in infrastructure development and electric vehicle conversion, maintenance, and operation. They will perform infrastructure testing and development, infrastructure installation, and system integration. The Transportation Research and Education Center (TREC) at the Georgia Institute of Technology was established in 1991 to foster interdisciplinary research and education activities in transportation. They will be responsible for test planning, evaluation and data analysis for the Georgia Team.

Roles within the Georgia North Team

The Georgia North team will focus their efforts around the metro Atlanta area. They will develop all electric and electric hybrid bus technology employing diesel powered auxiliary power units (APU). Metrotrans Corporation will act as the team leader for the Georgia North team. Metrotrans will build the bus bodies and install the system components. In addition, they will check-out and road test the vehicles. Spartan Motors will design and manufacture the custom chassis including the suspension, brakes, steering, and cooling system. Chassis and body design will be integrated by Spartan and Metrotrans. GNB Industrial Battery Company will provide an electric vehicle battery design based on its patented ABSOLYTE Valve Regulated Leas Acid technology. In addition, GNB will engineer the battery trays to protect the battery from damage during vehicle operation, to provide shock and vibration resistance and to provide thermal management of the battery during operation and charging. They will perform battery performance verification testing and conduct performance simulations and life testing of the battery modules. GNB will also identify the requirements of the opportunity charger as part of the development effort; and, working with Georgia Power Company, will specify the equipment requirements to complete the demonstration installations. General Electric will develop the power train based on the AC drive that they developed for the DOE Modular Electric Vehicle Program. All team members will provide training and support. Public awareness will be accomplished through trade journal advertising, international press releases, newsletters to public utilities, and direct mail to users in the AFNAF network for which Metrotrans currently supplies internal combustion coaches.

Roles within the Tennessee Team

The Tennessee team will have operations in both Chattanooga and Atlanta. They will develop a system employing lead-acid batteries in conjunction with a gasoline powered internal combustion engine APU. Advanced Vehicle Systems, Inc. (AVS) will serve as the team leader for the Tennessee team with Joe Ferguson as the project manager. AVS will manufacture the 30 foot buses proposed for this project at its Chattanooga facility. In addition, as team leader AVS will be ultimately responsible for the systems integration, operation and maintenance of the buses, project documentation, and publicity. Delco-Remy/Allison Transmission will design, engineer, and manufacture the energy system (batteries), propulsion system, and tailor the APU and generator set to the 30 foot bus. Electronic Power Technology, Inc. will design, engineer, and build state-of-the-art rapid charging equipment to demonstrate very advanced charging techniques for the 30 foot bus. Georgia Power Company will manage, maintain, and assist in the operation of electric buses in Atlanta, Georgia.

Roles within the Texas Team

The Texas team will have activities in Texas and Atlanta, Georgia. They will develop an electrically peaking hybrid design that consists of an internal combustion engine driving an electric generator. The Texas Applied Power Electronics Center at Texas A&M University will be the team leader for this project, with Dr. Mark Ehsani as the principal investigator. Texas A&M University will also have responsibility for the following: Power electronics, controls, and motor drives concept development through the Texas Applied Power Electronics Center, Vehicle system simulation through the Center for Innovative Design and Electrical Engineering Department, Engine design and operational studies through the Department of Mechanical Engineering, Battery simulation, testing, and design through the Center for Electrochemistry and Hydrogen Research, and Soft sciences such as total cycle emissions, vehicle safety, ELPH product acceptance, transportation infrastructure economics, and personnel training through the Texas Transportation Institute and Texas Engineering Extension Service. Texas A&M will also be responsible for the development of a flywheel battery and the fiber optic combustion pressure sensor. A.A. Technologies in Atlanta GA, will perform vehicle fabrication and integration, vehicle instrumentation, and will supply vehicle maintenance. The General Electric Company, will provide the electric motor drive. Lone Star Gas Company will be responsible for the internal combustion engine and natural gas conversion, vehicle evaluation, dynamometer and emissions measurements, and a demonstration infrastructure development on a military base and in the private sector. Micron Engineering in College Station TX, will produce the vehicle master microcomputer controller hardware and software. ElectroSource, Inc., Austin TX, will provide a lead-acid battery system and support hardware.

F. SCAT'S PREVIOUS ACCOMPLISHMENTS AND RELATED EXPERIENCE

Table 6 lists the contract related experience of the SCAT team members. All seven SCAT teams have as members companies with long track records of contract work for federal and state governments as well as private industry. These well established, core companies include Westinghouse, Georgia Power, Delco Remy/Allison, TRW, and General Electric. In addition, the universities such as Duke, South Florida, Texas A&M, and Georgia Tech are well known for their government sponsored research programs. These groups provide the experience and infrastructure for dealing with large government contracts.

The teams also consist of vehicle chassis manufacturers who are well established as the nation's leading manufacturers of buses and vans. Metrotrans is a final stage manufacturer of medium duty coaches and specializes in the union of the power train, chassis, and coach components. Spartan Motors is a custom heavy chassis manufacturer of fire trucks, motor homes, and buses. Blue Bird Body Company is the number one bus manufacturer in the United States with over 65 years of experience.

Major utility companies have been recruited because of their expertise in infrastructure development, market research, and publicity. Georgia Power, one of the nation's largest investor owned utilities has extensive experience in infrastructure development and electric vehicle conversion, maintenance, and operation. Florida Power and Light is the fourth largest owned electrical utility in the U.S. with infrastructure capability and a full range customer research department. Lone Star Gas company is a large natural gas pipeline and distribution company with major interests and facilities in internal combustion engine vehicle conversion and testing.

The battery companies in SCAT have extensive experience in the development of advanced batteries. GNB Industrial Battery has completed contracts with the Department of Defense through the U.S. Navy and the Air Force, the Department of Energy through Sandia and Argonne National Laboratories, and Newport News Shipbuilding and General Dynamics as a subcontractor to Boeing

Aerospace Corporation. Trojan Battery has developed bipolar technology under a South Coast Air Quality Management District contract. MATSI has been funded by both the Dept. of Energy and NASA to develop its zinc-oxygen battery which it intends to use in an electric car. Electrosource has been funded by EPRI which has identified Electrosource's technology for its near term focus.

The teams are rounded out by specialty companies including start-up firms whose key personnel have experience in technologies required to develop electric vehicles. A.A. Technologies has 20 years of experience in designing, prototyping, and evaluating electric vehicles. Solar Car Corporation has experience in research and development, systems integration, production of subsystems, and vehicle retrofit activities for solar electric vehicles. EPTI has patented technology pertaining to the development of rapid charging stations for electric vehicles. Advanced Vehicle Systems is presently producing 12 electric buses for the Chattanooga Area Rapid Transit Authority. The DeVry Institute's personnel have experience in cultural and marketing research as well as in data acquisition. Advanced Transportation Research has expertise in systems integration, software design, and data acquisition.

G. DESCRIPTION OF FACILITIES & EQUIPMENT

Table 5 of the Executive Summary shows the resources, facilities, and equipment for the SCAT team members listed by company. Each of the seven regional SCAT teams has access to office, machine shop, and manufacturing facilities as well as to R&D and testing labs. Each team is fully equipped to develop, test, and analyze their designs. Below are some of the teams' facilities that are of particular interest for this proposal.

Atlanta Team

The Atlanta team will have access to TRW's anechoic chamber for exhaustive free-space EMI testing. They will also have the use of the University of Central Florida's engineering and test facilities for electric vehicles. In addition, arrangements have been made to secure the use of 5 Ford Ranger pickup trucks from the Georgia Department of Transportation.

Florida East Team

The Florida East team has an Electric Vehicle Dynamometer Lab and a Vehicle Electronics Integration Lab. Cooperation with Patrick AFB and several county transit authorities has been secured to gain access to their motor pools and maintenance facilities.

Florida West Team

The Florida West team's resources include: the University of South Florida (USF) Electric Vehicle Lab facility, a 20 KW recharging station, a mobile data acquisition system, the USF Center for Urban Transportation and Research, and an HVAC environmental testing lab.

Georgia Team

The Georgia team has access to the Transportation Research and Education Center (TREC) at the Georgia Institute of Technology which conducts transportation related research.

Georgia North Team

The Georgia North team has access to a high volume drive component manufacturing facility and a pilot production facility for manufacture of electric vehicle components. In addition, they have field service personnel throughout the world.

Tennessee Team

The Tennessee team has access to Allison Transmission's Noise and Vibration Lab, precision gear and machining equipment, and transmission manufacturing facility. Delco Remy provides an Electronic Assembly Lab, Thermal Test Facility, Shock Test Facility, Electromagnetic Radiation facility, Noise Reduction Lab, Ultra high speed rotor spin pit, Battery Test Lab, Material Test Lab, and Chemical and Material Analysis Laboratory.

Texas Team

The Texas team has the following research centers: Texas Applied Power Electronics Center, Center for Innovative Design, Center for Electrochemistry and Hydrogen Research, Center for Electromechanics, ElectroOptics Laboratory, the Texas Transportation Institute, and the Texas Engineering Extension Service.

H. PERSONNEL QUALIFICATION SUMMARY AND MAJOR SOURCES OF SUPPORT

Table 4 in the Executive Summary lists the key personnel for the seven SCAT teams along with their roles and qualifications. All key personnel are highly qualified with either many years of experience, advanced degrees, or both. Manufacturing and business personnel typically have more than 15 years of experience in addition to undergraduate degrees in applicable fields. Many of the business managers also have MBAs. Research personnel are typically lead by a principal investigator with a Ph.D. in an appropriate field such as electrical engineering, mechanical engineering, chemical engineering, chemistry, electrochemistry, or materials.

Most key manufacturing and business personnel are full time employees of companies with ongoing contracts and business in applicable areas. In fact, most of the contract related experience listed in Table 6 refers to ongoing programs. Key personnel are involved with these contracts and are currently pursuing developments that are directly related to the electric hybrid vehicle program. In addition, these personnel have been designated to be available at the time of the contract award. For example, GNB Industrial Battery Company personnel are currently engaged in contracts with Naval Sea Systems Command, Sandia National Laboratories, Newport News Shipbuilding, and General Dynamics Electric Boat Division. These contracts will come to successful completion in late 1993 through late 1994. Similarly, Solar Car Corporation is currently executing a two year contract with the Florida Energy Office. Personnel are involved in retrofitting Chevy S-10 pickup trucks to be electrically powered which has direct application to ARPA's proposed electric hybrid vehicle program. A.A. Technologies has several ongoing joint programs with French and German manufacturers to develop 2 and 4 seat electric vehicles. These programs are entering various stages of production and provide royalties which fund further company developments. The larger, core companies (GE, Westinghouse, Blue Bird, Delco Remy/Allison, TRW, and Georgia Power) have sources of support too numerous to list. They have identified key personnel having the requisite expertise within their organizations and will make them available at the time of the contract award.

TABLE 6. RELATED EXPERIENCE OF PARTICIPATING SCAT MEMBERS

CO.	RELATED EXPERIENCE
AAT	20 years of experience in designing, prototyping, testing and evaluating electric vehicles. Ongoing contracts with French, German, and Mexican firms for electric vehicle development.
ATEC	Caltrans Ross contract currently underway for $1.5 million
AVS	Presently manufacturing 12 electic buses for CARTA. AVS subcontractors have had two FTA grants: one for 22 electric powered buses and 3 parking garages with infrastructure for change-out and charging and one for a clearinghouse for information on electric buses, hybrids fuel cells and infrastructure. 14 programs on advanced battery technology and charging systems, 9 programs on EV and electric buses, and 1 on the electric road way analysis.
BBBC	Number one bus manufacturer in the United States with over 65 years of experience. Ongoing and completed GSA contracts for DoD buses
DRAT	Delco Remy is the world's largest producer of electrical power and ignition products for vehicles, Allison is the world's leading producer of medium and heavy duty automatic transmissions
DVRY	Training assessment and development contracts with Northern Telecom and Bell South, grants to individual faculty from National Science Foundation
ESI	Contracts with EPRI for advanced battery development
FPLC	Numerous and various projects related to electric vehicles including electrificaton of airports and EV Research Network (w/ EPRI and 14 utilities)
GEC	World leader in the design and manufacturing of drives, controls automation, and a leading supplier of components for electric vehicle systems. 16 electrical vehicle programs (1959-1985), Modular Electric Vehicle Program, Hybrid Electric Bus Program and Ultracapacitor Interface Study.
GNB	Completed contracts with DoD-U.S. Navy &Air Force, DoE-Sandia and Argonne National Laboratories, current contracts to supply submarine batteries to Naval Sea Systems Command, Neport News Shipbuilding, GD-Electric Boat Division and DCMAO CHICAGO.
GP	One of the nation's largest investor owned utilities, has extensive experience in infrastructure, development and electric vehicle conversion, maintenance and operation.
GT	Ongoing and completed contracts in Intelligent Vehicle Highway System, transportation management systems, program and project evaluation for U.S. DOT, EPA, and numerous other federal/state agencies, numerouse projects on vehicle testing and siluation models, large scale emissions testing experience, and battery research.
GTRI	Numerous contracts with government agencies including FAA and DOD in aerospace and radar developments
LSG	FleetStar of Texas CNG fueling station program— 6 stations in DFW area, TRANSTAR Natural Gas Service Center— warranty service on the Sierra, GMC's dedicated natural gas pickup trucks.

TABLE 6. RELATED EXPERIENCE OF PARTICIPATING SCAT MEMBERS

CO.	RELATED EXPERIENCE
MATSI	$900,000 in contracts funded by the U.S. Dept. of Energy for the development of an electrically rechargeable zinc-oxygen fuel cell system for electric cars. $800,000 in contracts with NASA for the development of primary zinc-oxygen fuel cells for the space shuttle and rechargeable zinc-oxygen fuel cells for the space station.
ME	NASA contract to design a new concept for an automated power system which includes protection, control, and monitoring functions, cooperative project with Schlumberger-Sangamo Electric to design a computer based data analysis system for storing, retrieving, and analyzing large quantities of data, cooperative effort with #M-Sumotomo to design test instrumentation for use in diagnostics associated with the Japanese telephone network.
MTC	Ongoing contracts for internal combustion vehicles for clients such as Ryder, Marriott, Alamo, Budget and AFNAF
SCC	2 year, $250,000 contract with Florida Energy Office to retrofit Chevy S-10 pick-up trucks for fleets in eight counties. Contract being increased to include two more vehicles from a ninth county.
SMI	
T A&M	Over $50 million of similar federally matched projects at Texas A&M, such as the Center for Space Power ($3M/yr), Foundation for Engineering Education ($15M), Alliance for Minority Participation ($5M), Off Shore Technology Research Center ($2.5M/yr). Each of the participating cneters and labs in the Texas team also has several million dollars of their own annual funding for various projects.
TBC	68 years experience in development and manufacturing of lead-acid recyclable batteries for SLI and deep-cycle applications.
USF	DoE grant and Florida Energy Office contract-EV/Photovoltaic (PV) evaluation and demonstration program; DoE, NREL-PV system for EV charging,utility EV demonstration program; DARPA grant for Advanced Microelectronics and Materials Program.
UTA	7 DoD-Army and Navy programs for EM suspensions, bearings , homopolar generators and power supplies for railguns, EM launchers and EM gun systems.
WEC	Quality supplier of state-of-the-art electric and electronic equipment for over 105 years. Ongoing DOT/FTA electric vehicle development project.

Most research personnel are attached to research centers as is the case for the Texas A&M, University of South Florida, and Georgia Tech engineers and scientists. These centers continue to receive government and industry funding allowing them to conduct relate research and to be available at the time of contract award. For example, the Transportation Research and Education Center (TREC) at Georgia Tech has ongoing contracts with the Environmental Protection Agency, the U.S. Army Signal Center, the Federal Highway Administration, and the Georgia Department of Transportation. TREC staffers include full time faculty and research personnel at Georgia Tech who can be called upon for the electric hybrid vehicle program. Similarly, the University of South Florida has current contracts with the Florida Energy Office and NREL for an Electric Vehicle/Photovoltaic Test and Evaluation Program. Texas A&M has several current contracts with the Texas Department of Transportation through its Texas Transportation Institute. Additional key personnel for Texas A&M are assigned to participating centers and lab within the university that have several million dollars of their own annual funding for various projects.

I. OPERATING PLAN

Georgia Tech will manage both technical and financial aspects of this project for SCAT, with the SCAT teams being subcontractors to Georgia Tech. For each of the team projects selected by ARPA, Georgia Tech will negotiate a Statement-of-Work that specifies the work to be accomplished. Each team leader will be required to prepare a detailed plan addressing both the "what" and "when" of all proposed technical activities, as well as progress reporting mechanisms. A spending profile will also be prepared by each team leader.

Georgia Tech's management approach will focus on the detailed technical and spending plans for each team. Regular reporting from each team will allow Georgia Tech to track their technical and financial progress with respect to the plan. Weekly telephone or electronic-mail activity reports will be required of each team. Formal progress and financial reports will be required on a monthly basis. Georgia Tech will consolidate the multiple teams' progress reports into a single document and provide the report to both SCAT and ARPA. This monthly report will cover, as a minimum, the past month's accomplishments, the next month's planned activities, problems encountered or anticipated (with solutions/approaches to dealing with them), monthly and cumulative spending, and a comparison of the current technical and financial status to the plan.

Current or potential problems will be identified as early as possible by carefully tracking each team's progress against the plans. These problems will then be thoroughly investigated with the affected team and the best approach to solutions worked out. SCAT and ARPA will be advised as soon as a problem—real or potential—is identified, so they can be involved in determining the solution if desired, and they will certainly be asked for approval of the solution.

Georgia Tech's internal project oversight procedures will be employed to assist the project director. These procedures include weekly activity reports to the responsible Laboratory Director, and monthly formal reviews of the project's status by each level of management up to GTRI's Office of the Director. Any technical, schedule or financial deficiencies, current or potential, that are identified in these reviews will receive constant tracking and attention until they are resolved. This GTRI management attention includes direct interaction with peer management levels in the team leader companies to assure corrective action is taken.

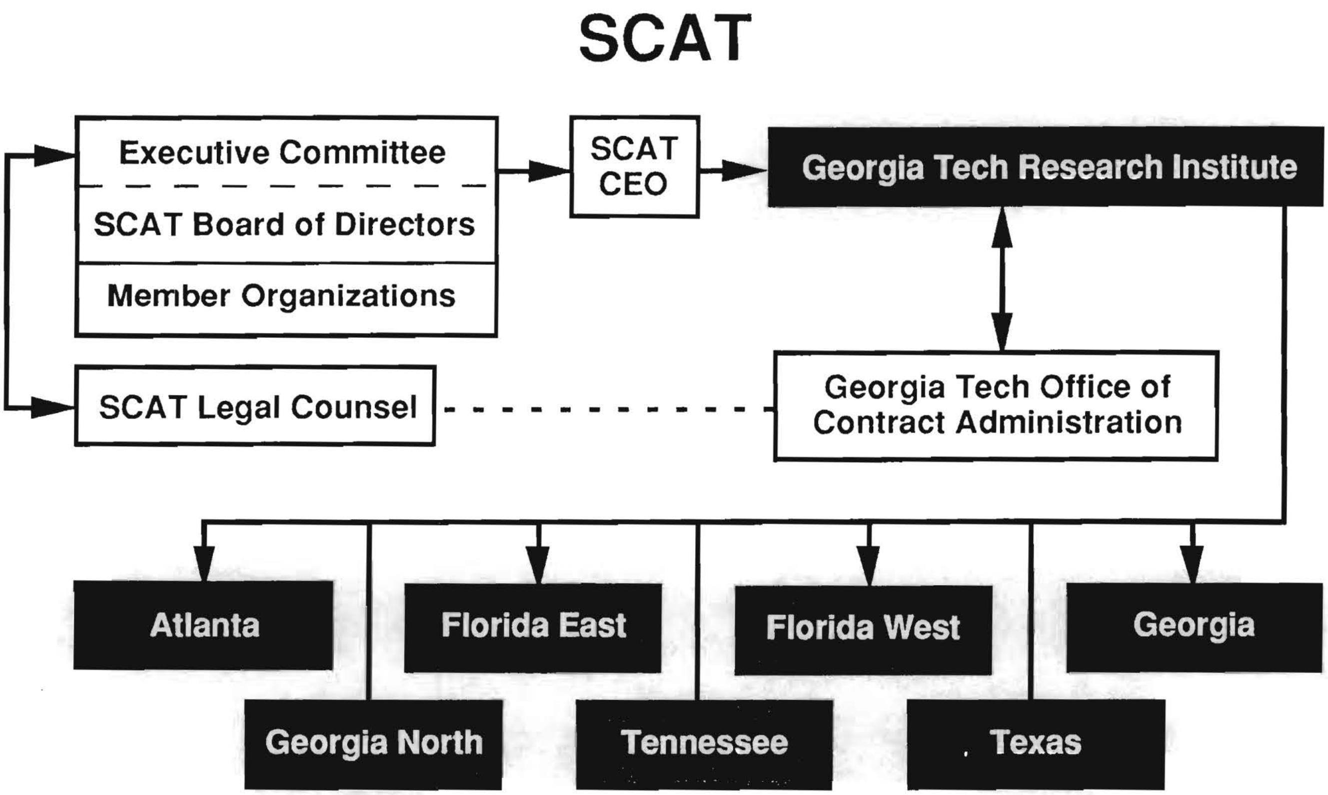

Figure 2. SCAT program organization.

(END OF SECTION 3)

Volume II
Cost Proposal

Innovative Electric Transportation Technology for Demonstration in the Military and Private Sectors

ARPA Electric and Electric Hybrid Vehicle Technology and Infrastructure Research Program

Points of Contract for this Proposal

	Technical	Administrative
	Robert C. Michelson	David A. Bridges
E-MAIL:	michelsn@prism.gatech.edu	david.bridges@oca.gatech.edu
Phone:	(404) 528-7568	(404) 894-4817
FAX:	(404) 528-3271	(404) 894-6956
Address:	GTRI-AERO-CCRF 7220 Richardson Road Smyrna, GA 30080	Georgia Tech Office of Contract Administration Atlanta, GA 30332

This proposal is being submitted by the Southern Coalition for Advanced Transportation (SCAT) which is comprised of numerous entities. SCAT members participating in the response to RA 93 - 23 have been organized into seven teams with interests spanning several electric transportation technology areas, with some SCAT members, for reasons of efficiency and economy, providing umbrella services to the entire effort of the consortium. The following list includes the names and telephone numbers for the various principal points of contact on each team that have been responsible for gathering input for use in this proposal:

Atlanta Team	Brad Worthington	(404) 913-9682
Florida East Team	Bob Suggs	(305) 552-4133
Florida West Team	George Moore	(813) 974-4771
Georgia Team	Curtis Pearson	(410) 765-3958
Georgia North Team	Terri Hobbs	(404) 229-5995
Texas Team	Mark Ehsani	(409) 854-7441
Tennessee Team	Joe Ferguson	(615) 821-3146

June 1993

SUMMARY OF COST

A detailed cost estimate has been prepared for the proposed work included in the proposal "Innovative Electric Transportation Technology for Demonstration in the Military and Private Sectors". This proposal and cost estimate was prepared by the Georgia Tech Research Institute for the Southern Coalition for Advanced Transportation in response to the ARPA Research Announcement 93-23. All input information was generated by the various teams that were formed and the participating organizations. This Coalition is representative of the southern geographic region of the country but the participating organizations are globally oriented when considering potential markets.

The consortia and their bottom line request are summarized as follows:

CONSORTIUM	TOTAL VALUE	ARPA REQUEST
Atlanta	$3,269,660	$1,634,830
Florida East	$5,797,070	$2,898,535
Florida West	$4,811,000	$2,405,500
Georgia	$6,516,586	$3,258,293
Georgia North	$4,008,000	$2,004,000
Tennessee	$5,151,000	$2,565,500
Texas	$6,826,000	$2,513,000
COALITION		
Devry	$792,762	$396,381
Georgia Power	$1,262,500	0
GTRI	$900,776	$900,776
SCAT-COO	$595,809	$297,905
TOTAL	$39,931,163	$18,874,720

For this proposal the total amount of In-Kind Cost Sharing is $12,000,623 and the total amount of Cash Cost Sharing is $8,824,321 for a total match of $20,824,944. This gives a favorable ratio of:

0.90635=(Federal dollars / Non-federal dollars)

DESCRIPTION OF COST MANAGEMENT PROCEDURES

The Southern Coalition for Advanced Transportation, Inc. (SCAT) is a non-profit Corporation of participating organizations, who have an interest in electric transportation products and systems, and are representative of the southern region but inclusive of global markets. SCAT was created to capture ARPA grant funding and will pursue all public and private funding to meet it's objectives. It will act as a catalyst to promote development, demonstration and commercialization of clean fuel transportation fueled mainly by electricity.

As an inclusive organization SCAT will consist of several levels of participation. The member organizations have funded SCAT initially by paying predetermined dues. These funds will apply toward matching requirements for the ARPA Research Announcement 93-23. A Chief Operating Officer will be hired when the proposal is funded. A Board of Directors has been established. They have elected the Officers of the Corporation, who along with the Chief Operating Officer constitute the Executive Committee. The activities and affairs of the Corporation are conducted by and under the direction of this Board of Directors and the Chief Operating Officer. The Chief Operating Officer will be responsible for the day-to-day administration and operation of the Corporation and shall report directly to the President.

SCAT will be the prime contractor for the ARPA program. To effectively coordinate all efforts, the Georgia Tech Research Institute will serve in the role of Program Director and as the Contracting Officer Technical Representative for the SCAT Board of Directors. General management oversight and coordination will be performed by GTRI, for SCAT. Contracts for SCAT members from ARPA will be made with the Georgia Tech Research Corporation, a non-profit corporation, set up to do the contracting for the Georgia Institute of Technology. Contracting with the various consortia, made up of participating organizations will be conducted through the Georgia Tech Office of Contract Administration. A Contracting Officer will be responsible for each contract issued to a funded consortium. There will be a requirement for both monthly technical and financial reports to GTRI. This information will be tracked on a timely basis to minimize or prevent both late deliverables and cost overruns.

Each separate contract with a consortium of participating organizations will be subject to a pass through charge equivalent to the overhead charge, by Georgia Tech, on the first $25,000 of the value of the contract. At the current DCAA audited rate this would be equivalent to $15,704 per contract. These contracts will be funded incrementally as the funds are released by ARPA through SCAT to Georgia Tech. Cost management procedures will flow down from ARPA to SCAT to GTRI to the various Consortia and hence to the participating organizations.

Atlanta Team

The Atlanta Team will implement the cost management procedures required by GTRI and SCAT. These will be implemented at the team level. Within the team, cost management will be effected by a project-wide budget planning process combined with budget administration at the project and work group level.

In the project planning process, a budget will be prepared for each work group based on planned work group tasks and requirements. This budget will be managed at the work group level by the work group manager working in concert with the project manager. All desired expenditures not in the approved budget will have to be approved by the project manager or his authorized representative prior to commitment of funds.

DESCRIPTION OF COST REPORTING PROCEDURES

GTRI will provide a composite narrative of the cost sharing activities of the coalition and various consortia for ARPA on a monthly basis. This will be submitted along with the associate financial values for the individual consortia and the participating members of the consortia teams. This narrative will include the actual or negotiated In-Kind cost sharing elements. A cost reporting format will be determined during negotiation of the awards to the participants. A draft reporting format was included in Research Announcement 93-23 and is reproduced in Figure 1. Each consortia will supply the information needed to complete this type of fiscal reporting form

Atlanta Team

The Atlanta Team will implement the Cost reporting procedures required by GTRI and SCAT at the team level. Within the team, reporting will be effected by a project-wide cost reporting process at the project and work group level.

The multi-user Project Management System (PMS) will serve as a tool for entry and tracking of book-keeping data at the work group level for later roll-up and aggregation at the project level. The designated work group support person will report cost data, expenditure data, and other financial data as necessary back to the project office in a timely manner via the PMS. This information will be collected monthly and compared to the overall program spend plan.

Georgia Team
The leader of the Georgia Team, Westinghouse will collect incurred costs from each of the consortium members and sub-tier suppliers on a monthly basis. These costs will be compared versus program spend plans and reported to ARPA using the format described in the Research Announcement 93-23 Attachment 9 and shown in Figure 1. This report will also include a description of costs incurred verses the work performed.

COST BREAKDOWN TO THE "MAJOR TASKS" LEVEL (INCLUDING MAJOR EQUIPMENT BUYS)

Cost breakdowns for the individual proposals are presented in this section. They were prepared by the various consortia with their own selected format and degree of depth. The consortia were formed by the participating organizations to accomplish a specific set of objectives. These have shaped the proposals and established their cost structure.

Major equipment purchases are indicated in the technical volume and are not highlighted in the cost breakdown due to the level of detail presented when several consortia are responding in different ways. A summary Total Cost Table for all of the consortia of SCAT has been developed and is also included. The breakdowns are presented in alphabetical order for the various consortia.

Atlanta Team
The Cost Breakdown for the Atlanta team is shown in Table 1 as supplied by the team. The amount of In-Kind Cost Sharing is listed at $1,634,830. The amount of Funds requested from ARPA is $1,634,830. The total value of the Atlanta team proposal is $3,269,660.

Florida East Team
The Cost Breakdown for the Florida East team is shown in Table 2. as supplied by the team. Both In-Kind and Cash Cost Sharing is indicated by this team for each task. The values of the In-Kind contributions are estimated amounts. The exact values and the method of calculation against fair market value will be negotiated at the time of project award. The participating organizations have agreed to total Cost Sharing of $2,887,935. The amount of In-Kind cost sharing is $92,000 and the Cash Cost Sharing is $2,806,535. The amount of funds requested from ARPA is $2,898,935. The total value of the Florida East team proposal is $5,797,070.

Florida West Team
The Cost Breakdown for the Florida West team is shown in Table 3. as supplied by the team. The Cost Sharing is on a total bases. Each individual task has a different level of cost sharing. The participating organizations have agreed to a total Cost Sharing of $2,405,500. This is broken down into $335,500 of In-Kind Cost Sharing and $2,070,000 of Cash Cost Sharing. The amount of fund requested from ARPA is $2,405,500. The total value of the Florida West team proposal is $4,811,000.

Georgia Team

The Cost Breakdown for the Georgia team is shown in Table 4. as supplied by the team. Each team member has executed a participation agreement that details the tasks they will perform during this program, the value of the effort and the cost sharing they are providing by way of In-Kind contribution to match the ARPA funds requested. The In-Kind Cost Sharing for this team proposal is $3,258,293. Westinghouse has bid their portion of this effort as a cooperative Research and Development, R&D, program. This eliminates their G&A and profit from their costs. This further reduces the total program cost and maximize the work performed for the ARPA funds. The amount of funds requested from ARPA is $3,258,293. The total value of the Georgia team proposal is $6,516,586.

Georgia North Team

The Cost Breakdown for the Georgia North team is shown in Table 5. as supplied by the team. Both In-Kind and Cash cost sharing is specified by this team. The In-Kind Cost Sharing for this team proposal is $400,000 and the Cash Cost Sharing is $1,604,000. The amount of funds requested from ARPA is $2,004,000. The total value of the Georgia North team proposal is $4,008,000.

Tennessee Team

The Cost Breakdown for the Tennessee team is shown in Table 6. as supplied by the team. Both In-Kind and Cash cost sharing is specified by this team. The In-Kind Cost Sharing for this team proposal is $1,561,500 and the Cash Cost Sharing is $1,024,500. The amount of funds requested from ARPA is $2,565,500. The total value of the Tennessee team proposal is $5,151,000.

Texas Team

The Cost Breakdown for the Texas team is shown in Table 7. as supplied by the team. Both In-Kind and Cash cost sharing is specified by this team for each task. The total In-Kind Cost Sharing for this team proposal is $3,687,500 and the total Cash Cost Sharing is $625,500. The amount of funds requested from ARPA is $2,513,000. The total value of the Texas team proposal is $6,826,000.

Additional Cost Proposals

Additional cost proposals have been supplied to meet specific needs of the coalition and are also included. The Devry Institute of Technology has specifically addressed the requirements of RA 93-23 Part 4. Their Cost Proposal is included as Table 8. Cash Cost Sharing will be required from any of the consortia that wish to work with Devry. They have been included in the Florida East Team Cost Proposal shown in Table 2. The value of the ongoing SCITREK exhibit has been detailed by Georgia Power and is shown in Table 9 to be $1,262,500 in In-Kind Cost Sharing. A portion of this In-Kind Cost Sharing, $231,500, was include in The Tennessee Team Cost Proposal shown in Table 7.

The Georgia Tech Research Institute, GTRI, Cost Proposal is included as Table 10. GTRI will have general management oversight and coordination responsibility when the program is funded. The total cost to ARPA for this task will be $431,438. Contracting with the funded consortia will be through the Georgia Tech Research Corporation, a non-profit corporation setup to do the contracting for the Georgia Institute of Technology. The cost per contract would be $15,704, or $125,628 for eight sub contracts. The instrumentation and data acquisition task addressing 40 vehicles will cost $343,710. The total value of the GTRI proposal is $900,776.

A Chief Operating Officer of SCAT will be hired when the program is funded. SCAT does not have an accounting system in place at this time. The GTRI budget for the Chief

Operating Officer has been used to estimate the cost for this position plus part time secretary. The Chief Operation Officer will a full time employee of SCAT. The total value of this requirement will be $595,809.

Southern Coalition for Advanced Transportation

The Cost Breakdown for the total Southern Coalition for Advanced Transportation coalition is shown in Table 11. as compiled from the individual cost proposals supplied by the seven Teams, Devry and the Georgia Tech Research Institute. Both In-Kind and Cash Cost Sharing is specified by the teams for their proposals. The total In-Kind Cost Sharing is $12,000,623 and the total Cash Cost Sharing is $8,824,321. The total amount of funds requested from ARPA is $18,874,720. The total value of the tasks proposed by the coalition is $39,931,163.

DESCRIPTION OF COOPERATIVE FUNDING AGREEMENTS (COST SHARING)

The following Cost Sharing principles will apply to the programs proposed by the various consortia of SCAT. Participants will be expected to negotiate a mutual understanding on the cost treatment of In-Kind contributions with the government prior to the execution of the financial instrument. Each participant will maintain records of the costs it claims as contribution in accordance with accepted accounting practices. All non-cash contributions which have not been covered by advanced agreement, must be documented carefully by the participants. They must explain the determination of the fair market value.

Atlanta Team

The Atlanta Team has secured In-Kind Cost sharing equivalent to its requested dollar funding from ARPA.

Florida West Team

The total matching funds of $2,405,500 for the Florida West Team is divided into $2,070,000 Cash and $335,000 In-Kind Cost Sharing. The in-kind value is established as the replacement value of power supply facilities, test equipment, electric vehicles and the estimated pro rata share (rent) of the laboratories and test facilities. The matching cash funds are provided by Florida Power Corporation, Tampa Electric Company, Micron, EV-Cells, Martin-Marietta Specialty Components, Renaissance Cars, The Advanced Lead Acid Battery Consortium and the University of South Florida. Letters of intent have been received from all participants and are on file.. The matching funds are based on the total Florida West Team proposal. Each individual project of the proposal has a different level of matching funds.

Georgia Team

Each team member has executed a participation agreement that details the tasks they will perform in support of the team project as well as the amount of that effort that will be cost shared either through In-Kind or Cash contributions. The value of all in-kind services is based on fair market value for equipment purchased, market value of leased equipment as compared to similar equipment or facilities, and existing labor rates as they would normally be charged to a customer.

Westinghouse has bid their portion of this effort as a cooperative R&D program. This eliminates from their cost both G&A and profit. This reduces the total cost of the program and consequently maximizes the effort performed for ARPA funds.

Blue Bird Body Company does not normally do outside engineering work. They have used their internal engineering labor rates to estimate the labor portion of their in-kind services for the program.

Georgia North Team

The value of the In-Kind Cost Sharing has been detailed by the Georgia North Team. Metrotrans Corporation is currently developing a small, rear engine, low floor coach in conjunction with Spartan Motors. Over $1,000,000 has been estimated to have been expended on this effort. It is conservative to estimate that $100,000 of this will be applicable to the electric vehicle low-floor design. General Electric has several parallel programs that are related to the development of the hybrid and all electric shuttle buses. These include the following programs: the hybrid transit bus; AC inverter and motor development; vehicle control computer; and the hybrid automobile development. General Electric has funded these programs at approximately $1,200,000. Again it is conservative to estimate that 25% or $300,000 is directly applicable to this new shuttlebus program.

Contractor				From:	To:			
	Planned Period Expenditure	Actual Period Expenditure	Cumulative Planned Expenditure	Cumulative Actual Expenditure	Planned Next Period Expenditure	DOD Funds Expended To Date	Contractor Expenditures To Date	Deviation From Plan %
Member 1								
Member 2								
Member n!								
Totals								

Figure 1. Draft Cost Reporting Format (RA 93-23)

TASK	LABOR COST	MATERIAL & SUPPLIES	TRAVEL	EQUIP	MISC	TOTAL	ARPA MATCH	CONSORT. MATCH IN-KIND
CEVLE-community based EV laboratory experiment	$989,360	$158,000	$96,000	$768,000	$30,000	$2,041,360	$1,020,680	$1,020,680
Zinc-air/lead acid hybrid battery development	$215,060	$240,920	$12,000	$48,820		$516,800	$258,400	$258,400
Onboard microwave charging & highway data link	$253,000	$30,000	$4,000	$20,500		$307,500	$153,750	$153,750
Regenerative braking system	$10,000	$36,000	$6,000	$15,000		$67,000	$33,500	$33,500
Driver friendly dashboard data display	$5,000	$10,000	$4,000	$15,000		$34,000	$17,000	$17,000
Deployment & user eval. study; concept/prod. mkt test	$39,000	$2,000				$41,000	$20,500	$20,500
Electrical vehicle policy decision model	$12,000			$10,000		$22,000	$11,000	$11,000
Comprehensive training model and tools	$12,000	$10,000		$20,000		$42,000	$21,000	$21,000
Public education/public acceptance activities & events	$26,000	$12,000	$24,000		$36,000	$98,000	$49,000	$49,000
International scholastic clean air Grand Prix	$60,000	$20,000			$20,000	$100,000	$50,000	$50,000
TOTAL	$1,621,420	$518,920	$146,000	$897,320	$86,000	$3,269,660	$1,634,830	$1,634,830

Table 1. Cost Proposal for the Atlanta Team.

TASK	LABOR COST	MATERIAL & SUPPLIES	TRAVEL	EQUIPMENT	TOTAL	ARPA MATCH	CONSORTIUM MATCH IN-KIND	CONSORTIUM MATCH CASH
GM Impact	$35,000	$2,500	$3,000	$1,250,000	$1,290,500	$645,250		$645,250
Patrick AFB Pickup Trucks	$84,000	$0	$5,500	$198,900	$288,400	$144,200		$144,200
Station Car Project	$150,000	$0	$0	$570,000	$720,000	$360,000	$20,000	$340,000
High Eff. Climate Control System	$53,190	$0	$0	$84,200	$137,390	$68,695		$68,695
Rapid Battery Charging System	$37,836	$9,960	$4,200	$264,006	$316,002	$158,001		$158,001
Adv. Lead/Acid Battery Project	$472,738	$0	$0	$65,800	$538,538	$269,269		$269,269
Broward County Veh. Proj. Pt-1	$73,500	$0	$2,600	$128,850	$204,950	$102,475	$15,000	$87,475
Broward County Veh. Proj. Pt-2	$97,000	$0	$2,200	$208,050	$307,250	$153,625	$15,000	$138,625
Broward County Veh. Proj. Pt-3	$38,920	$0	$950	$137,300	$177,170	$88,585	$10,000	$78,585
Broward County Sr. Cit. Proj.	$16,920	$0	$1,250	$146,200	$164,370	$82,185	$7,000	$75,185
Customer Acceptance & TRA	$727,500	$0	$0	$0	$727,500	$363,750	$25,000	$338,750
Fuel Cell Powered Bus	$725,000	$0	$0	$200,000	$925,000	$462,500		$462,500
TOTAL	$2,511,604	$12,460	$19,700	$3,253,306	$5,797,070	$2,898,535	$92,000	$2,806,535

Table 2. Cost Proposal for the Florida-East Team.

TASK	LABOR COST	MATERIAL & SUPPLIES	TRAVEL	EQUIPMENT	CONSULTANT	OVERHEAD	TOTAL	ARPA MATCH	CONSORTIUM MATCH IN-KIND	CONSORTIUM MATCH CASH
Military Vehiles				$105,000			$105,000	$52,500		
Military Infrastructure				$20,000			$20,000	$10,000		
MDSA & SOC				$60,000			$60,000	$30,000		
Data Processing				$60,000			$60,000	$30,000		
Civilian Vehicles				$525,000			$525,000	$262,500		
Civilian Infrastructure				$60,000			$60,000	$30,000		
Advanced Vehicle	$18,000	$5,000	$2,000	$55,000		$20,000	$100,000	$50,000		
Charger	$227,000	$19,000	$5,000	$300,000	$127,000	$113,000	$791,000	$395,500		
Motor Controller	$153,000	$12,000			$70,000	$84,000	$319,000	$159,500		
EMF				$15,000			$15,000	$7,500		
SOC	$40,000	$10,000				$23,000	$73,000	$36,500		
Capacitors	$90,000	$10,000					$100,000	$50,000		
Human Factors	$10,000	$2,000	$4,000			$7,000	$23,000	$11,500		
Project Management	$320,000		$30,000			$154,000	$504,000	$252,000		
Subcontract Administration						$79,000	$79,000	$39,500		
Light Utility Vehicle				$84,000			$84,000	$42,000		
Buses	$100,000	$27,000	$4,000	$410,000		$59,000	$600,000	$300,000		
A/C	$15,000			$28,000		$7,000	$50,000	$25,000		
A/C	$144,000	$12,000	$5,000	$35,000		$84,000	$280,000	$140,000		
Dieter	$152,000	$15,000	$5,000	$12,000			$184,000	$92,000		
Lighting				$50,000			$50,000	$25,000		
Batteries	$250,000	$150,000		$100,000		$100,000	$600,000	$300,000		
Education	$41,000	$14,000	$6,000	$60,000	$8,000		$129,000	$64,500		
TOTAL	$1,560,000	$276,000	$61,000	$1,979,000	$205,000	$730,000	$4,811,000	$2,405,500	$335,500	$2,070,000

Table 3. Cost Proposal for the Florida-West Team

TASK	TOTAL	ARPA MATCH	CONSORTIUM MATCH IN-KIND
Economical and environmental evaluation	$321,360	$0	$321,360
System design and interface engineering	$1,603,552	$563,326	$1,040,226
Testing and evaluation	$1,637,570	$370,773	$1,266,797
Electric pick-up fabrication	$549,792	$354,112	$195,680
Electric bus fabrication	$887,717	$740,527	$147,190
Piston electric hybrid fabrication	$895,120	$749,950	$145,170
Sure charge station fabrication	$323,275	$228,145	$95,130
Program management, cost control and reviews	$298,200	$251,460	$46,740
TOTAL	$6,516,586	$3,258,293	$3,258,293

Table 4. Cost Proposal for the Georgia Team.

TASK	ENGINEERING	MATERIAL & LABOR	TRAVEL	TOTAL	ARPA MATCH	CONSORTIUM MATCH IN-KIND	CONSORTIUM MATCH CASH
YEAR ONE							
System design Wheel motor design/manufacture APU test Detailed component design Build components Build chassis Bus assembly							
SUBTOTAL	$1,505,000	$306,000	$29,000	$1,840,000	$920,000	$203,000	$717,000
YEAR TWO							
HYBRID ELECTRIC BUS							
First bus evaluation Update with changes Deliver hybrid bus							
SUBTOTAL	$1,022,000	$126,000	$20,000	$1,168,000	$584,000	$138,000	$446,000
TWO ELECTRIC BUSES							
Build/test Deliver							
SUBTOTAL	$438,000	$554,000	$8,000	$1,000,000	$500,000	$59,000	$441,000
TOTAL	$2,965,000	$986,000	$57,000	$4,008,000	$2,004,000	$400,000	$1,604,000

Table 5. Cost Proposal for the Georgia-North Team

TASK BY TEAM MEMBER	NON-RECURRING EXPENSE	RECURRING EXPENSE	TOTAL VALUE	ARPA MATCH	CONSORTIUM MATCH IN-KIND	CONSORTIUM MATCH CASH
Delco Remy/Allison	$740,000	$2,108,000	$2,848,000	$1,424,000	$1,000,000	$424,000
AVS		$1,080,000	$1,080,000	$540,000	$280,000	$260,000
CARTA		$301,000	$301,000	$150,500	$50,000	$100,500
ETVI		$65,000	$65,000	$32,500		$32,500
GP/MARTA	$248,000	$215,000	$463,000	$231,500	$231,500	
EPTI		$249,000	$249,000	$124,500		$124,500
PART 4-to promote EV acceptance						
Training program		$75,000	$75,000	$37,500		$37,500
Market research		$50,000	$50,000	$25,000		$25,000
ETVI/Electric bus promotional video		$20,000	$20,000	$0		$20,000
TOTAL	$988,000	$4,163,000	$5,151,000	$2,565,500	$1,561,500	$1,024,000

Table 6. Cost Proposal for the Tennessee Team.

TASK	TOTAL VALUE	ARPA MATCH	CONSORTIUM MATCH IN-KIND	CONSORTIUM MATCH CASH
INDUSTRY-hardware and engineering				
Vehicle fabrication/integration	$1,400,000	$700,000	$500,000	$200,000
Electric motor drive	$126,000	$63,000		$63,000
Vehicle controller and software	$200,000	$100,000	$100,000	
ICE engine and natural gas conversion	$100,000	$0	$100,000	
Vehicle instrumentation and data acquistion	$100,000	$50,000	$25,000	$25,000
Lead acid battery system and support hardware	$100,000	$50,000		$50,000
Vehicle evaluation	$100,000	$0	$100,000	
Military base and commercial demo. infrastructure	$750,000	$0	$750,000	
Vehicle maintenance	$50,000	$25,000		$25,000
SUBTOTAL	$2,926,000	$988,000	$1,575,000	$363,000
UNIVERSITY-think tank,basic design concepts				
Power electronics,controls and motor drives	$250,000	$100,000	$150,000	
Vehicle system simulation, analysis and design	$250,000	$100,000	$150,000	
Engine design and operational studies	$100,000	$50,000	$50,000	
Battery simulation, testing and design	$300,000	$100,000	$200,000	
Total cycle emissions,vehicle safety etc.	$600,000	$300,000	$200,000	$100,000
SUBTOTAL	$1,500,000	$650,000	$750,000	$100,000
RIDERS-parallel component technology				
Flywheel battery storage	$1,000,000	$500,000	$500,000	
Fiber optics combustion pressure sensor	$750,000	$50,000	$700,000	
SUBTOTAL	$1,750,000	$550,000	$1,200,000	
PROJECT MANAGEMENT-staff				
Project engineer	$240,000	$120,000	$60,000	$60,000
Secretary	$60,000	$30,000	$15,000	$15,000
Principal investigator	$350,000	$175,000	$87,500	$87,500
SUBTOTAL	$650,000	$325,000	$162,500	$162,500
TOTAL	$6,826,000	$2,513,000	$3,687,500	$625,500

Table 7. Cost Proposal for the Texas Team.

TASK	TOTAL VALUE	ARPA MATCH	CONSORTIUM MATCH IN-KIND	CONSORTIUM MATCH CASH
MARKET ANALYSIS & POLICY				
Cultural/public acceptance	$175,662	$87,831		$87,831
Marketing research	$48,000	$24,000		$24,000
Public policy investigation	$2,000	$1,000		$1,000
SUBTOTAL	$225,662	$112,831	$0	$112,831
TRAINING				
Maintenance training	$41,800	$20,900		$20,900
Conversion/installation training	$41,800	$20,900		$20,900
Troubleshooting & repair trainin	$45,200	$22,600		$22,600
SUBTOTAL	$128,800	$64,400	$0	$64,400
DEMONSTRATION & SUPPORT				
Customer Support	$168,300	$84,150		$84,150
Demonstration Program	$24,900	$12,450		$12,450
Life cycle cost	$245,100	$122,550		$122,550
SUBTOTAL	$438,300	$219,150	$0	$219,150
TOTAL	$792,762	$396,381	$0	$396,381

Table 8. Cost Proposal for Devry Institute of Technology for Part 4.

TASK	TOTAL VALUE	ARPA MATCH	CONSORTIUM MATCH IN-KIND	CONSORTIUM MATCH CASH
SCITREK EXHIBIT-Phase 1				
EVRN	$500,000		$500,000	
SCITREK EXHIBIT-Phase 2 Power Your Future				
Construction of Electric Vehicle Research Center	$330,000		$330,000	
Transportation Element of the Exhibit	$432,500		$432,500	
TOTAL	$1,262,500	$0	$1,262,500 *	$0

* Note: $231,500 of this amount is included in the Tennesse Team Cost Proposal as Consortium Match In-Kind.

Table 9. Cost Matching for the Georgia Power Co.

TASK	LABOR	MATERIAL & SUPPLIES	TRAVEL	EQUIPMENT	OVERHEAD	TOTAL	ARPA MATCH
Program Support	$244,989	$0	$20,000	$0	$166,449	$431,438	$431,438
Subcontracting	$0	$0	$0	$0	$125,628	$125,628	$125,628
Instrumentation and Data Acquisition	$75,550	$20,000	$5,000	$180,000	$63,160	$343,710	$343,710
TOTAL	$320,539	$20,000	$25,000	$180,000	$355,237	$900,776	$900,776

Table 10. Cost Proposal for the Georgia Tech Research Institute.

ORGANIZATION	TOTAL VALUE	ARPA MATCH	CONSORTIUM MATCH IN-KIND	CONSORTIUM MATCH CASH
CONSORTIUM				
Atlanta	$3,269,660	$1,634,830	$1,634,830	$0
Florida-East	$5,797,070	$2,898,535	$92,000	$2,806,535
Florida-West	$4,811,000	$2,405,500	$335,500	$2,070,000
Georgia	$6,516,586	$3,258,293	$3,258,293	$0
Georgia-North	$4,008,000	$2,004,000	$400,000	$1,604,000
Tennessee	$5,151,000	$2,565,500	$1,561,500	$1,024,000
Texas	$6,826,000	$2,513,000	$3,687,500	$625,500
SUBTOTAL	$36,379,316	$17,279,658	$10,969,623	$8,130,035
COALITION				
Devry Institute of Technology	$792,762	$396,381	$0	$396,381
Georgia Power Comany	$1,262,500	$0	$1,031,000	$0
Georgia Tech Research Institute	$900,776	$900,776	$0	$0
SCAT-Chief Operating Officer	$595,809	$297,905	$0	$297,905
SUBTOTAL	$3,551,847	$1,595,062	$1,031,000	$694,286
TOTAL	$39,931,163	$18,874,720	$12,000,623	$8,824,321

Table 11. Total Cost Proposal for the Southern Coalition for Advanced Transportation.

COST ESTIMATE 06/08/93

------SCAT Program Support------

Georgia Tech Research Institute

Direct Salaries & Wages (DS&W)			Multiplier (note A)		
Principal Research Engineer/Scientist					
2088	person-hours @	$40.74	1.000		$85,065
Senior Research Engineer/Scientist					
1044	person-hours @	$32.64	1.000		$34,076
Secretary					
1044	person-hours @	$12.08	1.000		$12,612
Graduate Research Assistant					
1044	person-hours @	$15.18	1.000		$15,848
SUBTOTAL 1					$147,601
DS&W Related to Paid Absences					
(see exhibit for detailed computation)					$26,612
SUBTOTAL 2					$174,213
Project Mgmt Costs (PMC)		12.50 %	of Subtotal 2		$21,777
SUBTOTAL 3 (Total DS&W)					$195,990
Fringe Benefits (FB)					
27.20	% of Total DS&W (less students)				$48,999
Travel					$20,000
SUBTOTAL 4					$264,989
Allocated Project-Level Costs (APLC)					$29,308
DS&W	5.19	% of Subtotal 4		13,753	
FB	1.38	% of Subtotal 4		3,657	
M&S	4.47	% of Subtotal 4		11,845	
CUC	0.02	% of Subtotal 4		53	
SUBTOTAL 5 (Modified Total Direct Cost)					$294,296
Indirect Costs @	46.60	% of Subtotal 5			$137,142
TOTAL ESTIMATED HOURS		5220	TOTAL ESTIMATED COST		$431,438

Note (A) Salary rates are published averages for GTRI FY-93.

COST ESTIMATE
Subcontracting Cost

06/10/93

Direct Salaries & Wages (DS&W)				
Principal Research Engineer/Scientist				
0 person-hours @ $40.74		1.040		$0
SUBTOTAL 1				$0
DS&W Related to Paid Absences (see exhibit for detailed computation)				$0
SUBTOTAL 2				$0
Project Mgmt Costs (PMC)	12.50 %	of Subtotal 2		$0
SUBTOTAL 3 (Total DS&W)				$0
Fringe Benefits (FB)				
27.20 % of Total DS&W (less students)				$0
Materials and Supplies (M&S)				$0
Computer Use Charges (CUC)				$0
Travel				$0
Burdened Portion of Subcontracts				$200,000
SUBTOTAL 4				$200,000
Allocated Project-Level Costs (APLC)				$22,120
DS&W	5.19	% of Subtotal 4	10,380	
FB	1.38	% of Subtotal 4	2,760	
M&S	4.47	% of Subtotal 4	8,940	
CUC	0.02	% of Subtotal 4	40	
SUBTOTAL 5 (Modified Total Direct Cost)				$222,120
Indirect Costs @	46.60	% of Subtotal 5		$103,508
Unburdened Portion of Subcontracts				$17,476,039
Equipment				$0
TOTAL ESTIMATED HOURS	0	TOTAL ESTIMATED COST		$17,801,667

DETAILS OF NEW SUBCONTRACTS

SUBCONTRACTO	TOTAL AMOUNT	BURDENED PORTION	UNBURDENED PORTION
Atlanta Team	$1,634,830	$25,000	$1,609,830
Florida-East Team	$2,898,535	$25,000	$2,873,535
Florida-West Team	$2,405,500	$25,000	$2,380,500
Georgia Team	$3,258,293	$25,000	$3,233,293
Georgia-North Team	$2,004,000	$25,000	$1,979,000
Tennesse Team	$2,565,500	$25,000	$2,540,500
Texas Team	$2,513,000	$25,000	$2,488,000
Devry Institute of Technology	$396,381	$25,000	$371,381
TOTAL	$17,676,039	$200,000	$17,476,039

COST FOR PASS THROUGH OF 8 SUBCONTRACTS	$125,628
COST PER SUBCONTRACT	$15,704

COST ESTIMATE 06/10/93

------ DATA ACQUISTION------

SCAT

Georgia Tech Research Institue

Direct Salaries & Wages (DS&W)		Multiplier (note A)		
Principal Research Engineer/Scientist				
522 person-hours @	$40.74	1.000		$21,266
Research Engineer/Scientist II				
348 person-hours @	$24.43	1.000		$8,502
Electronics Specialist				
522 person-hours @	$18.42	1.000		$9,615
Secretary				
87 person-hours @	$12.08	1.000		$1,051
Graduate Research Assistant				
348 person-hours @	$15.18	1.000		$5,283
SUBTOTAL 1				$45,717
DS&W Related to Paid Absences				
(see exhibit for detailed computation)				$8,082
SUBTOTAL 2				$53,799
Project Mgmt Costs (PMC)	12.50 %	of Subtotal 2		$6,725
SUBTOTAL 3 (Total DS&W)				$60,524
Fringe Benefits (FB)				
27.20 % of Total DS&W (less students)				$15,026
Materials and Supplies (M&S)				$20,000
Travel				$5,000
SUBTOTAL 4				$100,550
Allocated Project-Level Costs (APLC)				$11,121
DS&W	5.19	% of Subtotal 4	5,219	
FB	1.38	% of Subtotal 4	1,388	
M&S	4.47	% of Subtotal 4	4,495	
CUC	0.02	% of Subtotal 4	20	
SUBTOTAL 5 (Modified Total Direct Cost)				$111,671
Indirect Costs @	46.60	% of Subtotal 5		$52,039
Equipment				$180,000
TOTAL ESTIMATED HOURS	1827	TOTAL ESTIMATED COST		$343,710

Note (a) Salary rates are published averages for GTRI FY-93.

COST ESTIMATE
---SCAT Chief Operating Officer---

06/10/93

Direct Salaries & Wages (DS&W)			Multiplier (note A)		
Principal Research Engineer/Scientist					
2 man years @		$100,000.00	1.000		$200,000
Secretary					
1044 person-hours @		$12.08	1.000		$12,612
SUBTOTAL 1					$212,612
DS&W Related to Paid Absences (see exhibit for detailed computation)					$43,115
SUBTOTAL 2					$255,727
Project Mgmt Costs (PMC)		12.50	% of Subtotal 2		$31,966
SUBTOTAL 3 (Total DS&W)					$287,693
Fringe Benefits (FB)					
27.20 % of Total DS&W (less students)					$78,252
SUBTOTAL 4					$365,945
Allocated Project-Level Costs (APLC)					$40,474
DS&W	5.19	% of Subtotal 4		18,993	
FB	1.38	% of Subtotal 4		5,050	
M&S	4.47	% of Subtotal 4		16,358	
CUC	0.02	% of Subtotal 4		73	
SUBTOTAL 5 (Modified Total Direct Cost)					$406,418
Indirect Costs @	46.60	% of Subtotal 5			$189,391
TOTAL ESTIMATED HOURS		5220	TOTAL ESTIMATED CO		$595,809

SUPPORTING INFORMATION

This section includes items that are not part of the proposal page count and are offered as amplification for topics discussed in the reviewable pages. The following is available for review in support of the SCAT proposal at the discretion of ARPA and its reviewers.

Attached as part of this Supporting Information section, and not counting against the page count, is a copy of a paper entitled, "A Moving Magnetic Field Electric Power Converter" by Kenneth A. Buckle, and John W. Luce describing technology related to the Florida West project.

The following references are pertinent to the Texas team project and are offered as sources of corroborating information (those typed in bold are cited in the Texas team sealed proprietary information package that accompanies this proposal:

[1] A. Severinsky, "Battery Viability in Automotive Propulsion," IEEE-IAS-1983 Annual Meeting Conference Record.

[2] M. Ehsani, "Electrically Peaking Hybrid System and Method," U.S. patent pending.

[3] R. Mackay, " Gas Turbine Generator sets for Hybrid Vehicles," SAE Paper 920441, Feb. 1992.

[4] J.S. Reuyl, " XA-100 Hybrid Electric Vehicle," SAE paper 920440, Feb. 92.

[5] A.F. Burke, " Hybrid/Electric Vehicle Design Options and Evaluations," SAE Paper 920447, Feb. 92.

[6] A.S. Keller, et. al., " Performance Testing of the Extended Range (Hybrid) Electric G Van," SAE Paper 920439, Feb. 92.

[7] M. Fukino, et. al., " Development of an Electric Concept Vehicle with a Super Quick Charging System," SAE Paper 920442, Feb. 92.

[8] J. Diekmann, et. al. " Variable Speed Compressor, HFC-134a Based Air Conditioning System for Electric Vehicles," SAE Paper 92044, Feb. 92.

[9] Propulsion Technology: An Overview, " Automotive Engineering," Vol. 100, No. 7, Page 29-33.

[10] G. Brusaglio, " Electric Vehicle Development in Fiat," SAE Paper 910244, Feb. 91.

[11] K. Faust, et. al., " Introduction to the BMW-EL, "SAE Paper 920443, Feb. 92.

[11] R.D. King, "ETX-II 70 Hp MCT Inverter Electric Drive System Performance Tests," SAE Paper 920445, Feb. 92.

[13] M.C. Chaiky, et. al., " Second Generation Zinc-Air Powered Electric Minivans, " SAE Paper 920447, Feb. 92.

[14] F.A. Wyszalek, et. at., " Regenerative Braking Concepts for Electric Vehicles, " SAE Paper 920648, Feb. 92.

[15] M. Ehsani, et. al., "Integrated Current Regulation for Brushless ECM Drive," IEEE Trans. on Power Electronics, Vol. 6, No. 1, Jan. 91.

[16] M. Ehsani, et. al., " Low Cost Sensorless Switched Reluctance Motor Drives for Automotive Applications, " IEEE Joint Power Electronics and Industry Applications Society Workshop on Electronic Applications in Transportation, Dearborn, Mich., Oct. 90.

[17] M. Ehsani, et. al., "An Algebraic Algorithm for Microprocessor Based (Direct) Inverter Pulse-Width Modulation, " IEEE Trans. on Ind. Appl. Vol. IA-23, No. 4, Jul./Aug.,87.

The following attachments (B through D) referenced in the body of the proposal provide detailed specifications and further explanations of the Tennessee team project.

TENNESSEE TEAM ATTACHMENT B

System Ambient Specifications - All components shall perform to the extent specified herein under the following ambient and system conditions unless otherwise noted.

Standard Operating Conditions:

Temperature	21 deg C (70 deg F)
Humidity	50% relative humidity (RH)
Altitude	-131 to 610 meters (-430 to 2000 ft) mean sea level (MSL)

Propulsion System Temperature Range (without batteries)

Operating	-20 to +40 deg C (-4 to +104 deg F)
Non-Operating	-20 to +70 deg C (-4 to +158 deg F) with no damage to components or function after returning to the Operating Temperature Range

Battery Pack Temperature Range

Operating	-18 to +38 deg C (0 to +100 deg F) without thermal management system
Non-Operating	-18 to +66 deg C (0 to +150 deg F) with SOC>20% and no damage to components or loss of function after returning to operating temperature

Relative Humidity

Altitude

Operating	-131 to 3,353 meters (-430 to 11,000 ft) MSL
Non-Operating	-131 to 13,716 meters (-430 to 45,000 ft) MSL

Surface Water	Conforms to GM Standard Test Procedures
Sand and Dust	Conforms to GM Standard Test Procedures
Salt Exposure	Conforms to GM Standard Test Procedures
Corrosion	Conforms to GM Standard Test Procedures
EMC Environment	Conforms to GM Standard Test Procedures

Component Performance Goals - All components shall perform to the extent specified herein unless otherwise noted.

Rated nominal system voltage	312 VDC
Inverter PWM switching frequency	18 kHz
Nominal operating speed range	0 to 11,000 RPM (rotor speed)
Maximum speed (transient)	13,000 RPM (rotor speed)

Max. mechanical output power	75 kW for 5 minutes between 6600 and 10,000 rotor RPM, subject to mission analysis
Nominal starting torque	40 kW for one hour between 6600 and 10,000 rotor RPM, subject to mission analysis
Maximum starting torque	108 Nm for 10 minutes between 0 and 6600 rotor RPM, subject to mission analysis
Peak efficiency	90% (estimated) for motor and inverter combined at high speed under moderate load

Battery pack, drive unit, inverter, and DC-to-DC converter physical parameters will be determined as the design is finalized following mission analysis activities.

Reliability Prediction and Allocation — Failure rate predictions shall be calculated for the battery pack, drive unit, inverter, and DC-to-DC converter prior to vehicle fielding. Motor failure rate predictions will be based on both engineering experience and industry data, including the U.S. Defense Technical Information Center (DTIC) Non-Electronic Reliability Notebook, Battery Pack, inverter, and DC-to-DC converter failure rate predictions will be based on engineering experience and data provided in U.S. Mil-Handbook-217D, Reliability Prediction of Electronic Equipment.

Cooling System Requirements — The drive unit, inverter, and DC-to-DC converter specified herein share a liquid coolant loop. Coolant passages shall be designed to minimize fluid thermal resistance and fluid inlet to outlet pressure drop. Adherence to component specifications is highly dependent on cooling system performance compliance with the requirements listed below.

Coolant medium	50/50 water/ethylene glycol
Maximum coolant operating temperature	60 deg C (158 deg F)
Maximum coolant non-operating temperature	80 deg C (176 deg F)
Nominal coolant flow rate	1136 1/hr (5.0 GPM)
Maximum fluid fill time, 60% nominal flow rate	30 sec

Fluid filling (air bubble evacuation) shall require only the action of the coolant system pump. The filling process shall be quick, eliminating the possibility of passage cavitation during operation and the resulting over temperature condition. Although this condition occurs only during a maintenance fluid change, it is an important system protection requirement.

TENNESSEE TEAM ATTACHMENT C

An internal Drive Unit Validation Test Plan will be used to confirm product conformance to the customer's requirements. Validation test parameters will be customized to duplicate the customer's operating environment. Components are listed below.

Drive Unit Assembly Validation Tests:
- Minimum Operating Temperature Performance
- Maximum Operating Temperature Performance
- Minimum Ambient Temperature Storage
- Maximum Ambient Temperature Storage
- Minimum/Maximum Ambient Temperature Thermocycle
- Humidity/Water Spray
- Salt Exposure
- Corrosives Exposure (fluids compatibility)
- Electromagnetic Susceptibility and Emissions
- Grade Tilt Angle Operation
- Shipping Tilt Angle
- Drive Unit Performance
  - power and efficiency
  - oil pressure output signal
  - regeneration
  - oil pressure output signal
  - encoder output signal
- Dynamometer Durability
  - design life
  - structural support
  - encoder function
  - thermal system function
  - pressure switch function
  - temperature sensor function
  - lubrication system function
- Drive Unit Physical Dimensions
- Sound
- Lock Rotor
- Vibration
- Shock
- Towing
- Differential Rotary Fatigue
- Differential Scoring

Motor Component Validation Tests:
- Encoder
  - Durability/Thermocycle
  - Vibration
- Oil Pump and Motor
  - Durability
  - Vibration
- Pressure Switch
  - Durability
  - Vibration

Temperature Sensor
- Vibration

Seals
- Dust

AC Power Cycle

Rotor
- Hi Speed Spin
- No Load Performance
- Locked Rotor Performance

Stator
- Electrical Parameters

Filter
- Life

An internal Inverter Validation Test Plan and DC-to-DC Converter Validation Test Plan will be used to confirm product conformance to the customer's requirements. Validation test parameters will be customized to duplicate the customer's operating environment.

Minimum Operating Temperature Performance
Maximum Operating Temperature Performance
Minimum Ambient Temperature Storage
Maximum Ambient Temperature Storage
Minimum/Maximum Ambient Temperature Thermocycle
Humidity/Water Spray
Salt Exposure
Corrosives Exposure (fluids compatibility)
Electromagnetic Susceptibility and Emissions
Inverter Performance
- Power and Efficiency

Inverter Physical Dimensions
DC-to-DC Converter Performance
- Power and Efficiency

DC-to-DC Converter Physical Dimensions
Vibration

TENNESSEE TEAM ATTACHMENT D

Battery Voltage	312 volts*
Battery Capacity	TBD*
Battery Types	Lead Acid Nickel Cadmium Nickel Metal Hydride Zinc-Air* (Under test)
Input Voltage	AC - VAC: H2 Three Phase

Input Protection: Protection from overload or failure of input power. Capable of resuming operation when interrupted.

Power Output: The maximum current and voltage provided by the charging station will be 500 AMPS and up to 400 volts DC dynamically adjustable for battery voltage

Control Parameters	Open circuit voltage Charging current Voltage under charge condition + Delta I Shut-off current Temperature of a representative battery

Operating Temperature: The charging system will operate at temperatures ranging from -25 degrees C to 50 degrees C without degradation of the charger performance

Output Terminal: The output terminal will be on the top of the back panel of the rack cabinet of devices and have easy access for connection

*To be finalized when battery choice is finalized

TENNESSEE TEAM ATTACHMENT E

Battery Pack Thermal Management Challenges - By nature lead-acid batteries operate in a relatively temperate environment. However, since the lead-acid chemistry is exothermic during the charging process, temperature increases due to rapid charging add to the ordinary conduction (resistive) losses, particularly when such charging is frequent and the batteries are not allowed a "rest" period. At temperature extremes, battery pack life and performance degrade. The use of an on-board battery pack monitoring and control system minimizes temperature excursions through intelligent charging and Pack conditioning. Careful consideration of battery pack location and use during mission analysis and design activities will greatly reduce risk of failure due to excessive battery pack temperatures.

Manufacturing, Packaging, and Safety Challenges - While the need for manufacturability and sensible packaging are easily understood, the nuances associated with safety of electric propulsion systems are not clearly defined because electric vehicles (EVs) are relative newcomers to the transit vehicle market. DR/A is regularly consulted by outside organizations in matters of EV standardization, including areas of safety. DR/A requires high voltage and EV safety training of each of its employees associated with EV development. DR/A will show due care in the design and construction of the motor and inverter to minimize potential for electrical or structural mishaps.

Reliability Challenges - Reliability will be another significant technical challenge. Intelligent component selection and derating will be implemented early in the design phase. Appropriate cooling measures will be taken to insure acceptable component ambient temperatures. Manufacturing processes will be continually reviewed for the minimization of process-induced defects.

Design Failure Modes and Effects Analysis (DFMEA) and Process Failure Modes and Effects Analysis (PFMEA) will be conducted during the design activity to further ensure product quality. Integration will be investigated at every available opportunity in order to reduce parts count. Quality components, appropriate derating, DFMEA and PFMEA activities, and part count reduction will lead toward a more reliable propulsion system.

Attached as part of this Supporting Information section, and not counting against the page count, is a copy of a paper entitled, "Advanced Battery Development," prepared by GNB/MATSI for the United States Advanced Battery Consortium, describing technology related to the Atlanta project.

Attached as part of this Supporting Information section, and not counting against the page count, is a copy of a paper entitled, "Clemson's Alternative Automotive Technologies Electric Vehicle Conversion," describing the Clemson electric entry into the Clean Air Grand Prix referenced by the Atlanta project. Also attached is a copy of the 1993 Clean Air Vehicle Conference, Exposition & Grand Prix materials.

A MOVING MAGNETIC FIELD ELECTRIC POWER CONVERTER
(The MAGNESTAT™ Low Distortion Rectifier)

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ABSTRACT

An entirely new concept in power conversion has been developed and initial test results are promising. The concept of using the rotating field of a polyphase AC system as the direct excitation of secondary coils for the purpose of rectification to produce DC power has distinct advantages with respect to isolating the input AC system from and therefore avoiding the severe current distortion present in conventional rectifier circuits. The new concept has been built into a 10 kW operating model and tested to compare its performance with conventional six pulse and twelve pulse rectifier circuits. The improvement in line distortion is major and is discussed in detail.

I. INTRODUCTION

The conversion of electrical power is typically accomplished by discrete electrical power components such as rectifiers, thyristors, inductors and capacitors or by rotating machinery.

More particularly, AC to DC conversion is predominantly accomplished by rectifying alternating current to produce pulsating direct current. Unfortunately, pulsating direct current is satisfactory only for a limited range of applications such as battery charging or electroplating. When smoother direct current is needed, such as for most electronic applications, the pulsating DC is filtered by means of capacitors and/or inductors.

Since rectifiers intermittently draw current from the AC supply, harmonic current distortion and less than unity power factors are unavoidable. Furthermore, when capacitive filters are used to smooth the DC, current distortion on the AC side increases due to the discontinuous power demand on the line. Thus, additional input AC line filtering is usually required to prevent harmonic distortion, particularly for compliance with military specifications (MIL-E-16400)[1] and in commercial applications IEEE 519[2] in the United States and IEC 555-2[3] in Europe. The military specification limits harmonic current distortion in shipboard equipment and the commercial specification limits distortion caused by customers of utilities. The impending introduction of battery powered vehicles and the effect of their charging on the utility systems is also a timely issue which has been studied by Lafon, et. al.[4], with respect to current distortion.

The input and output waveform distortions discussed are typically avoided through the use of a motor-generator set or a synchronous converter, both of which can convert AC to DC[5,6,7]. Unfortunately, the expense, size, weight, noise, and high maintenance of such machines precludes their wide use. As a cost effective alternative many applications employ passive or active filters to overcome the input and output distortion problem. Therefore, it was an objective of this research to provide an apparatus and method of implementation which overcomes the aforementioned inadequacies of the existing state of the art AC to DC converters.

This paper will describe the theory of operation for a moving field AC to DC converter as a solution to the line current distortion problem. The following sections will describe the theory of operation of this new converter, an experimental system built to verify the theory, description of the experimental results obtained in tests of the prototype, and conclusions reached by this investigation.

II. MOVING MAGNETIC FIELD CONVERTER THEORY

The moving magnetic field converter is a new technique for converting polyphase alternating current (AC) power into direct current (DC) power. The unique advantage of this converter is that it inherently produces minimal distortion for both the input AC current and the output DC voltage and accomplishes this objective without any filters. To accomplish this action, the converter employs a rotating magnetic field having a constant magnitude and constant angular velocity. This is exactly the same rotating field that occurs in standard polyphase induction motors.

Conceptually the idea can be described as follows: the armature of a DC generator is placed inside the stator of a polyphase AC motor. The armature is held stationary and the commutator and brushes are replaced with rectifier diodes as illustrated in Figure 1. The circuit symbolically illustrated in Figure 1 has a three phase AC input and a five coil/ten diode DC output. In operation, polyphase AC power is applied to the motor stator. The well known rotating magnetic field is established in the air gap of the machine. Due to the polyphase excitation, the rotating field has a constant magnitude and a constant angular velocity. As the flux of the rotating field cuts the conductors on the stationary armature, it induces AC currents in the armature windings which are rectified by the diodes to produce the DC output.

The DC output is similar to that of a DC generator and has many small voltage ripples per cycle of the AC input line frequency. This output is adequate for many applications, but if filtering is required it is quite simple. Due to the small amplitude and high frequency of the ripples, smaller and less costly filters may be employed when compared to a conventional rectifier design. The AC input line current is nearly a perfect sine wave as seen in Figure 2. This current wave form occurs because all phases of the AC supply are continuously delivering power to the stator. The power from all of the phases is combined magnetically into a single rotating field. To illustrate this point, Figure 2 shows the DC output voltage, top trace, which has 2.4% ripple and the lower trace is the input line current which displays a 1.4% total harmonic distortion (THD).

This method contrasts with all ordinary rectifier circuits in which the two phases having the highest potential difference supply all the output DC load current at any instant of time, and the remaining phase supplies no current until the nonconducting phases voltage rises to exceed one of the two conducting phases. Figure 3 shows the output voltage and input current of a conventional three phase full wave rectifier to illustrate the advantage of the moving field converter.

One convenient way to view this apparatus is as a motor generator set that has no moving parts and has the motor and generator blended into a single machine. It could also be viewed as a type of transformer that operates with a rotating magnetic field instead of the usual sinusoidally oscillating magnetic field. Like a transformer, this apparatus has a ratio of input to output voltage that is fixed by the number of turns of wire in the input and output windings. With no moving parts, the air gap between the rotor and stator could be reduced or eliminated. This would reduce the exciting current drawn from the AC supply line and improve the systems power factor.

As discussed above, the device has a fixed output to input voltage ratio, but one of the winding sets could be split with part on the stator and part on the rotor. The two sections could then be connected in a buck-boost arrangement and would thus provide an adjustable DC output voltage derived from a fixed AC input voltage by rotating the armature a portion of a revolution. With the limited rotation, connections could be made to the armature through flexible leads rather than with brushes and slip rings.

The magnetic forces in this system create a torque on the armature that must be resisted. In the fixed voltage ratio design the armature can simply be clamped. In the adjustable version, a worm and wheel gearset would prevent the armature from spinning due to the torque developed while still allowing adjustment of the output voltage.

The number of coils on the armature is not critical, but it has been found advantageous to construct the machine with an odd number of coils on the armature winding instead of an even number. With the odd number the DC output has one ripple per diode in each cycle of the input AC input supply frequency, whereas with an even number of coils there is one ripple per pair of diodes per cycle of the supply frequency. This difference is the result of simultaneous switching of diode pairs in the even configuration and alternate diode switching in the odd configuration.

A simple phenomenological computer model was developed to predict the input and output waveforms and system performance as an indicator of design trends. The computer model, at this stage of development, is configured with zero input line impedance. As such it is expected that the predicted performance will be a worst case prediction and that test results should be better when observing both the DC output ripple and the AC input line current THD. Table I is a summary of the predicted results for systems with three to fourteen coils in the secondary. Figure 4(a-f) are computer predictions of the DC voltage waveform and the AC input line current for MAGNESTAT™ systems with three to eight secondary coils and Figure 5(a-f) are the comparable predicted waveforms for systems with nine to fourteen secondary coils.

Table I Predicted MAGNESTAT™ Performance

MESH MAGNESTAT™ PREDICTED PERFORMANCE
(Zero Input Impedance Source)

No. Coils	No. Diodes	No. Pulses per Cycle	P-P Ripple Percent	THD
3	6	6	14.4	15.11
4	8	4	34.3	41.03
5	10	10	5.0	6.90
6	12	6	14.4	20.14
7	14	14	2.5	3.75
8	16	8	7.9	11.72
9	18	18	1.5	2.33
10	20	10	5.0	7.62
11	22	22	1.1	1.58
12	24	12	3.5	5.34
13	26	26	.7	1.14
14	28	14	3.0	3.62

III. EXPERIMENTAL SYSTEM HARDWARE

Several small power bench top experimental models were built and tested to evaluate coil connections and the effect of the number of diodes before a significant power system was designed and constructed. Fifty watt systems with 3,4,6,7, and 12 coil taps were constructed and tested.

As illustrated in Figure 1, the electric converter is comprised of a three phase delta connected primary winding and a five coil mesh connected secondary. Effectively the coils are daisy chained with the coil ends forming five nodes which are brought out of the machine for connection to the rectifiers. At each node two rectifiers are employed, one rectifier connected with its cathode to the node and anode to the negative DC bus and the other with its anode connected to the node and its cathode connected to the positive DC bus.

For the experimental 10 kW model the three phase delta connected stator was configured for a maximum V_{LL} of 208 (V) and the nine coil secondary was connected to eighteen diodes in a manner similar to that described in Figure 1. As wound the device produces a no load DC voltage of approximately 23. V_{dc} when the stator V_{LL} is 208 (V). The DC output bus was loaded with a resistive load, for the developmental tests, but eventually this system will become the rectifier portion of a high rate battery charger. A head to head comparison was made between this moving field AC to DC converter and a conventional, commercially available, six pulse rectifier circuit with a heavily filtered DC output. A generic six pulse circuit is illustrated in Figure 6. A detailed performance comparison between the MAGNESTAT™ and the six pulse configuration was made and the results are presented next.

IV. EXPERIMENTAL RESULTS

The two systems examined in detail were the 10 kW MAGNESTAT™ with an eighteen pulse armature circuit and a commercial 15 V_{dc}, 200 A_{dc} filtered power supply. Both systems were supplied from a three phase 208 V_{ac} building circuit and were operated to deliver 192 amps DC into a resistive load at 14.5 V_{dc}. Measurements were made with a Dranetz 8000 power analyzer and a Fluke 87 true RMS multimeter. The results of these tests are summarized in Table II.

Table II: Circuit Performance Comparison

Comparative Data At 192 Amp DC
and 14.5 Volts DC Out

	MAGNESTAT™ 18 Pulse	Transformer Six Pulse
Input AC Volts (L-L)	208.00	208.00
Input Phase Current	13.90	13.29
Input kW	3.79	3.89
Power Factor	.747	.739
AC Current THD (%)	.98	43.02
AC Voltage THD (%)	.89	.89

Figure 7 illustrates the AC input voltage and phase current of the commercial six pulse power supply at the test load point and Figure 8 is the comparable set of voltage and current traces for the 10 kW MAGNESTAT™ at the same test point. Figure 9 depicts the current harmonic content for the base line six pulse circuit at the test point and Figure 10 the same information for the 10 kW MAGNESTAT™. In both figures 11 and 12 the abscissa covers the first 50 harmonics, but the ordinate is scaled to the largest observed harmonic magnitude in both cases. As shown in Figure 9 the second harmonic had the largest magnitude in the commercial circuit which was 33.3% of the fundamental magnitude. By comparison, for the MAGNESTAT™, Figure 10 indicates that the largest magnitude harmonic was the third with a value .53% of the fundamental.

As a base line evaluation the voltage THD of the three phase power into the laboratory with the test circuits disconnected was measured and found to very between 1.5% and 2.0%. The two circuits under test conditions indicated a phase current THD of .98% for the MAGNESTAT™ and 43.02% for the commercial six pulse supply.

Previous analysis and tests on low power models of the MAGNESTAT™ and comparable state-of-the-art rectifier circuits is summarized in Table III where the calculated results for the MAGNESTAT™ were from our computer program and those for the six pulse and twelve pulse rectifier circuits use the method described by Kassakian[8].

Table III Comparison of MAGNESTAT™ with state-of-the-art

MAGNESTAT™ and Transformer/Rectifier Circuit Comparison

Coils	Diodes	Ripples per Cycle	Percent Ripple (RMS)	AC Current % THD Calculated	AC Current %THD Measured
3	6	6	5.08	15.11	7.71
4	8	4	12.10	41.03	16.30
6	12	6	5.08	20.14	7.48
7	14	14	.90	3.75	1.56
9	18	18	.54	2.33	.99
12	24	12	1.22	5.34	1.50
Transformer/Rectifier Summary					
3	6	6	5.08	32.80	16.89
6	12	12	1.22	15.29	11.75

V. CONCLUSIONS

The MAGNESTAT™ provides a low distortion rectifier alternative to the conventional six and twelve pulse transformer circuits presently available. As the MAGNESTAT™ provides flexibility in selection of the number of diodes needed to meet a particular distortion specification, the optimum design would consist of an odd number of coils sufficient to meet the current THD specification. The IEEE 519[1] specification requires 5% THD. It is speculated that in most applications either a six or ten diode circuit would be sufficient. Table III compares the calculated and measured parameters of several MAGNESTAT™ configurations with conventional transformer rectifier circuits at six and twelve pulse.

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3. IEC-555-2

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FIGURE CAPTIONS

Figure 1. Schematic diagram of a five coil mesh connected moving magnetic field AC to DC converter.

Figure 2. Measured sine wave input AC current and DC output voltage of moving magnetic field AC to DC converter.

Figure 3. AC line current and DC output voltage of an ordinary three phase six pulse rectifier circuit with resistive load.

Figure 4. AC line current and DC output voltage waveforms predicted for:(a) three coils,(b) four coils,(c) five coils,(d) six coils,(e) seven coils, (f) eight coils.

Figure 5. AC line current and DC output voltage waveforms predicted for:(a) nine coils,(b) ten coils,(c) eleven coils,(d) twelve coils,(e) thirteen coils, (f) fourteen coils.

Figure 6. Ordinary three phase rectifier circuit schematic.

Figure 7. Ac phase voltage and current of the commercial power supply at the test load point.

Figure 8. Ac phase voltage and current of the MAGNESTAT™ at the test load point.

Figure 9. Harmonic content histogram of current for the commercial power supply at the test load point.

Figure 10. Harmonic content histogram of current for the MAGNESTAT™ at the test load point.

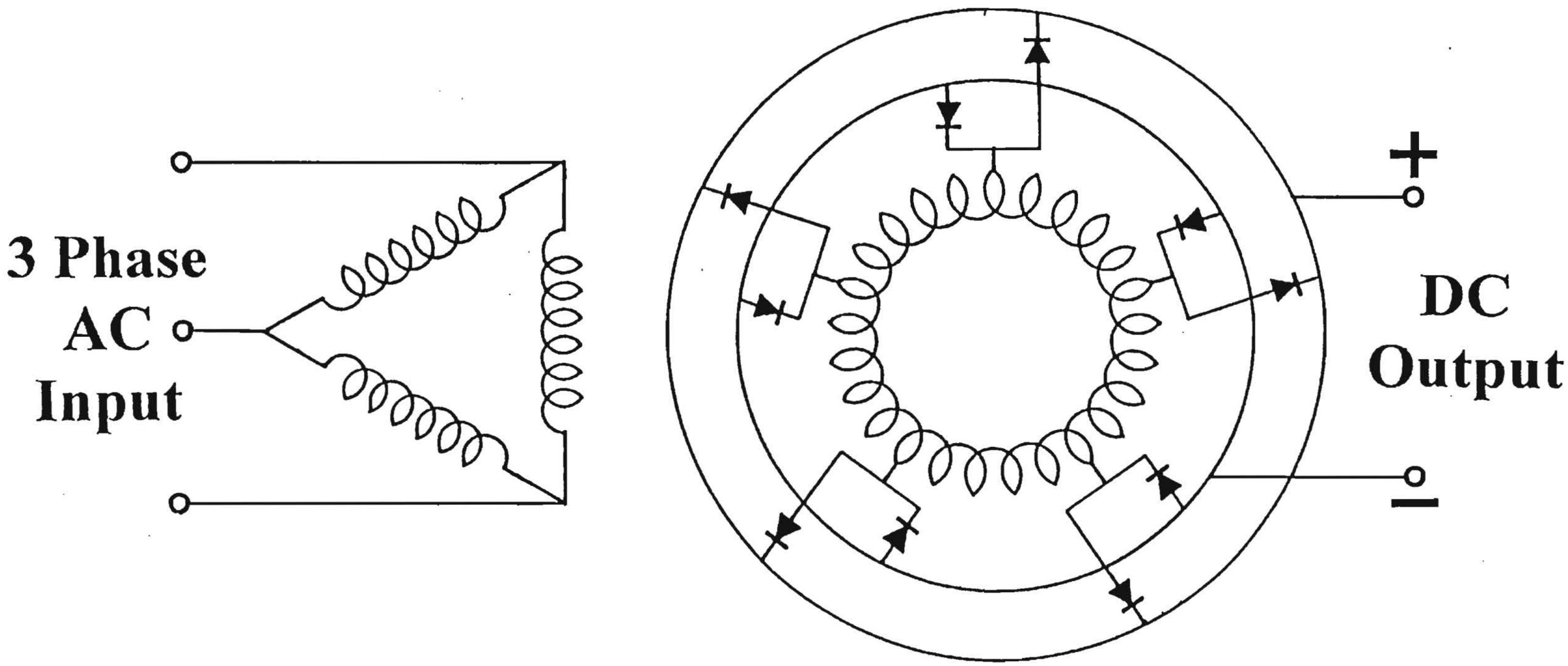


Figure 1

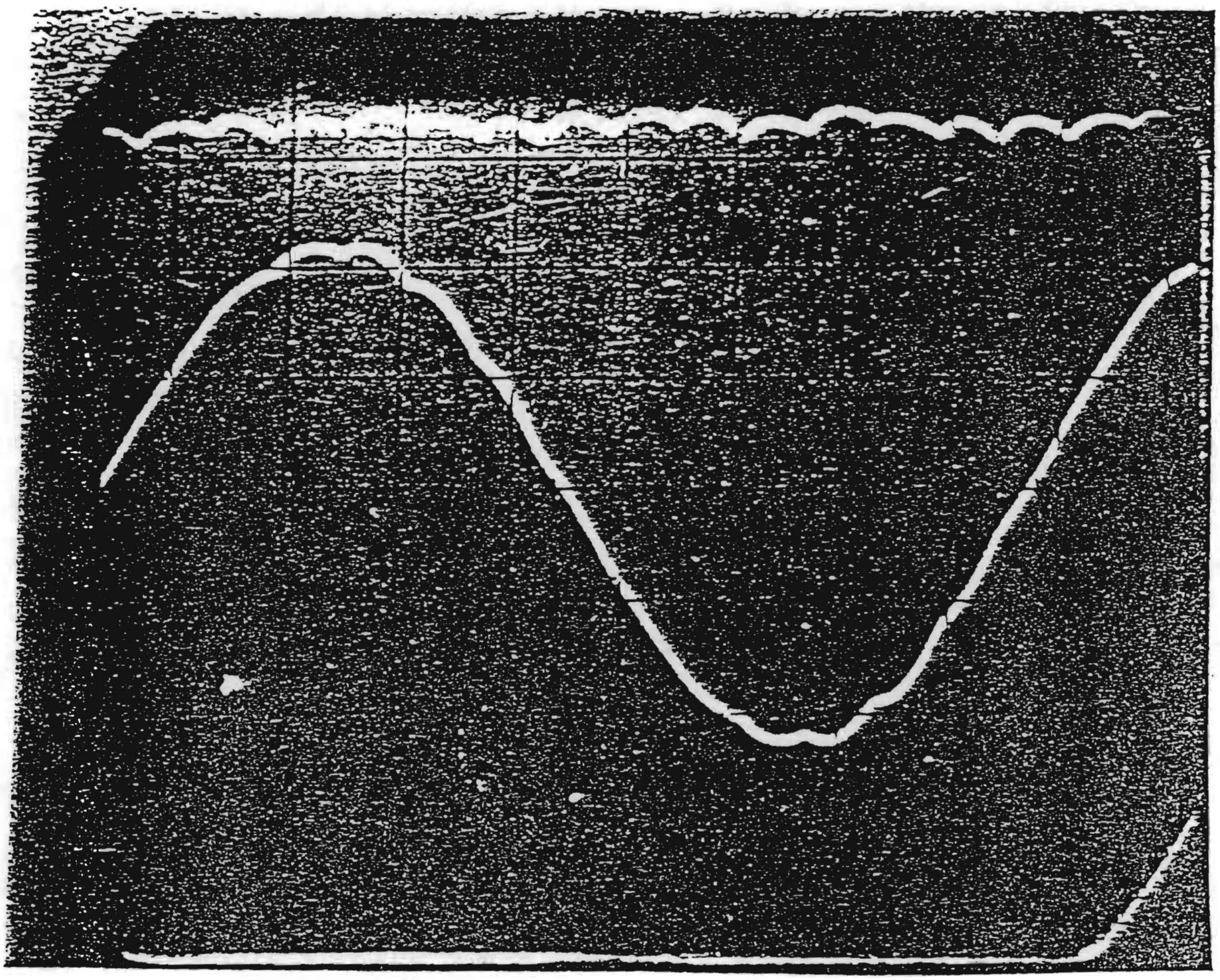


Figure 2

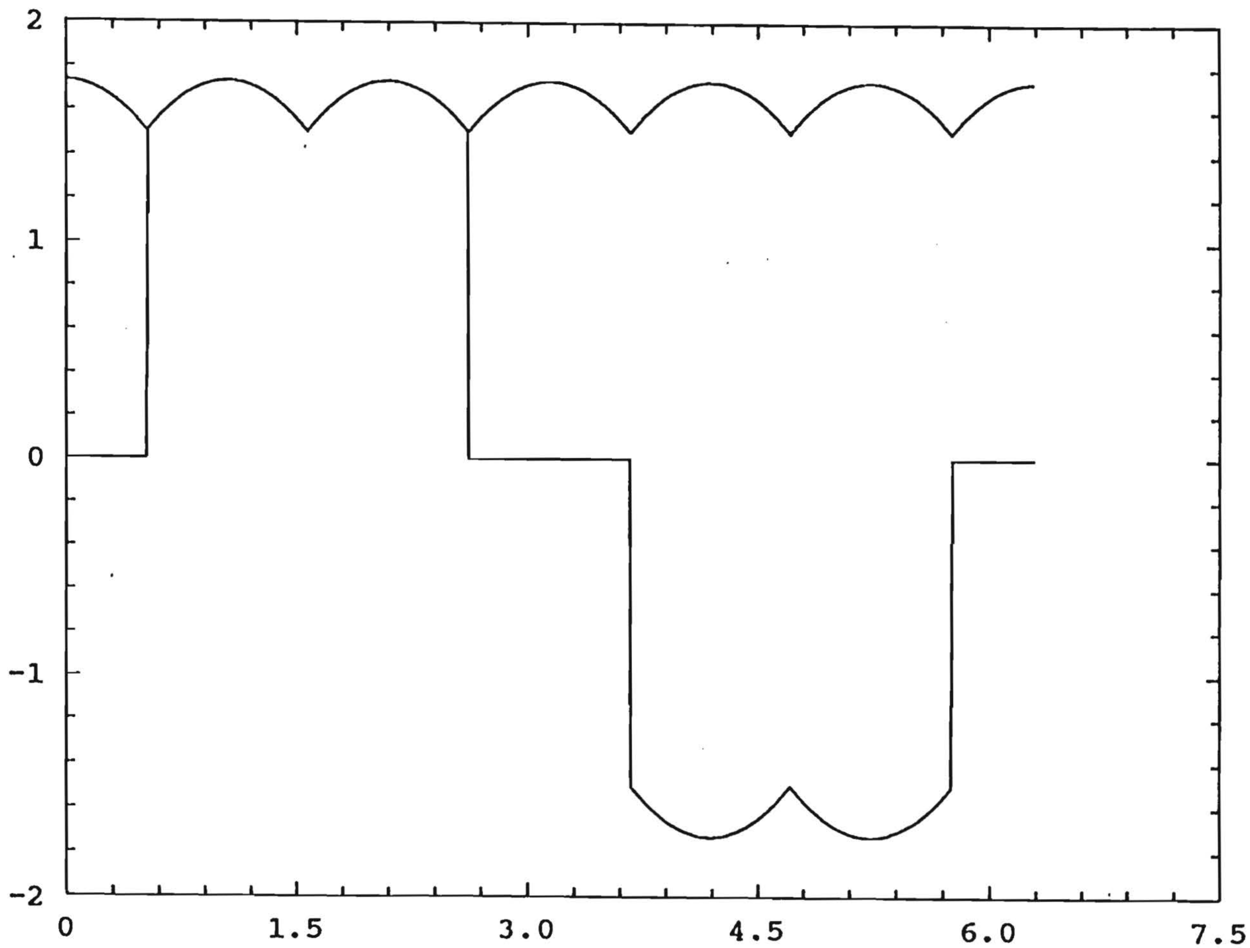


Figure 3

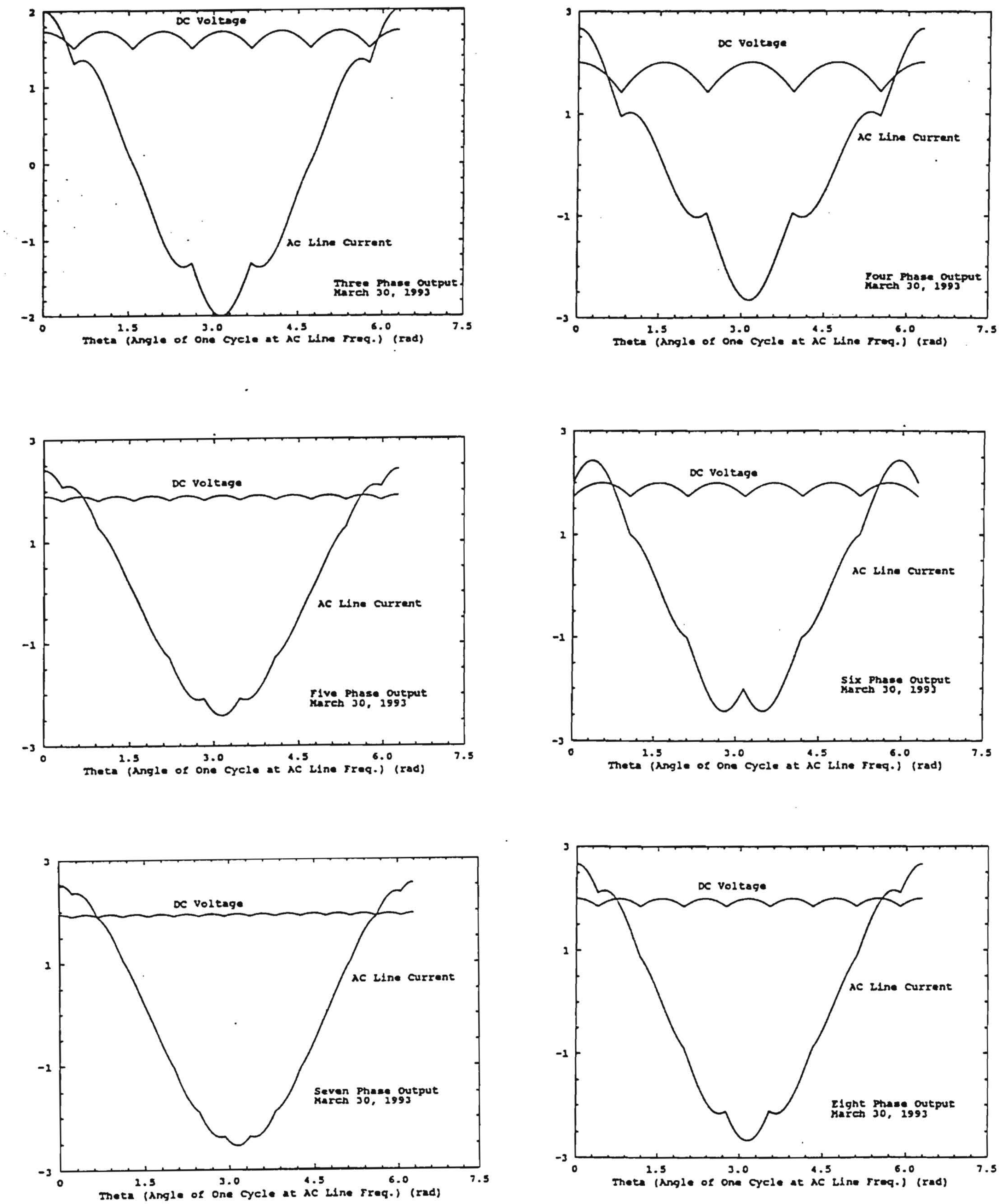

DC Voltage
AC Line Current
Three Phase Output
March 30, 1993
Four Phase Output
March 30, 1993
Five Phase Output
March 30, 1993
Six Phase Output
March 30, 1993
Seven Phase Output
March 30, 1993
Eight Phase Output
March 30, 1993
Theta (Angle of One Cycle at AC Line Freq.) (rad)
0
1.5
3.0
4.5
6.0
7.5

Figure 4

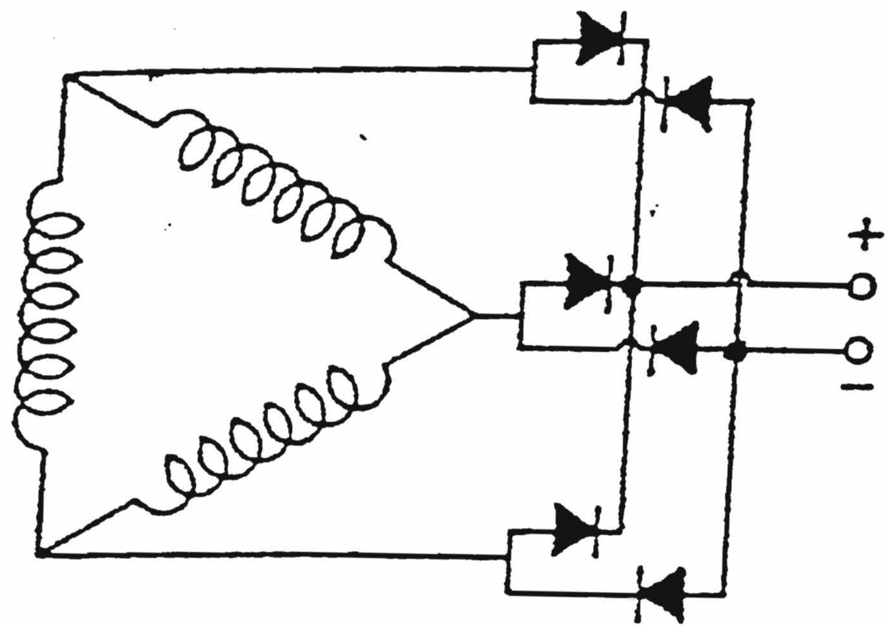


Figure 6

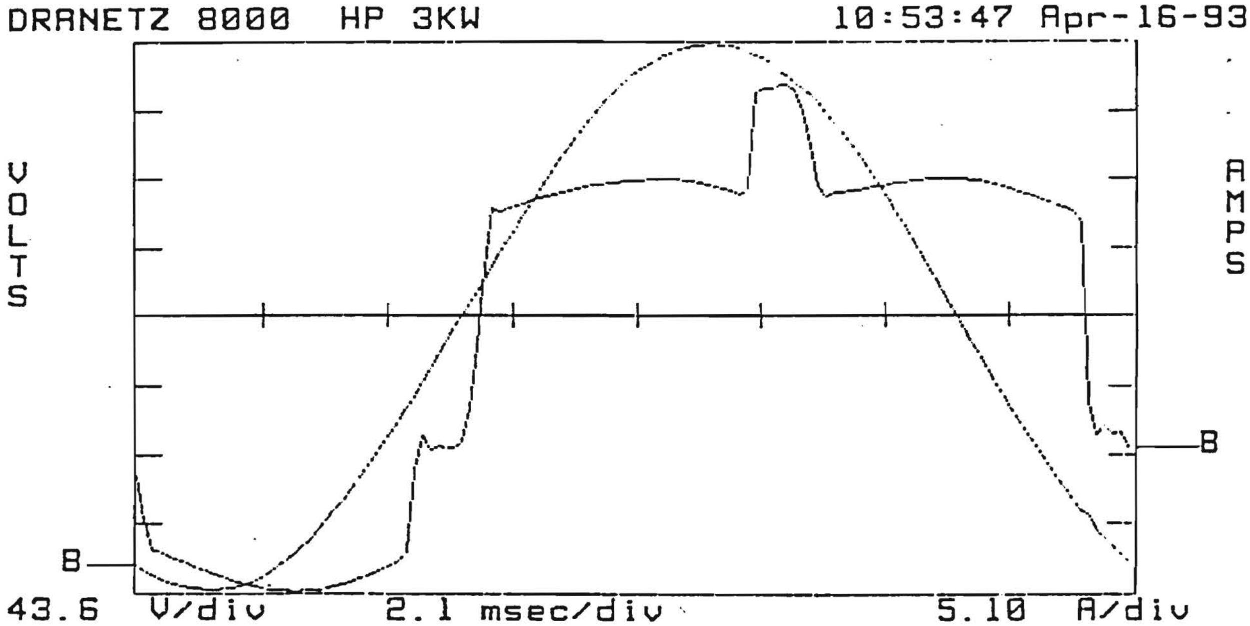

DRANETZ 8000 HP 3KW
10:53:47 Apr-16-93
VOLTS
AMPS
B
B
43.6 V/div
2.1 msec/div
5.10 A/div

Figure 7

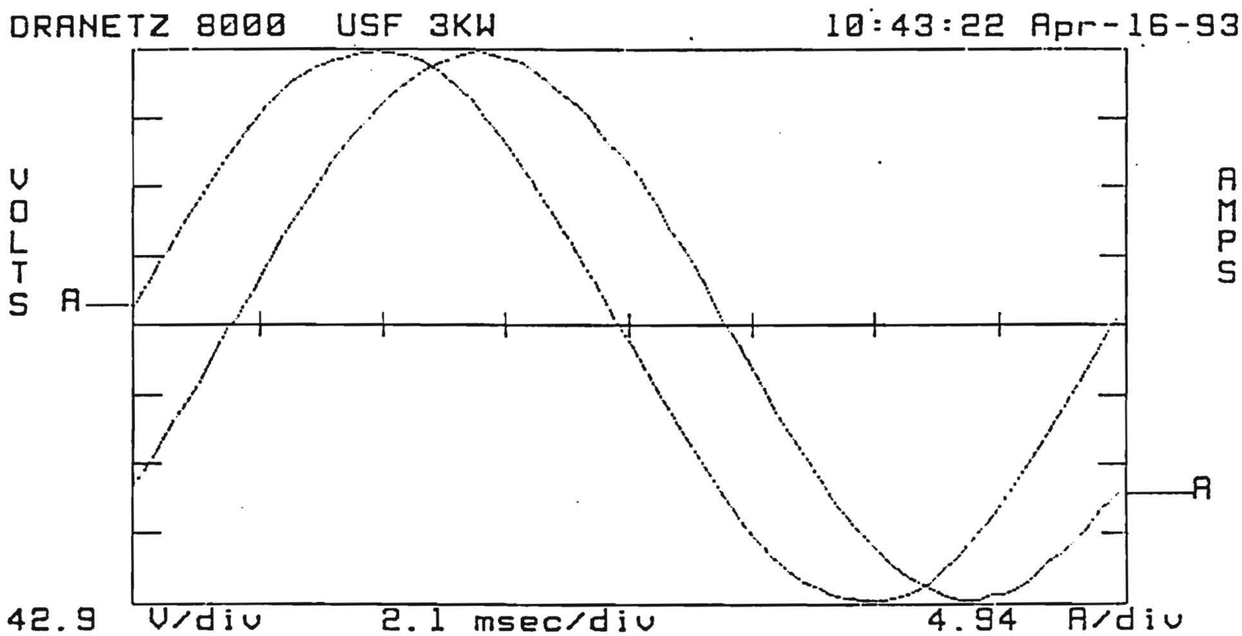

DRANETZ 8000 USF 3KW
10:43:22 Apr-16-93
VOLTS
A
AMPS
A
42.9 V/div
2.1 msec/div
4.94 A/div

Figure 8

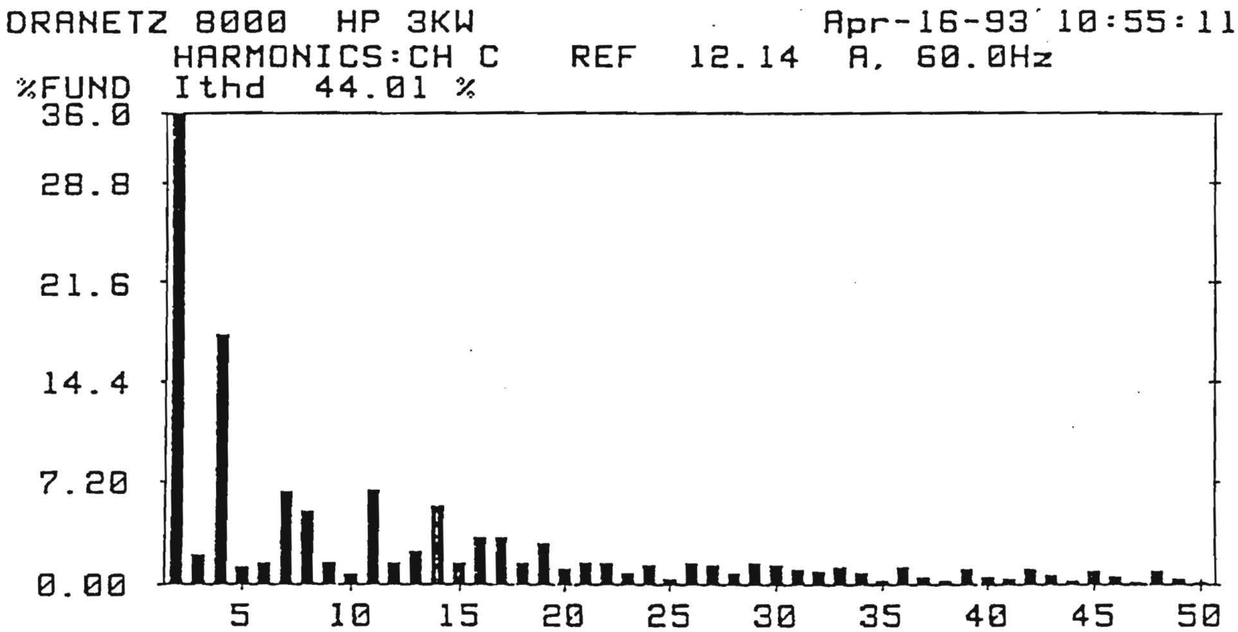
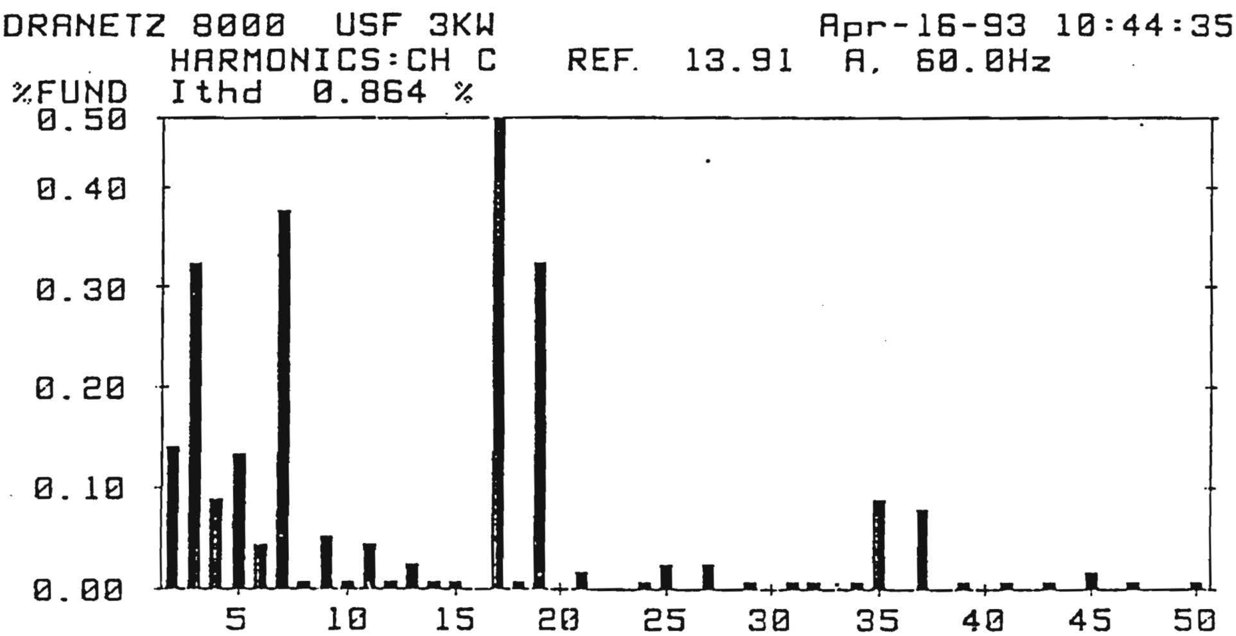

DRANETZ 8000 HP 3KW Apr-16-93 10:55:11
HARMONICS:CH C REF 12.14 A, 60.0Hz
%FUND Ithd 44.01 %
36.0
28.8
21.6
14.4
7.20
0.00
5
10
15
20
25
30
35
40
45
50

Figure 9



DRANETZ 8000 USF 3KW
Apr-16-93 10:44:35
HARMONICS:CH C REF. 13.91 A, 60.0Hz
%FUND Ithd 0.864 %
0.50
0.40
0.30
0.20
0.10
0.00
5 10 15 20 25 30 35 40 45 50

Figure 10

ADVANCED BATTERY DEVELOPMENT

Prepared for the

United States Advanced Battery Consortium

<u>Revised August 13, 1991</u>

GNB/MATSI ELECTRIC VEHICLE BATTERY TECHNOLOGY
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Table of Contents

Executive Summary

This document is a revision of the original proposal submitted by GNB/MATSI to USABC on April 29, 1991. Although we are prepared to proceed with the original program as proposed, this revision presents an alternative program which may prove more attractive to USABC.

The principal elements of this revision are threefold. First, we now focus exclusively on the electrically rechargeable version of our zinc-air/lead-acid battery system. Second, we have revised the performance and cost projections for the zinc-air battery based upon the very substantial improvements gained from a recent redesign. Third, we now target the development program based upon the long range schedule, culminating in the testing of a full scale (40 kWh) vehicle battery in 1994.

While we continue to believe that the zinc-air primary battery, with its very high specific energy, has the potential for capturing a significant share of the EV market, we understand that there are infrastructure requirements unique to this battery which USABC may not choose to deal with at this time. Furthermore, the improvements made in rechargeable zinc-air battery specific energy narrow the gap between the two.

We have increased the projected specific energy of our rechargeable zinc-air battery from 101 Wh/kg to 182 Wh/kg, based upon recent success in our laboratory. We have achieved this improvement by combining two zinc electrode technologies, both developed independently at Lawrence Berkeley Laboratory, to maximize both specific energy and cycle life.

The first technology employs a metal foam substrate for the zinc electrode, through which electrolyte flows during battery operation. Electrolyte flow is necessary for long cycle life in rechargeable zinc-air batteries to provide electrolyte management in this open system. The second technology avoids zinc electrode densification by minimizing zinc ion solubility. We have, thus, created a flowing electrolyte version of the insoluble zinc electrode, which reduces the electrolyte requirement, for a 40 kWh battery, by 160 kg and 133 ℓ. As a result, the projected weight and volume of the 40 kWh / 75 kW battery system have been reduced to 282 kg and 205 ℓ, respectively. This change favorably impacts cost as well, reducing the cost for purchased materials and components to $47/kWh.

The revised program described herein modifies the hardware development schedule, with the goal of demonstrating design feasibility in 1994 through the construction and testing of one or more full scale (40 kWh) EV battery systems. This is to be followed by EV engineering and independent verification tasks, culminating in the installation of a pilot plant for EV battery production by 1998.

The GNB/MATSI team believes, based on the high specific energy of the rechargeable zinc-air battery and the high specific power of the Pulsar lead-acid technology, that our proposed battery system is a very attractive candidate for electric vehicle propulsion.

6.2 Proposed Advanced Battery Technology

Introduction

The zinc-air battery employs the electrochemical oxidation of zinc to produce energy, as follows:

$$Zn + \tfrac{1}{2}O_2 \rightarrow ZnO.$$

It has a high specific energy because the oxygen is taken from the ambient air, and zinc has a high specific capacity (0.82 Ah/g). Zinc-air is the safest of all high specific energy batteries because both of its electrodes are benign and also because it operates at ambient temperature and pressure. For these reasons we believe that the zinc-air system is an excellent candidate for electric vehicle propulsion.

The zinc-air battery is unique in that it can be made either as a high cycle life, high specific energy rechargeable battery or as an ultra-high specific energy primary battery. We believe that the electric vehicle market, like many other markets, will be highly segmented and served by many different propulsion technologies, as required by many different drive cycle requirements and recharge constraints. The EV market will probably include utility/commuter vehicles with a 120-200 mile range limit between recharges, which can be serviced by a 40 kWh battery, as well as touring/luxury vehicles with ranges of more than 500 miles between refuelings. The zinc-air battery can meet both of these requirements, the former as a rechargeable, the latter as a primary.

Historically, battery designers have traded off energy and power, owing to the negative slope of Ragone plots of specific energy versus specific power. For the electric vehicle propulsion market, however, both must be high, making this application one of the most demanding for batteries. We have resolved this dilemma by proposing a dual battery system which consists of both an energy section and a power section. The energy section is zinc-air, designed for high specific energy. The power section is lead-acid, designed for high specific power. As described in section 6.2.C, we plan to use GNB Incorporated's Pulsar semi-bipolar, lead-acid SLI technology, which boasts a specific power of more than 800 W/kg, for the power section of our system.

The following sections describe the proposed rechargeable zinc-air/lead-acid battery system, including a design specification for a benchmark 40 kWh (minimum) battery pack.

6.2.A Rechargeable Battery System

(1) Technical Description

Overview

Our rechargeable zinc-air battery design is based on the zinc-electrode invented at Lawrence Berkeley Laboratory in 1985 (P. N. Ross, Jr., Proceedings of the 21st Intersociety Energy Conversion Engineering Conference, p 1066 [1986]), in combination with a bifunctional oxygen electrode and a microporous separator (*Figure 1*). The battery module comprises a series of zinc electrode frames and oxygen electrode frames interleaved in a multiplate, filter press stack

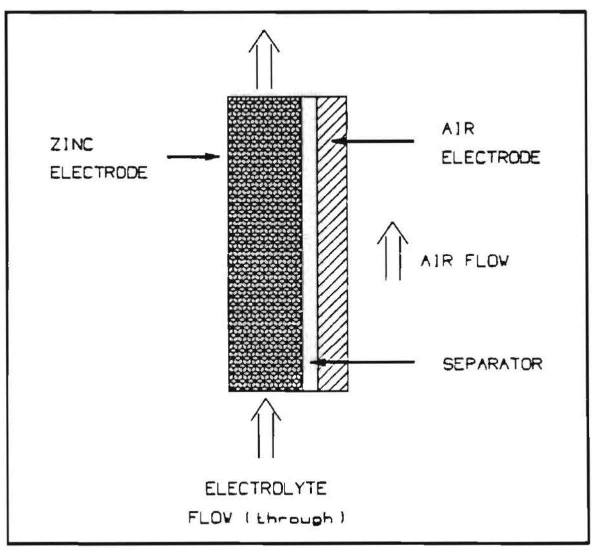


Figure 1: Rechargeable Zinc-Air Cell Design

(*Figure 2*). The battery system consists of one or more modules, an electrolyte circulation system, and an air circulation system (*Figure 3*).

Zinc Electrode

The zinc electrode comprises a copper metal foam substrate onto which zinc is deposited during charge, and through which the electrolyte is circulated. The foam substrate (*Figure 4*) is very sparse and macroporous (*Table 1*). This provides space along its surface for the zinc electrodeposit formed during charge and allows for unimpeded vertical electrolyte flow through the center position.

Table 1: Metal Foam Properties

- Density 3 to 6%
- 4 to 6 Pores/cm
- Pore Diameter 0.2 cm
- Filament Diameter 0.4 mm
- Effective Surface Area 10-100 cm^2/cm^3

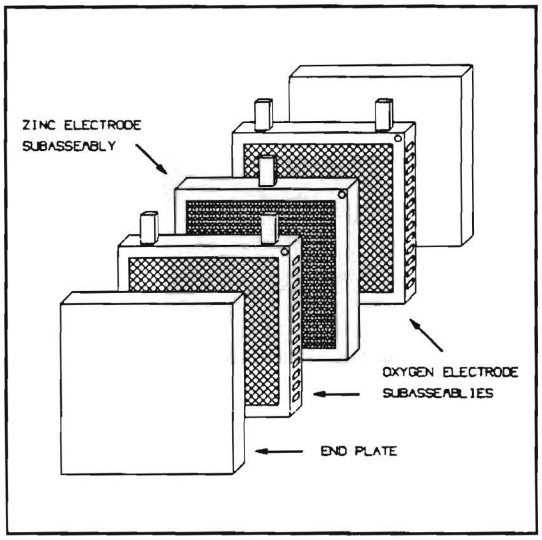


Figure 2: Rechargeable Battery Stack

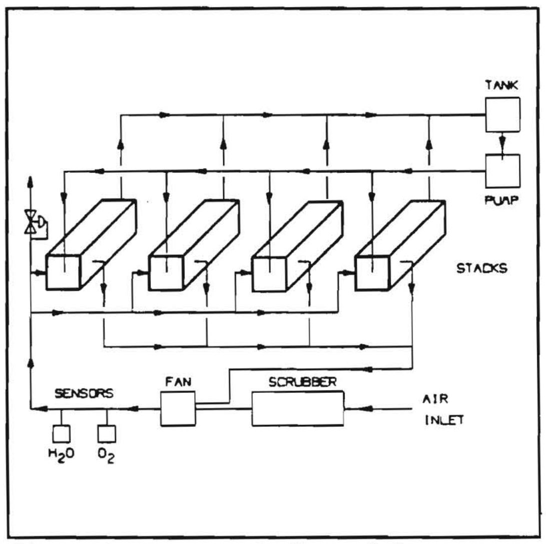


Figure 3: Battery Air Control System

Figure 4: Copper Metal Foam

The LBL electrode, as invented, is a soluble zinc electrode, in which the discharge product, potassium zincate, is dissolved in the electrolyte. This is in contrast to the insoluble zinc electrode, as employed in silver-zinc and nickel-zinc batteries. The LBL electrode was designed to avoid shape change by allowing complete stripping of the electrodeposit during discharge. Further, by providing electrolyte circulation through the electrode, it avoids the dryout problem associated with the static zinc electrode in a zinc-air battery, since the zinc-air system is open to the atmosphere.

One disadvantage of the soluble LBL electrode is that it limits the specific energy of the battery to approximately 100 Wh/kg. This is because the maximum practical solubility of zincate in the concentrated (45% KOH) electrolyte is 350 g/ℓ (as zinc), which is achieved through solubility extenders such as potassium silicate or lithium hydroxide. This corresponds to an electrolyte ampere-hour capacity of 260 Ah/ℓ. For a 40 kWh battery the electrolyte weight is 232 kg, which is 58% of the total battery weight.

MATSI has dramatically increased the specific energy of the battery by transitioning the LBL electrode to an insoluble form, in which, while retaining the metal foam substrate and electrolyte flow, the electrolyte volume and concentration are reduced substantially. This has the following effect on the system:

Table 2: Effect of Electrolyte Form

	Electrolyte		Battery
	Weight	Weight Percent	Specific Energy
LBL Soluble	232 kg	58%	101 Wh/kg
Insoluble	72 kg	33%	182 Wh/kg

We minimize the densification problem associated with the insoluble electrode by employing the technology, also developed at LBL (F. McLarnon, LBL, private communication, 1991), in which low concentration electrolytes (3.2 M KOH) have been shown to extend zinc electrode cycle life beyond 500 cycles. Furthermore, <u>the provision for electrolyte flow allows electrode reconditioning at periodic service intervals by circulating high concentration electrolyte to strip and redeposit the zinc electrodes.</u>

Oxygen Electrode

It has been generally accepted by the electrochemical community that a rechargeable zinc-oxygen battery is not feasible because there is no electrode which is capable of both reducing oxygen on discharge and generating it on charge. Certainly, the electrode potential swing between charge and discharge (2.05 V and 1.25 V, respectively), is very large, such that few materials are stable over that range. And the highly oxidizing conditions during charge quickly corrode the popular carbon substrates used in oxygen cathodes. The use of noble metals, *e.g.* platinum and ruthenium, is discouraged both by cost and by the gassing problem they create at the zinc electrode as they slowly dissolve and diffuse through the cell. Some work has been done on two-oxygen-electrode designs, having an oxygen anode and an oxygen cathode which are electrically isolated, but the complexity of switching between them for charge and discharge, coupled with the generation of oxygen gas bubbles inside the cell during charge which somehow must be removed, has stood in the way of demonstrating practical feasibility for this "three electrode cell".

However, research during the past five years has produced an efficient, durable, bifunctional oxygen electrode. The key development was by Ross at Lawrence Berkeley Laboratory (P.N. Ross and M. Sattler, Journal of the Electrochemical Society, <u>135</u>; #6, p. 1464;[1988]), who showed that graphitization of certain carbons rendered them highly resistive to oxidative attack at oxygen evolution potentials. Of the ten or more carbons he studied, one in particular, SRF (N774), proved capable of being fully graphitized and thus particularly stable to oxidation.

Solomon (F. Solomon, Electromedia Corporation, private communication, 1991), has built upon the developments of Ross, incorporating graphitized carbon catalyst supports into a series of bifunctional oxygen electrodes which, over the last two years, have shown markedly improved performance and cycle life. These are PTFE-bonded, two layer structures similar to the oxygen cathodes which have been used with excellent results in the NASA zinc-oxygen primary battery development program at MATSI.

Figure 5 shows the voltage-current density relationship for the best bifunctional electrode formulation; the polarization is less than 50 mV for current densities up to 100 mA/cm².

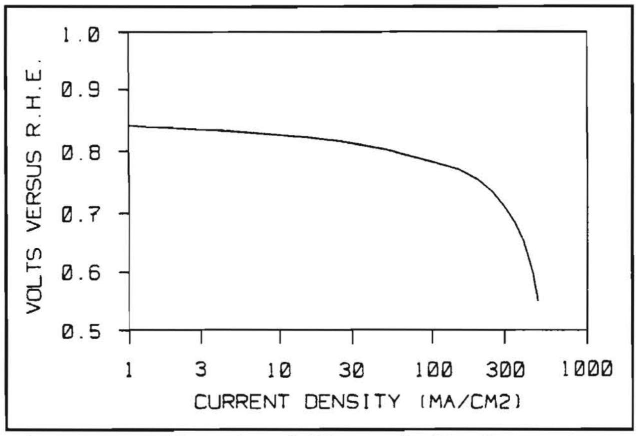


Figure 5: Bifunctional Electrode Performance on Discharge (Electromedia Corporation)

Figure 6 shows the charge and discharge voltages during an accelerated cycle life test. For this test the electrode performed steadily for over 350 cycles, under accelerated stresses of temperature (60 C) and current density (20 mA/cm²), indicating that the cycle life under normal stress conditions (25 C / 5 mA/cm² charge current density) could well exceed 500 cycles. The cycle life and performance of these electrodes in zinc-air cells will be discussed fully in Task 4.

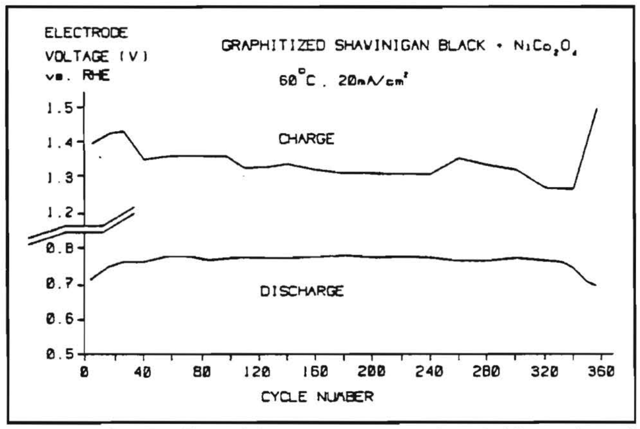


Figure 6: Cycle Life Test Data for Bifunctional Oxygen Electrode (Electromedia Corporation)

Electrolyte

The electrolyte solution is 3.2M (16%) potassium hydroxide in water. Various supporting electrolytes, *e.g.* KF and K_2CO_3, are being evaluated presently for their effect on cycle life and electrochemical performance.

(2) Technology Status

Performance

We have conducted performance and cycle life testing on this system for the past 30 months. For the first 18 months we focused exclusively on the zinc electrode, using zinc-zinc half-cells. These cells (*Figure 7*) employ soluble zinc electrodes, with an active area of 10 cm², for the working and counter electrodes. They are driven by constant current power supplies on both charge and discharge, and the electrolyte is pumped in series from the working to the counter electrodes for simplicity and reliability.

During the half-cell testing program we identified the key requirements for achieving high cycle life on the soluble zinc electrode. These include preplating the copper foam with dense zinc for corrosion protection and limiting the specific capacity to 200 mAh/cm².

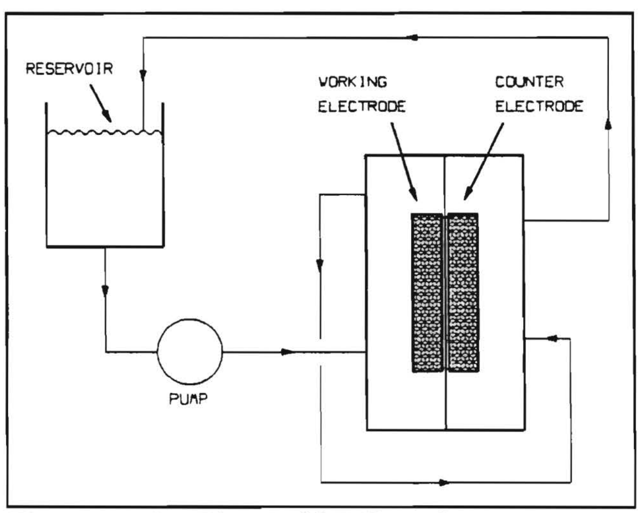


Figure 7: Zinc-Zinc Half-Cell Design

By observing these requirements we are able to cycle the soluble zinc electrode indefinitely, to full or partial discharge, with no degradation in performance with cycling. ***Figure 8*** shows the charge-discharge curves for a zinc-zinc cell at two different points in cycle life. While cell voltage varies somewhat from cycle to cycle, the performance at cycle #835 is actually better than at cycle #180. With cycle testing ongoing as of this writing, the maximum cycle life achieved to date on a soluble zinc electrode is 838 cycles, while other electrodes have accrued 200-600 cycles to date.

During the past year, once efficient and durable oxygen electrodes became available from Electromedia Corporation, we broadened our testing program to include zinc-air cells. A typical charge-discharge curve is shown in ***Figure 9***, while ***Figure 10*** shows the cycle voltages for the first 50 cycles of testing conducted. We are optimistic, based on results to date, that the 600 cycle goal of this solicitation is achievable with the present oxygen electrode or with only incremental improvements to it.

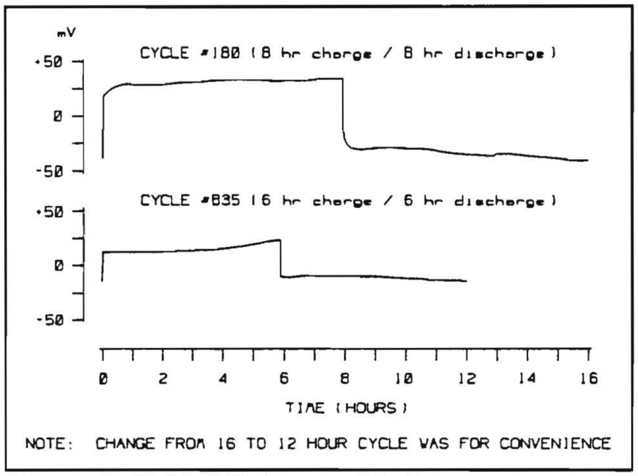


Figure 8: Half-Cell Charge-Discharge Curve

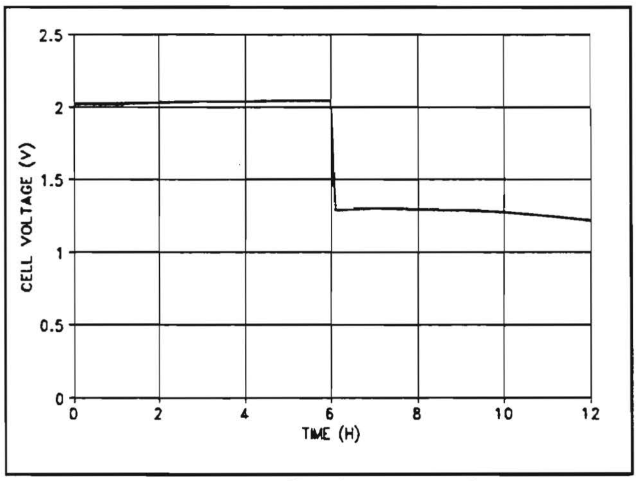


Figure 9: Zinc-Air Cell Charge-Discharge Curve

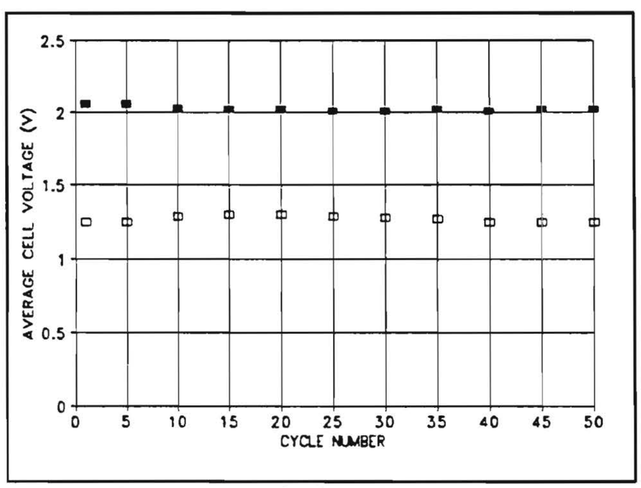


Figure 10: Zinc-Air Cell Cycle Data

(3) Design Specification

The following is a benchmark design for a 40 kWh rechargeable zinc-air battery, based on the insoluble version of the metal foam zinc electrode.

Basis	
Electrode Configuration	1000 cm^2 active area, both sides active
Cell Performance	1.2 V average voltage, 50 mA/cm^2 average current density (C/3); 100 mW/cm^2 peak power
Zinc Electrode	0.3 cm thick, 3% dense foam substrate, 150 mAh/cm^2 capacity density
Oxygen Electrode	2 bifunctional oxygen electrodes 0.5 mm thick (0.05 g/cm^2), back to back, 0.15 cm air flow gap between them
Electrolyte	3M KOH, 1.35 g/cc density
Zinc	85% utilization
Hardware Requirements	15% of total system weight and volume

Design Calculations		
Negative Electrode Capacity	150 mAh/cm^2 x 1000 cm^2 = 150 Ah	
Number of Negative-Positive Electrode Pairs Required	40 kWh / (1.2 V x 150 Ah) = 222	
Stack Weight Per Electrode Pair	negative electrode substrate	80 g
	positive electrodes	100
	separator	16
	negative electrode frame	57
	positive electrode frame	48
	electrolyte	324
	zinc oxide	215
	subtotal	840 g
Total Stack	840 g x 222 = 186 kg	
Total Weight of Energy Section	186 kg / 0.85 = 219 kg	
Stack Volume	34 cm x 35 cm x (0.3 + 0.25 cm) x 222 = 145 ℓ	
Total Volume of Energy Section	145 ℓ / 0.85 = 170 ℓ	
Energy Section Power	Peak: 100 mW/cm^2 x 1000 cm^2 x 222 = 22 kW Average (C/3): 1.2 V x 50 mA/cm^2 x 1000 cm^2 x 222 = 13 kW	
Power Section Requirements	Peak Power: 75 kW - 22 kW = 53 kW Weight: 53 kW / 836 W/kg = 63 kg Volume: 53 kW / 1504 W/ℓ = 35 ℓ	

Results

Summarized below in ***Table 3*** are the weight, volume, power and energy values resulting from the design calculations.

Table 3: Rechargeable 40 kWh Zinc-Air Battery Specifications

Variable	Energy Section	Power Section	Total
Weight	219 kg	63 kg	282 kg
Volume	170 ℓ	35 ℓ	205 ℓ
Energy	40 kWh	-	40 kWh
Power	22 kW	53 kW	75 kW
Specific Energy	182 Wh/kg	-	142 Wh/kg
Energy Density	235 Wh/ℓ	-	195 Wh/ℓ
Specific Power	100 W/kg	836 W/kg	266 W/kg
Power Density	129 W/ℓ	1504 W/ℓ	366 W/ℓ

As shown below in ***Table 4*** the calculated performance for the system compares very favorably with the Primary Criteria of the Mid Term specification.

Table 4: Rechargeable Battery Primary Criteria

Variable	Calculated	Specification	Ratio (C/Sx100)
Power Density	366 W/ℓ	250 W/ℓ	146%
Specific Power	266 W/kg	150 W/kg	177%
Energy Density	195 Wh/ℓ	135 Wh/ℓ	144%
Specific Energy	142 Wh/kg	80 Wh/kg	178%

(4) Other Considerations

There are no significant packaging constraints for this system. In addition, the environmental & safety issues which would need to be addressed during manufacture, use, recycling or disposal would be limited to the proper handling of the potassium hydroxide electrolyte. The only known degradation or failure mechanism (aside from possible mechanical failures) for the system is carbonation of the oxygen electrode.

6.2.C Pulsar Lead-Acid Battery

(1) Technical Description

Overview

Our EV battery strategy is to couple a zinc-air (either primary or rechargeable) energy section with a lead-acid power section. This takes advantage of the high specific energy and deep discharge cycle attributes of zinc-air with the high specific power of lead-acid. In this approach the lead-acid battery operates on a positive float / shallow discharge regime very similar to that for the SLI application, for which there is no better battery system.

This is in contrast to EV battery systems based entirely on lead-acid batteries, which require not only high power levels but also deep cycles. Demanding both is asking too much of lead-acid technology, and the result is short lifetime for the battery packs. In addition, lead is too heavy to provide capacity; the specific energy of lead-acid is too low for second generation electric vehicles.

We have selected an advanced design lead-acid SLI battery for the power section, called Pulsar. Pulsar (***Figure 11***) is a novel approach to SLI battery design which employs a plate and frame configuration (***Figure 12***), in which expanded lead alloy grids are insert-molded into plastic frames, then pasted with active materials, to form power panels, and separator material is molded into plastic frames as separator panels. These panels are interleaved and friction-welded together to form the finished battery. Importantly, from a manufacturing perspective, this plate and frame design is very similar to that which will be employed by our zinc-air batteries.

The current path in the Pulsar battery, as shown in ***Figure 12***, is from the positive terminal panel of the terminal frame, through a separator panel, to the first negative side of the first bipolar panel of the floater frame. Current then flows through the lead grid to the positive side of the first bipolar panel of the floater frame, then through a separator panel to the negative side of the first bipolar panel of the terminal frame. Each time it travels through a separator panel the voltage falls by 2 V. By the time the current reaches the negative terminal of the terminal frame there is a total voltage drop of 12 V.

Figure 11: Pulsar Lead-Acid SLI Battery

Figure 12: Current Path in Pulsar Battery

This semi-bipolar design is a breakthrough in lead-acid battery technology because it dramatically reduces the path length for the flow of current. The result is a more compact, lightweight battery, boasting a specific power of over 800 W/kg and an energy density of more than 1500 W/ℓ. These values are at least 25% greater than those for conventional SLI batteries. Furthermore, the configuration of the external cell interconnections can be modified to achieve a wide range of current-voltage combinations, imparting excellent design flexibility.

(2) Technology Status

The Pulsar technology is in full scale commercial production at GNB's Columbus, Georgia plant. The production process is fully integrated, combining the core technologies of metal expanding, insert molding, grid pasting, and friction welding. These are, in fact, the very same technologies that will be applied in the manufacture of our zinc-air primary and rechargeable batteries.

GNB has been in the forefront of product life cycle management. In 1970 it was one of the first automotive battery companies to close the loop with the opening of its first secondary lead smelter. Today GNB operates 3 smelters in the U.S., producing more than 160,000 tons of lead and 15 million pounds of plastic each year. There is currently 100% recycling of both materials within GNB.

(3) Design Specification

The design basis, calculations and results for the Pulsar power module required by the rechargeable and primary zinc-air range modules are contained within sections **6.2.A** and **6.2.B**, respectively.

(4) Other Considerations

There are no significant packaging constraints for this system. The environmental & safety issues which would need to be addressed during manufacture, use, recycling or disposal are limited to the proper handling of lead, lead oxide and the sulfuric acid electrolyte. The only known degradation or failure mechanisms (aside from possible mechanical failures) for the system are positive grid corrosion and densification of the negative active material.

(5) Cost Breakdown

The detailed costs shown for the rechargeable zinc-air battery (page 11) are for pilot plant production levels (100 or more batteries per year). The pilot plant will use semi-automated process equipment, similar to that envisioned for full production, as well as injection-molded electrode frames, and molded or NC-machined end plates.

The present costs for some components, notably the copper foam and oxygen electrode, are based upon fully manual production by skilled technicians in a laboratory setting.

(5) Cost Breakdown (continued)

The cost breakdown for the components of the rechargeable zinc-air battery are as follows:

Rechargeable Zinc-Air Battery

Copper Foam	(0.3 cm thick, 3% dense, \$5 per pound as finished material) 0.3 cm x 1000 cm^2/0.18 kWh x 8.9 g/cm^3 x 0.03 x 1 lb/454 g x \$5 /lb = \$4.90/kWh
Separator	(3 layers Celgard 3401, 0.0025 cm thick, 25% larger than electrode for seal, 1 g/cm^3 density, \$50/lb purchase price) 1000 cm^2/0.18 kWh x 3 x 2 x 1.25 x 0.0025 cm x 1 g/cm^3 x 1 lb/454 g x \$50/lb = \$11.47/kWh
Oxygen Electrode	(0.05 g/cm^2, \$10/lb as finished material) 1000 cm^2/0.18 kWh x 0.05 g/cm^2 x 2 x 1 lb/454 g x \$10/lb = \$12.23/kWh
Electrode Frames	(34 cm x 35 cm outside dimensions, glass filled polypropylene, 1.2 g/cm^3 density, \$1.50 per pound as molded) Negative: 0.3 cm thick x (34 cm x 35 cm - 1000 cm^2) x 1.2 g/cm^3 x 1 lb/454 g x \$1.50/lb / 0.18 kWh = \$1.25/kWh Positive: 0.25 cm thick x (34 cm x 35 cm - 1000 cm^2) x 1.2 g/cm^3 x 1 lb/454 g x \$1.50/lb / 0.18 kWh = \$1.05/kWh
Electrolyte	(324 g/cell, \$19.50/100 lb as 45% solution) 324 g / 0.18 kWh x 16/45 x \$19.50/100 lb x 1 lb/454 g = \$0.27/kWh
Zinc Oxide	(85% utilization, \$1.15/lb) 1.22 g/Ah / 1.2 V x 1 lb / 454 g / 0.85 x \$1.15/lb x 1000 Wh/kWh = \$3.03/kWh
End Plates	(34 cm x 35 cm x 2.5 cm, glass filled polypropylene, 1.2 g/cm^3 density, \$1.50 per pound as molded, 4 sets per battery system) 34 cm x 35 cm x 2.5 cm x 1.2 g/cm^3 x 1 lb/454 g x 8 x \$1.50/lb / 40 kWh = \$2.40/kWh
Balance of System	(pump, plumbing, blower, scrubber, hardware, sensors and controls) \$400 (est) / 40 kWh = \$10/kWh

Summary

Copper Foam	\$ 4.90/kWh
Separator	11.47
Oxygen Electrode	12.23
Negative Electrode Frames	1.25
Positive Electrode Frames	1.05
Electrolyte	0.27
Zinc Oxide	3.03
End Plates	2.40
Balance of System	10.00
Total	\$ 46.60/kWh

(5) Cost Breakdown (continued)

Pulsar Lead-Acid Battery

Lead

Separator

Lead Oxide

Electrode Frames

Separator Frames

Electrolyte

End Plates

Balance of System

PROPRIETARY

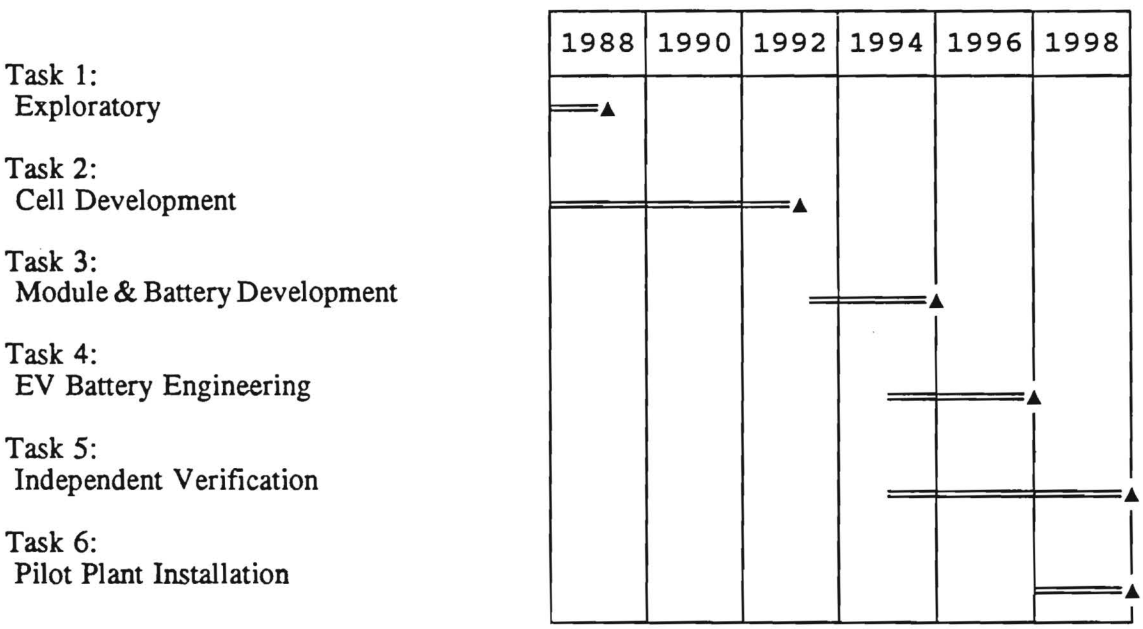
NOTE: The anticipated cost of the Pulsar batteries will not result in an ultimate battery system price in excess of the mid term goal of <$150/kWh or long term goal of <$100/kWh.

6.3 Proposed Technology Development Plan

Introduction

The overall development schedule, shown below, culminates in the installation of a pilot plant in 1998 for EV battery manufacture. It follows the National Program Plan for Electric Vehicle Battery Research and Development (G. Henrickson, D. Douglas and C. Warde,[1989]). The present program focusses on Tasks 2 and 3 of that schedule, culminating in the construction and testing of a full scale EV battery by the end of 1994. The six tasks of the overall program are discussed below.

Schedule



Task 1: Exploratory

The exploratory phase of this program was carried out by Lawrence Berkeley Laboratory in the mid 1980's. It included the invention of the cell design concept, design of working laboratory cells, preliminary performance and cycle testing, fundamental materials selection, and a first cost and design study of an EV battery. These achievements established the technical and economic feasibility of the battery, encouraging LBL to contract with MATSI for Task 2.

Task 2: Cell Development

Task 2 was begun by MATSI in October, 1988, under the LBL subcontract, and will continue through the remainder of 1991. It has encompassed selection and testing of electrode structures, electrolyte formulations, separators, and cell design variables. Performance and cycle life testing have been conducted on zinc-zinc half-cells as well as zinc-air cells. A conceptual cost and design study for a full scale EV battery has been performed and refined. The results of this task serve as the basis for the proposed program, which is discussed in the following tasks.

Task 3: Module and Battery Development

The milestone for this task is the construction and testing of a full size (40 kWh) battery by the end of 1994. Activities in this task will include...

1. a conceptual design of the EV battery.

2. design, fabrication, testing of full scale cells, multiplate stacks, and full modules. Testing to be conducted will include design debug, electrochemical performance, hydraulic and thermal performance, cycle capability, reliability, and safety.

3. development of the manufacturing processes for the battery components, including pilot lines for the metal foam and the oxygen electrodes as well as tooling for injection molding of the electrode frames.

4. construction and bench testing of a complete EV system.

The output of this task will include specific energy and specific power data, calendar and cycle life, reliability and safety, thermal performance, and improved cost estimates for the components and battery assembly. Included in this task will be a preliminary FMEA and an environmental impact study. The testing program under Task 3 will provide data and demonstration of design feasibility and performance benefits of the rechargeable zinc-air battery, and will serve as the basis for Task 4 in a follow-on program.

Task 4: EV Battery Engineering

This task represents a major expansion of activity, targeted towards the installation of a pilot plant for small-to-medium scale production of zinc-air EV batteries. Activities will include...

1. battery engineering to meet the performance, dimensions, weight, and cost requirements for the EV battery.

2. testing batteries of the refined design and configuration towards design qualification.

3. process engineering to define fully the equipment, capital, and facilities required for the pilot plant.

We presume that the battery engineering conducted under Task 4 will result in a design incrementally different than that built and tested under Task 3, to incorporate improvements and refinements developed during the Task 3 testing. Task 4, starting in 1994, will overlap Task 3 by one year, and will continue through 1997, preparatory to pilot plant installation of Task 6.

Task 5: Independent Verification

Battery modules will be delivered to independent test organizations, *e.g.* ANL, EVTF, and INEL for verification of performance levels and lifetime. Testing will be performed on various drive cycles selected by the test organization, as well as cycle testing for durability, cycle and calendar life. This task will begin in early 1994 and continue through the remainder of Task 3 and through Task 4, to track improvements during the engineering and scaleup of the system.

Task 6: Pilot Plant Installation

The pilot plant for small-to-medium volume production of EV batteries will installed in 1997, subsequent to the refined battery design engineering and manufacturing process development carried out in Task 4. The pilot plant will be on line within one year, for initial production of commercial batteries in 1998, ten years after the beginning of the development program at MATSI.

6.4 Schedule, Deliverables, Cost, & Cost Shares

Cost & Cost Sharing

The total budget for the 3 year program is $4.703, of which $4.238 million is for operating costs (page 16) and $0.465 million is for non-refundable capital expenditures (page 17).

Because of the highly proprietary and patented nature of the GNB/MATSI technologies being made available to USABC in this program, and its very high known potential value in similar and other applications in U.S., European and Asian markets, no provision has been included for cost sharing or title to more than the data, results and hardware specifically developed as part of this program.

GNB/MATSI is, however, willing to negotiate with USABC for a licensing arrangement to provide for USABC members' use of the resulting technology in markets which are directly relevant, *e.g.* the U.S., for non-exclusive vehicle applications.

Program Budget (000 omitted)

Calendar Year		1991	1992				1993				1994				Totals
Program Quarter		Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	
Materials															
Chemical		3	3	3	3	3	6	6	6	6	8	8	8	8	71
Mechanical		3	3	3	3	3	6	6	6	6	8	8	8	8	71
Electrical		2	2	2	2	2	4	4	4	4	6	6	6	6	50
Electronic		2	2	2	2	2	4	4	4	4	6	6	6	6	50
Subtotal		10	10	10	10	10	20	20	20	20	28	28	28	28	242
Direct Labor (Group/Title/Education/Years Experience)															
Electrochemistry	Base														
Group Leader MS/PhD/10	65	16	16	16	16	16	18	18	18	18	20	20	20	20	232
Chemist BS/5	35	9	9	9	9	9	10	10	10	10	11	11	11	11	129
Chemical Engineer BS/MS/5	40	10	10	10	10	10	11	11	11	11	12	12	12	12	142
Chemical Technicians HS/5	25	12	12	12	12	12	7	7	7	7	8	8	8	8	120
Subtotal	NA	47	47	47	47	47	46	46	46	46	51	51	51	51	623
Engineering															
Group Leader BS/MS CheE/10	75	19	19	19	19	19	21	21	21	21	23	23	23	23	271
Process Engineer BS CheE/7	50	13	13	13	13	13	14	14	14	14	15	15	15	15	181
Design Engineer BS ME/5	35	9	9	9	9	9	10	10	10	10	11	11	11	11	129
Process Techs HS/5	25	12	12	12	12	12	7	7	7	7	8	8	8	8	120
Hazardous Waste Tech HS/5	25	6	6	6	6	6	7	7	7	7	8	8	8	8	90
Electrical Tech HS/5	25	0	0	0	12	12	7	7	7	7	8	8	8	8	84
Subtotal	NA	59	59	59	71	71	66	66	66	66	73	73	73	73	875
Production															
Supervisor BS IE/10	35	0	0	0	0	0	10	10	10	10	11	11	11	11	84
Production Tech HS/5	25	0	0	0	0	0	7	7	7	7	8	8	8	8	60
Subtotal	NA	0	0	0	0	0	17	17	17	17	19	19	19	19	144
Management															
Project Manager BS/MS/15	130	33	33	33	33	33	36	36	36	36	39	39	39	39	465
General Manager BA/MBA/15	130	33	33	33	33	33	36	36	36	36	39	39	39	39	465
Subtotal	NA	66	66	66	66	66	72	72	72	72	78	78	78	78	930
Total Direct Labor		172	172	172	184	184	201	201	201	201	221	221	221	221	2572
Labor Overhead @ 20%		35	35	35	37	37	41	41	41	41	45	45	45	45	523
Total Materials & Labor		217	217	217	231	231	262	262	262	262	294	294	294	294	3337
G & A Expense @ 15%		33	33	33	35	35	40	40	40	40	45	45	45	45	509
Total Direct Costs		250	250	250	266	266	302	302	302	302	339	339	339	339	3846
Profit @ 10%		26	26	26	27	27	31	31	31	31	34	34	34	34	392
Total Cost With Profit		276	276	276	293	293	333	333	333	333	373	373	373	373	4238

Program Capital Budget (000 omitted)

Item	Description	Cost
CAD System	2 486 PCs w/ Software and plotters	25
Machine Shop	2 Vertical Milling Machines, 2 Lathes, 2 Drill Presses, 2 Surface Grinders, 1 Arc Welder, 1 Band Saw, 1 Cutoff Saw, 4 Bench Grinders, 3 Tool Cabinets	30
Tooling	4 NC Programs and Fixtures, 2 Sets of Injection Mold Tooling	50
Test Equipment	5 Laboratory Power Supplies, 1 Data Acquisition System, 5 Strip Chart Recorders, 5 one kWh Battery Testers, 5 forty kWh Battery Testers, 10 Multimeters, 5 Power Supplies	80
Process Development	3 V Blenders, 2 Carver Presses, 2 Laboratory Balances, 1 High Speed Mixer, 1 Attritor Mill, 2 Ovens, 1 Filter Press, 1 Roller/Compactor	60
Oxygen Electrode Line	2 Feeders, 2 Screeners, 2 Presses, 1 Programmable Controller, 2 Ovens	40
Copper Foam Line	1 Plating Tank, 1 Mixing Tank, 1 Rinsing Tank, 1 Power Supply, 1 Programmable Controller	20
Analytical Laboratory	1 AA Spectrophotometer, 2 Laboratory Balances, 1 Carbon Analyzer, 1 Micro Trac, 1 Porosimeter, 1 Oxygen Analyzer	60
Facilities Modifications	Waste Treatment System, Chemistry Laboratory, Process Laboratory, Test Laboratory	100
Total		$465

6.5 Cooperative Relationships

Our team currently includes the following organizations which represent all of the critical aspects of developing and manufacturing the proposed electric vehicle battery system:

- Zinc Corporation of America; zinc oxide production technology.
- Eltech Research Corporation; copper foam production technology.
- Electromedia Incorporated; rechargeable oxygen electrode technology.
- MATSI, INC.; zinc-air range battery technology.
- Georgia Power Company; utility-side charging system requirements and interface technology.
- GNB Incorporated; semi-bipolar lead-acid power battery production and recycling technology.

To complete our access to all of the key suppliers and participants for our system, we have initiated discussions with the International Lead Zinc Research Organization (ILZRO) to obtain representation from the primary (mining) and secondary (recycling) producers of zinc and lead.

Clemson's Alternative Automotive Technologies Electric Vehicle Conversion

Authors

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Abstract

Clemson Alternative Automotive Technologies (CAAT) was founded in June 1992. The group converted a 1980 Volkswagen Rabbit using hardware and components donated by race sponsors. A General Electric d.c. motor and controller, twenty six-volt Trojan T-145 batteries, and Goodyear tires were items donated to CAAT and used in the conversion. The performance of the vehicle was enhanced by modifying the original suspension of the Rabbit and manipulating the set-up of the vehicle to compensate for the increase weight of the car.

The Rabbit is nearing completion but has not been road tested; therefore, actual performance data is not available at this time. However, computer simulations have been performed to predict the performance of the vehicle.

Introduction

Since the beginning of the automobile age, electric powered vehicles have maintained a second class role. In the early part of the twentieth century, the invention of the starter made the use of internal combustion engines more convenient and deterred the development of the electric powered automobile. However, due to depletion of natural resources, increased concern for the environment and government legislation (i.e. *The Clean Air Act*), interest in electric vehicles has increased drastically.

In June 1992, Wayne Parker of the Clean Air Vehicle Association (CAVA) contacted the Department of Mechanical Engineering at Clemson University to solicit participation in the Clean Air Conference, Exposition and Grand Prix, an electric vehicle conference and race. In this event college teams compete with electric vehicles in areas of endurance, range, speed, acceleration, appearance, design and presentation.

Clemson Alternative Automotive Technologies (CAAT) was formed by eight undergraduate mechanical engineering students on June 26, 1992 to compete in this event. From this point CAAT has grown to 17 undergraduate mechanical engineering students.

CAAT completed the conversion of a 1980 Volkswagen Rabbit in September 1992. The car was driven by a 28 horsepower d.c. motor coupled to the original 4 speed transmission. Fourteen six volt lead acid batteries powered the vehicle. The vehicle had a top speed of 65 mph and a range of approximately 60 miles.

CAAT worked diligently to have the electric vehicle incorporated into the mechanical engineering curriculum. In the fall of 1992, an experimental section was formed in the senior design course. Three teams worked on projects related to CAAT's electric vehicle: electric vehicle feasibility on the Clemson campus, vehicle dynamic performance design, and power source selection and design. The latter two studies were performed with the goal of improving the electric vehicle for the Clean Air Grand Prix. The reports made specific recommendations based on analysis and experimental data which were instrumental in the development of the current car for the race. This spring, two design teams were assigned to redesign a structural component on the CAAT electric Rabbit using a magnesium alloy to lighten the car and enhance its performance.

In order to prepare for the upcoming race, CAAT has redesigned and nearly completed the conversion of the Rabbit. The details of the conversion design as well as an overview of the entire process are presented in this paper.

Group Organization

For the Clean Air Grand Prix, the 17 members of CAAT were separated into four teams, each sharing a part of the overall responsibility. The group division can be found in Appendix A. The executive coordinator of CAAT serves as the project manager, and a team leader was designated for each subgroup. The team leader's responsibility was to oversee functions within his or her group and report any problems and accomplishments to the executive coordinator. Each team was given a certain amount of freedom with the understanding that all the groups must work closely together to successfully complete the project. The project manager was responsible for making sure the project was on schedule and that each group had the necessary information to design according to both Sports Car Club of America (SCCA) and CAVA requirements.

The four teams worked on different aspects of the electric car design and construction. The team members were assigned to the teams according to individual skills and interests. Following is a list of the four teams and a short description of their responsibilities.

Electrical: Responsible for the selection and wiring of the electrical components, and insuring that all electrical components meet safety and performance requirements. Also responsible for mounting of gages, controller, disconnect switches, watt meter, etc.

Mechanical: Responsible for the mechanical drive of the vehicle, safety of the vehicle, and the adherence to SCCA and CAVA supplemental rules. Also responsible for suspension modifications and other mechanical aspects of the design.

Electrical / Mechanical: Responsible for battery placement and mounting in the vehicle. This group worked as a crossover group between the electrical and mechanical teams.

Public Relations: Responsible for soliciting funding and sponsorship for the project and for informational services.

The above team divisions were chosen in order to ensure that the design and construction of the electric vehicle moved along as smoothly as possible. For the project to be successful, some order and division of responsibility had to be determined. With each team having defined responsibilities, there was a feeling of pride and ownership among each team. The temptation to allow a few others to complete the entire project was avoided.

Finally, this structure allows for some overlapping of responsibilities and mixing of groups. In many situations, the teams could not operate independently. By allowing for flexibility in the teams, the schedules and leisure time of each member was used more effectively.

Design Approach

The objective of this project is to design and construct an electric vehicle to compete in the Clean Air Grand Prix. The conversion is to be performed using the components and hardware provided through CAVA by the race sponsors. The conversion must use a General Electric motor and controller, Trojan batteries, and Goodyear tires. The vehicle must adhere to SCCA Improved Touring Rules and CAVA's supplemental rules.

Preparation

The first step in the design process was to remove the components related to the internal combustion (i.c.) engine. This included the i.c. engine, exhaust system, and fuel tank.

Drive Train

It was decided to use a transmission from a VW Rabbit to simplify the transfer of torque from the electric motor to the vehicle wheels. The transmission selected was a close ratio 5 speed with a final drive of

3.94:1. This transmission was chosen as the best transmission from those available for a 1980 Rabbit. The selection was based on a computer simulation of the electric vehicle's performance on the race course (Abercrombie et al, 1992).

An adaptor plate to connect the electric motor to the transmission was designed and machined from 6061-T6 aluminum. The transmission was used as a template for the machining of this plate.

A motor coupling to connect the motor shaft to the existing flywheel/clutch assembly was designed and machined from AISI 4140. A drawing of this coupling is shown in Figure1.

In order to mount the electric motor in the vehicle, the existing rear motor mount was modified. A bracket was designed to adapt the internal combustion engine mount for use with the GE electric motor. The drawing for the rear motor mount bracket can be seen in Figure 2.

Suspension and Vehicle Dynamics

The suspension was upgraded using a combination of aftermarket motorsport accessories to account for the weight addition associated with the conversion. This task was completed with the aid of the Automotive Performance Systems Research and Development team. The various upgrades included specially valved struts to reduce suspension oscillations due to the drastic increase in unsprung weight. In order to maintain suspension travel, uprated, progressive rate springs were incorporated on the front and the rear for a much more controlled ride.

To reduce vehicle sway, anti-sway bars were added to the front and rear (22mm front and 28mm rear) to produce a car which would be able to be driven at threshold with minimal body roll.

To increase the chassis stiffness and minimize alignment changes, stress bars were added at the front strut mounting points and at the rear shock towers. All suspension bushings were replaced with polyurethane bushings of a higher durometer (85 Shore Hardness) to minimize improper suspension deflections.

To reduce vehicle weight, and increase the vehicle's track. Wheels and tires were upgraded from 13 x 4.5 steel wheels with 155/80R13 tires to 13 x 5.5 alloy wheels and 185/70R13 tires.

Batteries

Perhaps the most crucial aspect of this design was the selection of battery type. The main concerns in this selection were performance, weight and space. Through consultation with an electric vehicle manufacturer and research done at Clemson by CAAT members on energy source performance

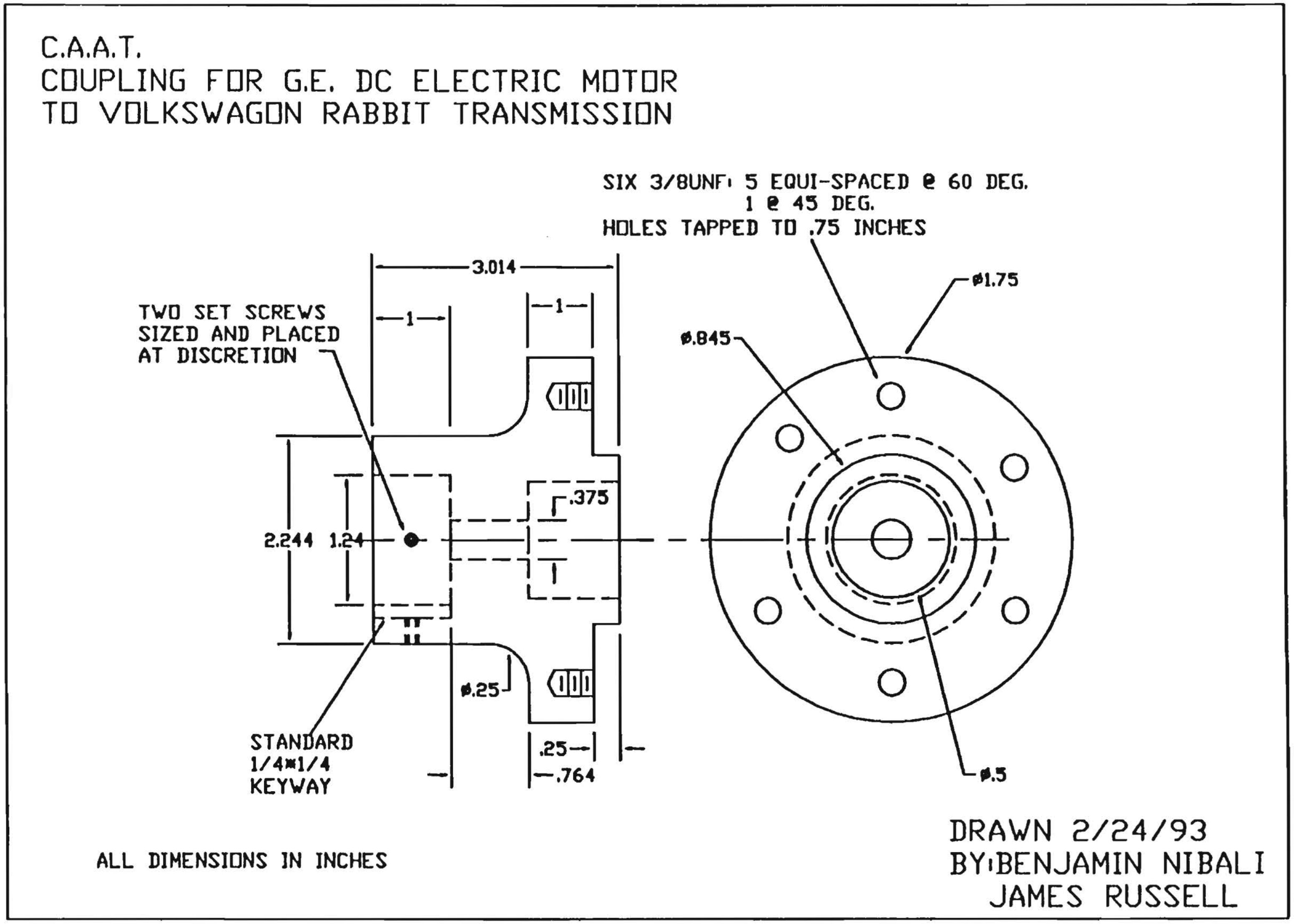


Figure 1: Motor Coupling

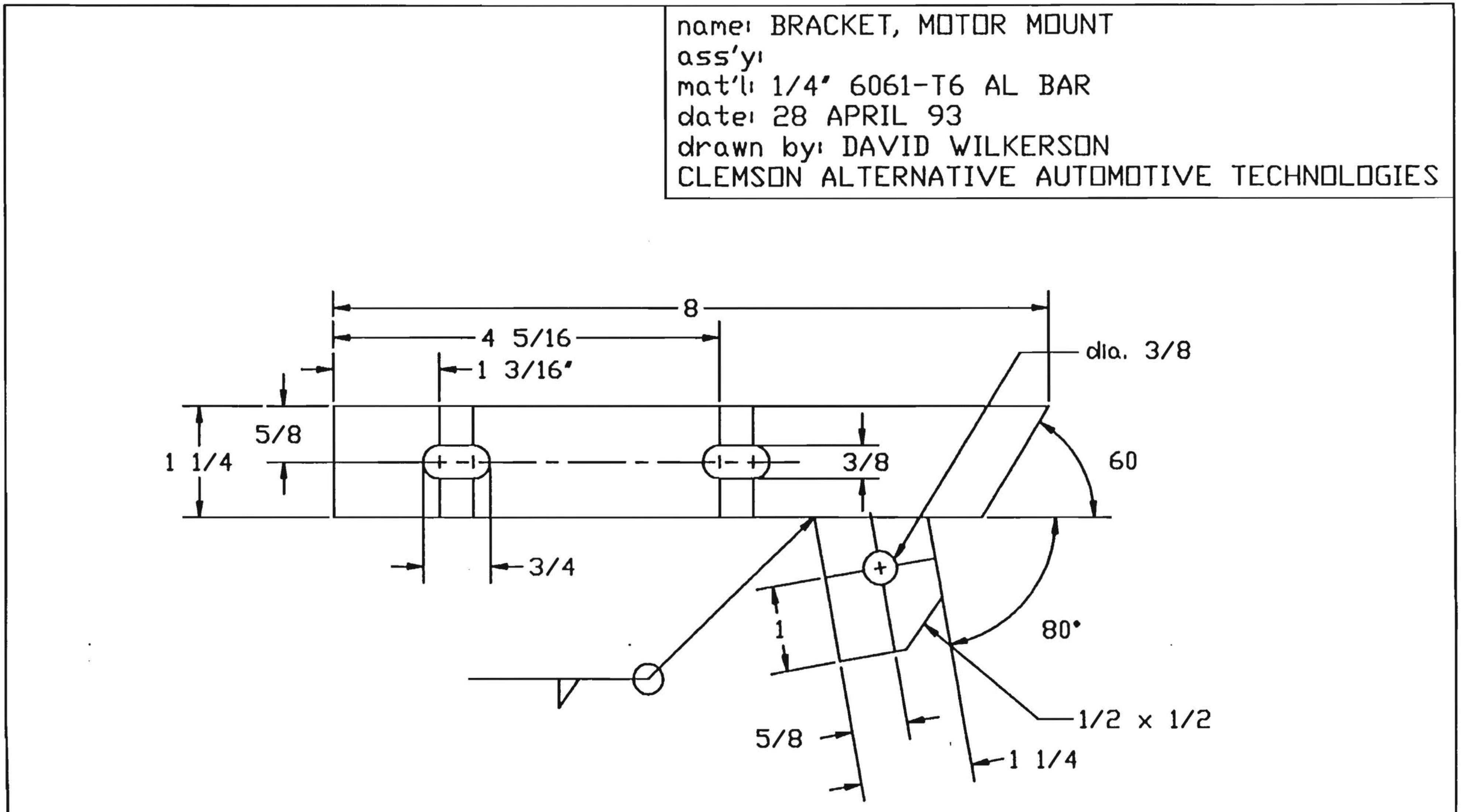


Figure 2: Rear Motor Mount Bracket

(Abercrombie et al, 1992), it was decided to use 20 Trojan T-145 six-volt batteries.

The positioning of these 20 batteries is important in determining the dynamic performance of the vehicle. To ensure a weight distribution similar to that of the original vehicle, it was decided that as many batteries as possible should be located in the motor compartment. The previous CAAT electric car had all the batteries located in the passenger compartment making the vehicle difficult to handle in turns due to extreme understeer (Abercrombie et al, 1992). After taking careful measurements, it was determined that eight batteries would be placed in the motor compartment, and the remaining 12 in the passenger compartment. The batteries in the passenger compartment were located as close to the center of gravity of the vehicle as possible in order to reduce the amount of weight on the back wheels. This positioning of batteries provided a weight distribution of 50/50 (front to rear). Figure 3 shows the car schematically with the center of gravity.

In accordance with the supplemental rules supplied by CAVA, battery boxes were constructed for the batteries. The batteries under the hood are held in place by two frames constructed from steel angle see Figures 4 and 5 for the battery box frames. The frames were secured to the subframe of the vehicle in four locations using 4 1/2" grade 5 bolts.. The motor compartment was itself considered a battery enclosure and ventilated during charging using a 27 CFM 12-volt electric fan (brushless and explosion proof).

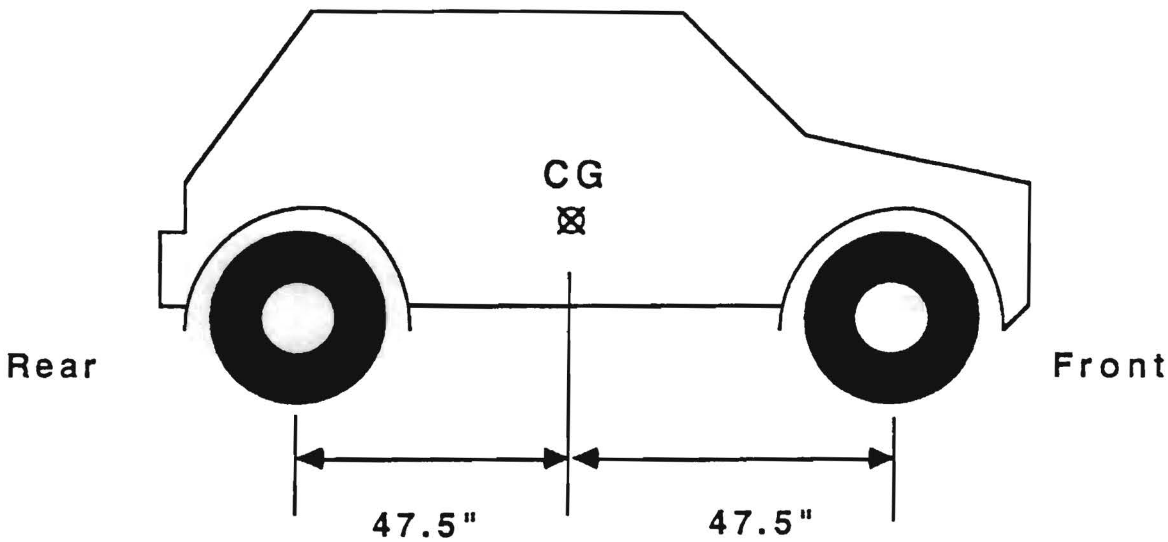
In the passenger compartment, the battery box consist of a frame to secure the batteries and a Plexiglass cover to isolate the driver from the batteries and gases generated during use. Figure 6 shows the rear battery box frame. The frame is mounted to the floor of the vehicle with 5 1/2" grade 5 bolts. This battery box is ventilated using a small 12-volt electric fan (brushless and explosion proof) wired across two batteries in the circuit. A manual switch allows this fan to be controlled by the driver.

Stress analysis was performed on battery box frames and mounts for an impact situation where the car was decelerated from 85 mph to 0 mph in 1 second. A sample calculation of one such stress analysis can be found in Appendix B
.

<u>Electrical Wiring and Component Installation</u>

In the wiring of the vehicle, care was taken to ensure that all the wire and connectors met the specifications set forth by CAVA. The main circuit, which includes the batteries, controller, and motor, was wired in series using 2/0 welding cable. The 20 six volt batteries wired in series provide a total of 120 volts in the circuit. Based on previous

V W Rabbit Center of Gravity



Weight Distribution

Front: 50% (1800 lbs.)
Rear: 50% (1800 lbs.)

Figure 3: Weight Distribution

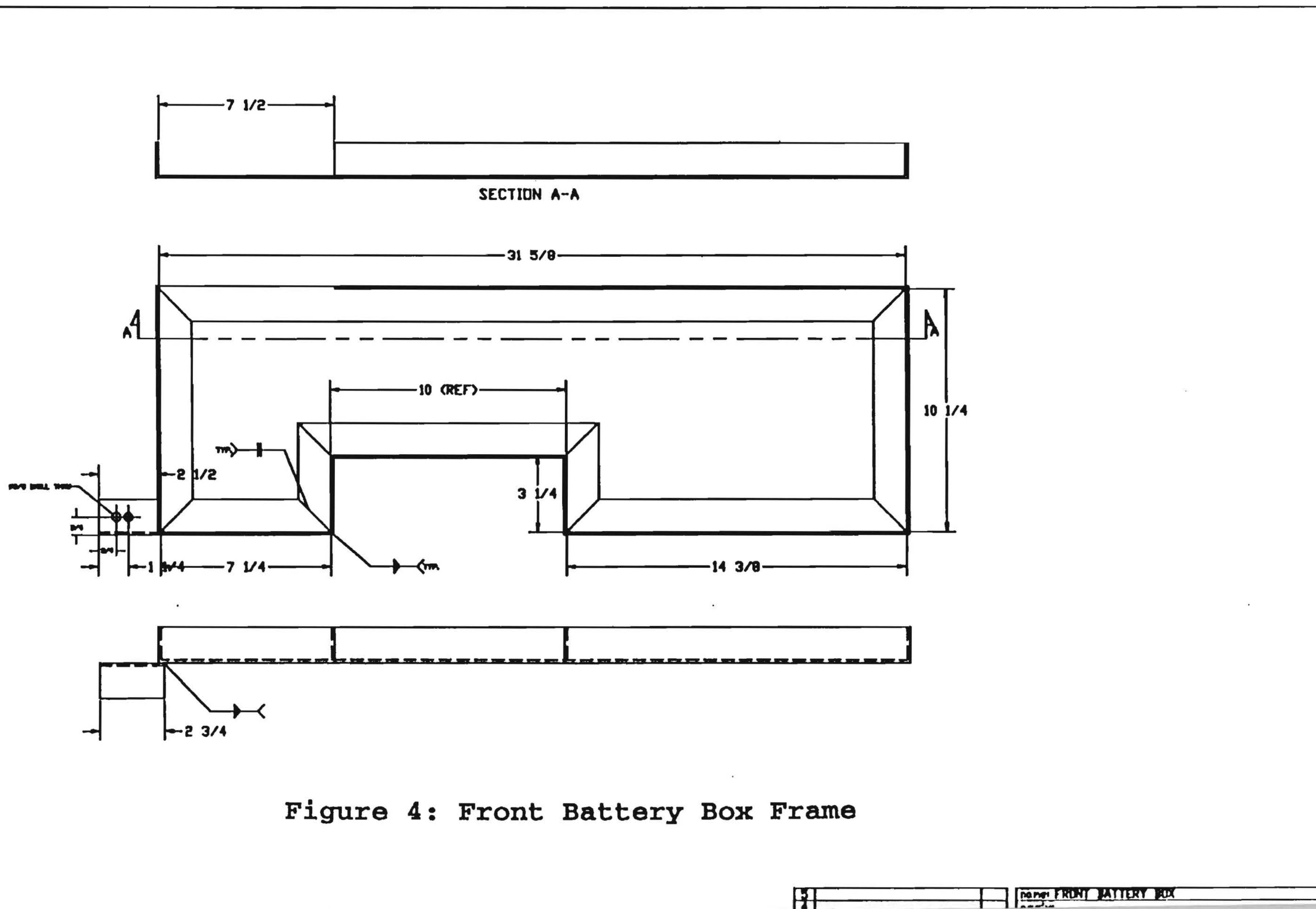


Figure 4: Front Battery Box Frame

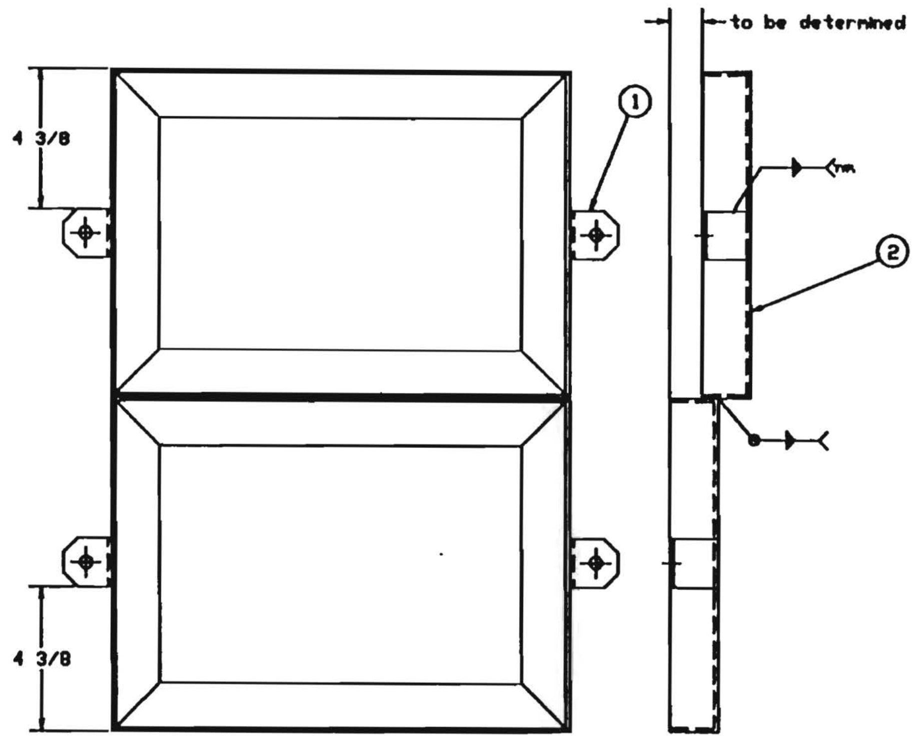


Figure 5: Middle Battery Box Frame

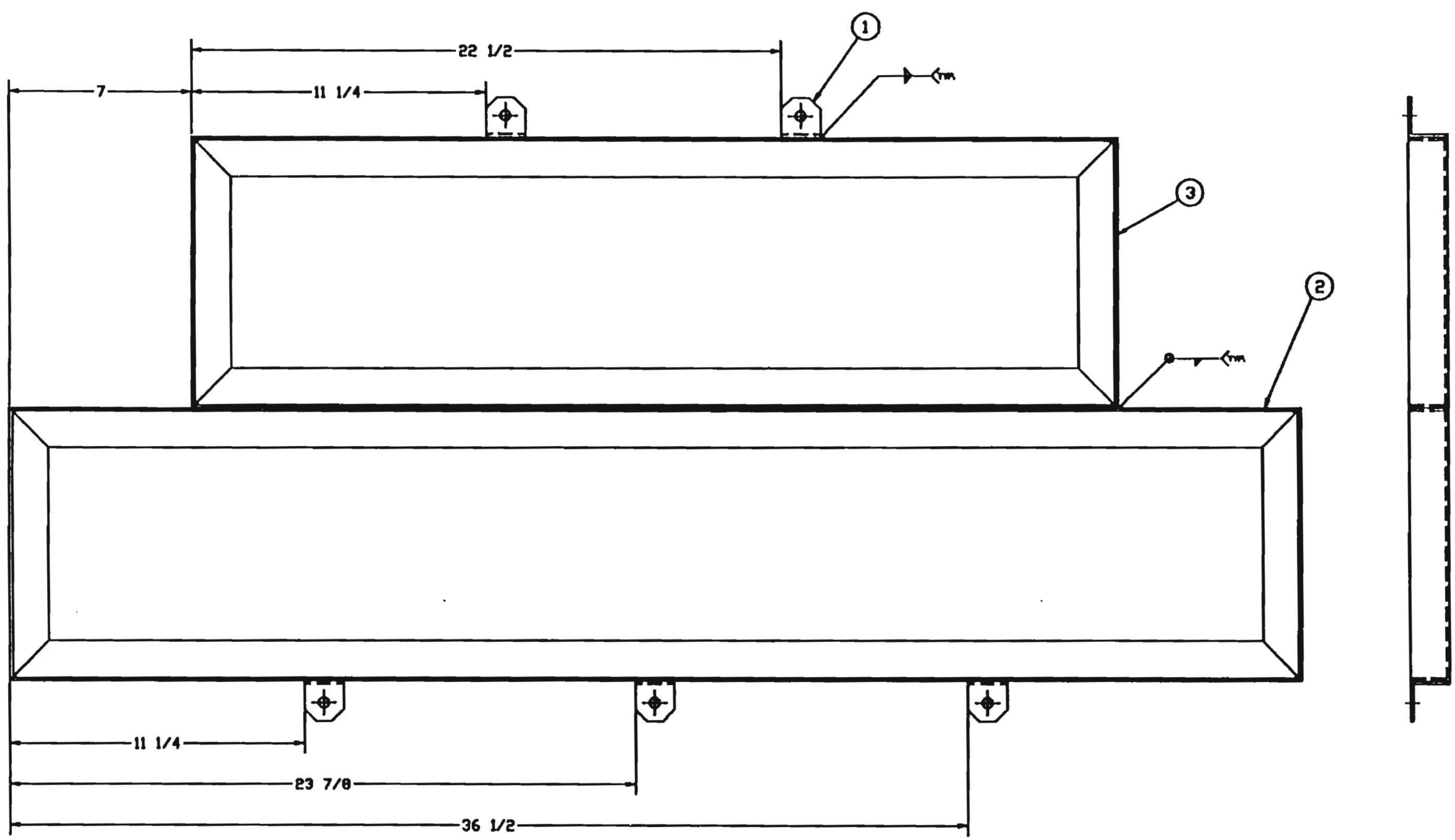


Figure 6: Rear Battery Box Frame

experience in developing electric cars (Batson, 1993) and performing some basic calculations, it was determined that this cable would provide the best performance without compromising safety.

The electrical components include the controller, accelerator, on-board charger, efficiency meter, and disconnect switch. These devices were all mounted with space and convenience in mind.

The controller was mounted behind the passenger seat for ease of modification and repair. A cover was fabricated for the controller for safety reasons.

The accelerator was mounted and connected to the existing 'gas pedal' linkage using a specially designed adaptor. Parts machined for this adaptation are shown in Figures 7, 8, and 9. The accelerator cable connection at the pedal was altered in order to ensure full accelerator travel for full pedal travel.

The watt meter was located behind the rear battery box along with the on-board charger for convenience.

Finally, the disconnect switch was mounted in close proximity to the driver and is accessible from outside the vehicle in case the driver is unable to operate the switch for any reason.

Safety Considerations

Many steps have been taken to ensure the safe operation of the CAAT electric vehicle. The most obvious safety concern is for the driver. The car was equipped with a racing seat and 5-point harness as well as a 6-point SCCA approved roll cage. The driver has been provided with a full flame-retardant racing suit complete with shoes, underwear and helmet. Also, in case of fire an extinguisher has been mounted within arms length of the driver. Care has also been taken to ensure that no dangerous high power equipment or connections are located close to the driver. For the safety of others, all high power connections and sources are clearly marked and covered to avoid the danger of shock.

Vehicle Performance

Because the electric vehicle conversion has not been completed, performance data cannot be provided at this time. However, using the weight, frontal area, tire size and type, and battery pack voltage, a simulation was run to determine the theoretical range of the vehicle. This simulation calculates an approximate range of the vehicle at varying speeds and road grades. At 0% grade the predicted range of the vehicle is 125 miles (Batson, 1993).

A simulation of the vehicle in the speed rase was also conducted. The predicted total race time was

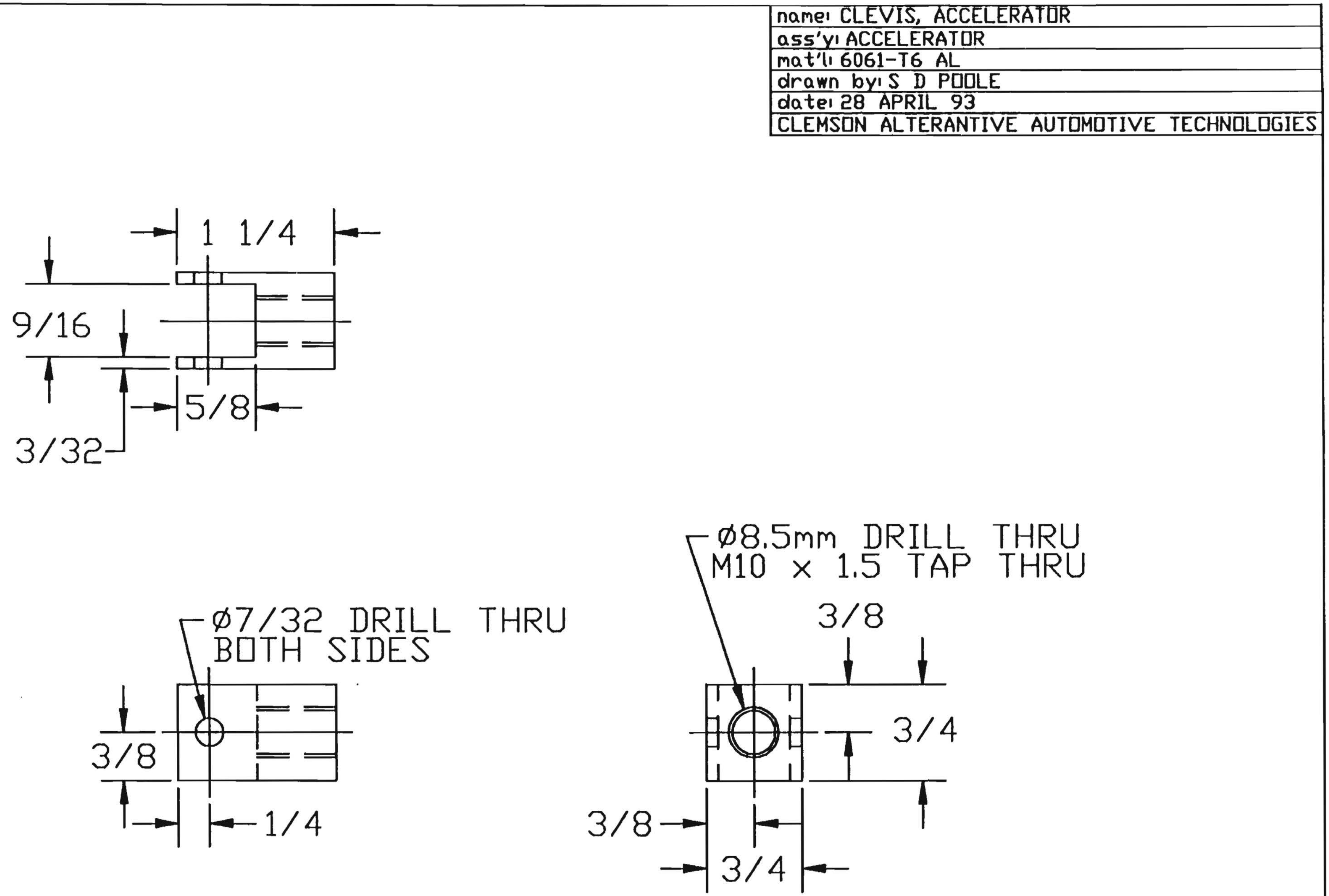
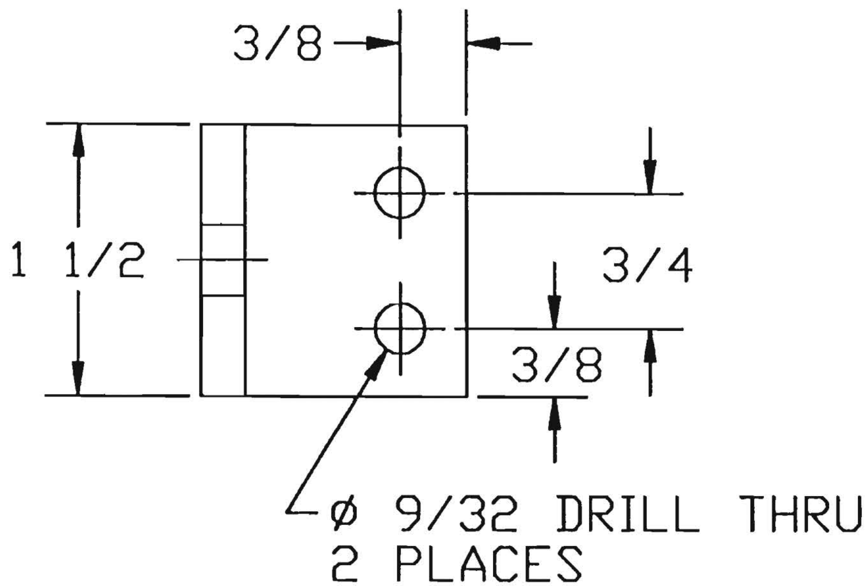


Figure 7: Accelerator Clevis

name: BRACKET, ACCLERATOR CABLE
ass'y: ACCELERATOR
mat'l: 6061-T6 AL angle
drawn by: S D POOLE
date: 28 APRIL 93
CLEMSON ALTERANTIVE AUTOMOTIVE TECHNOLOGIES



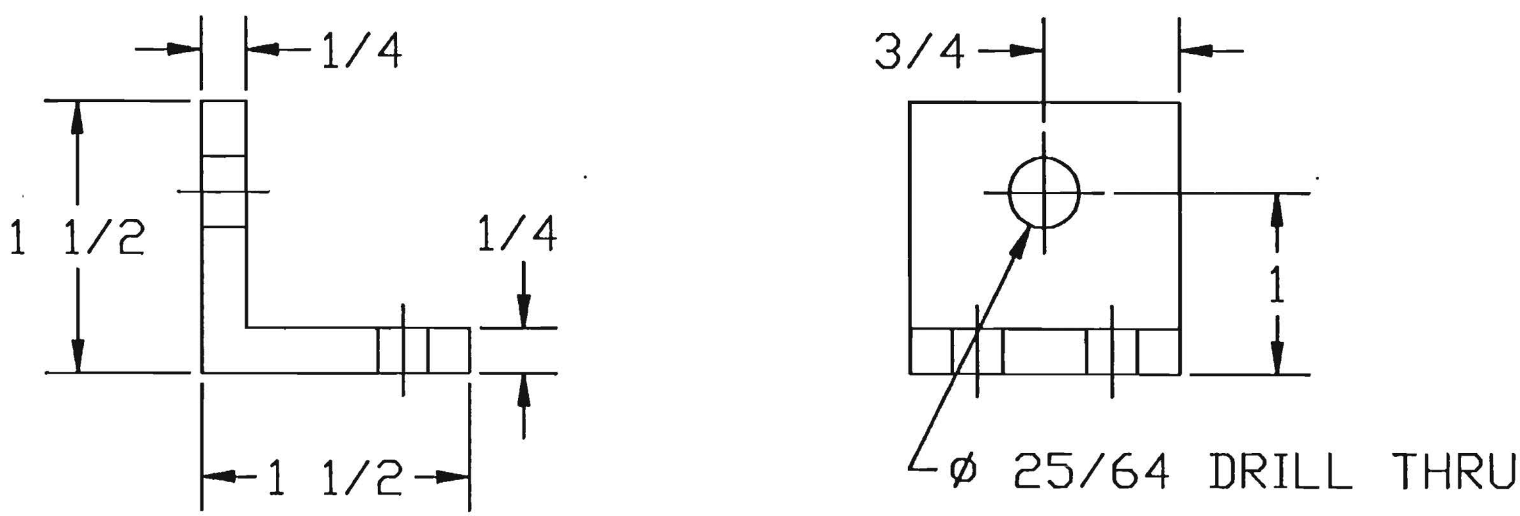


Figure 8: Accelerator Cable Bracket

name:	PLATE, ACCELERATOR
ass'y:	ACCELERATOR
mat'l:	6061-T6 AL
drawn by:	S D POOLE
date:	28 APRIL 93
CLEMSON ALTERANTIVE AUTOMOTIVE TECHNOLOGIES	

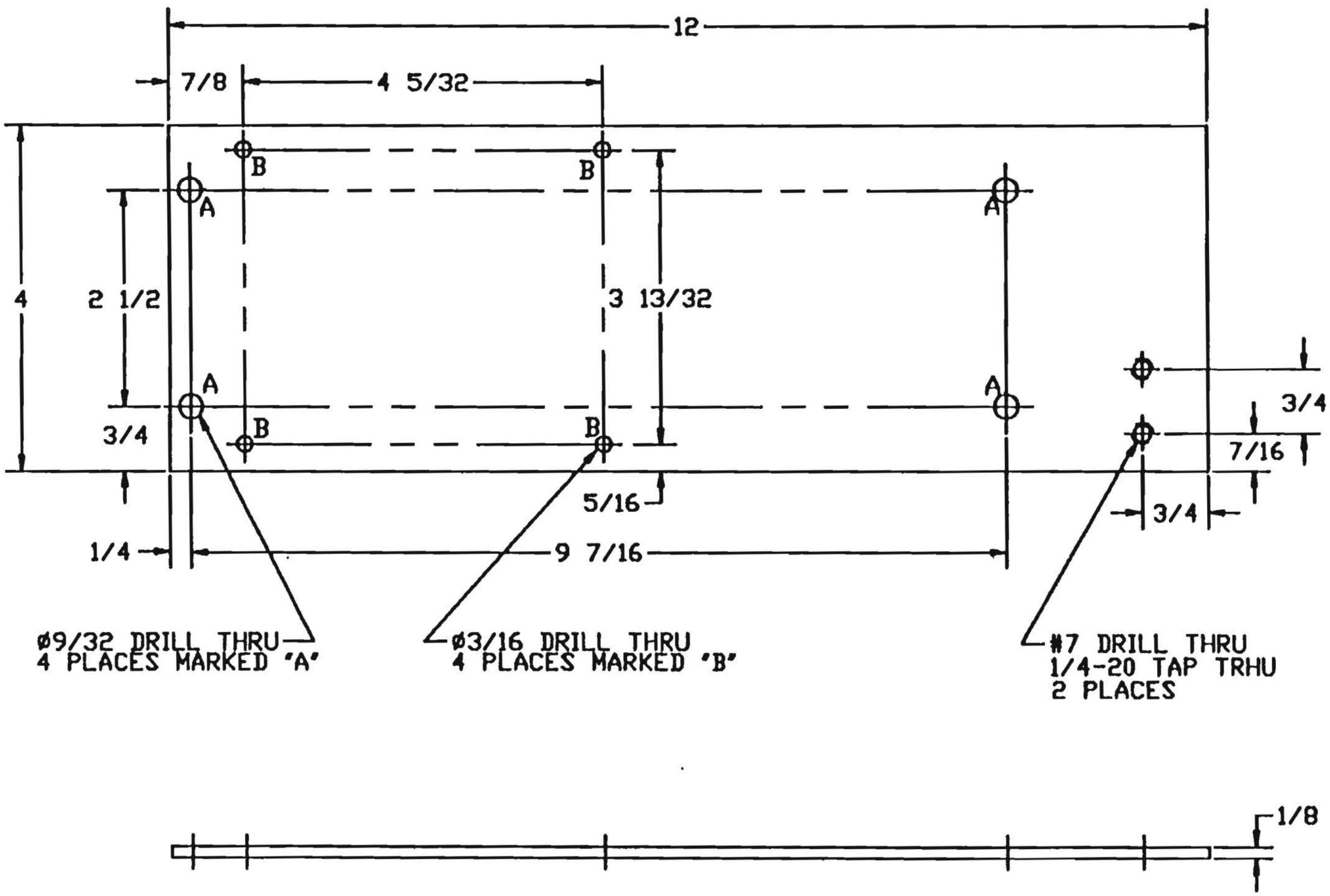


Figure 9: Accelerator Plate

appromimately 315 seconds (Abercrombie, 1992).

Conclusion

The goal of this project was to design and construct an electric vehicle for the Clean Air Grand Prix. As the CAAT electric vehicle nears completion, this objective is almost fully realized. Over the course of this design, several problems associated with electric vehicle conversion have been encountered. As in most electric vehicle conversions, the main problem in this project is the size, weight, and charging time of the batteries. Before widespread use of electric vehicles will be feasible, battery technology must be improved. Other problems such as the current lack of availability of electric vehicle parts and services, the significant costs of conversion, and lack of support infrastructure continue to prevent electric power from being a viable energy source in automobiles. Hopefully, efforts by organizations such as CAVA and CAAT will help eliminate these problems.

Through its involvement with CAVA, CAAT hopes to gain a better understanding of electric vehicles and their performance. One of the primary goals of the group is to help promote the awareness and use of electric vehicles as an alternative to the gasoline power automobiles. The Clean Air Conference and Grand Prix is an excellent means of increasing the public's awareness of alternative power automobiles and possibly dispelling many of the misconceptions associated with electric powered vehicles.

Acknowledgements

Dr. C. E. G. Przirembel, Mechanical Engineering Department Head

Amit Bagchi, Faculty Advisor

College of Engineering

Engineering Services

Mechanical Engineering Faculty

Mechanical Engineering Secretaries

Former members of CAAT
- Trey Thompson
- Steve Miles
- Mike Stiteler
- Mark Coughlin
- Don Abercrombie
- Brian Young

Ken Taylor

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Abercrombie, Doug, Irene Beyerlein, Albert Browder, Mark Coughlin, Michael Stiteler, Chip Tonkin, Eric Wood, and Brian Young; *Efficient Electric Powered Car*; Department of Mechanical Engineering Clemson University; December1992.

Batson, Bob, Electric Vehicles of America, Personal Communication, February 1993 and April 1993

Dillard, Tom, Brad Merrit, Trey Thompson, and Robert David Wilkerson; *Electric Vehicle Feasibility Study*; Department of Mechanical Engineering Clemson University; December 1992.

Appendix A

Group Division

C.A.A.T. GROUP DIVISIONS

<u>Electrical / Electrical</u>
Brad Merritt
Robert Beesley
Derek Brannon
Ken Voronin

<u>Electrical / Mechanical</u>
Brad Gauldin
Todd Gillespie
Brian Sloan
Jay Weaver

<u>Mechanical</u>
Nitin Shanbhag
Ben Nibali
Scott Poole
Jamie Russell

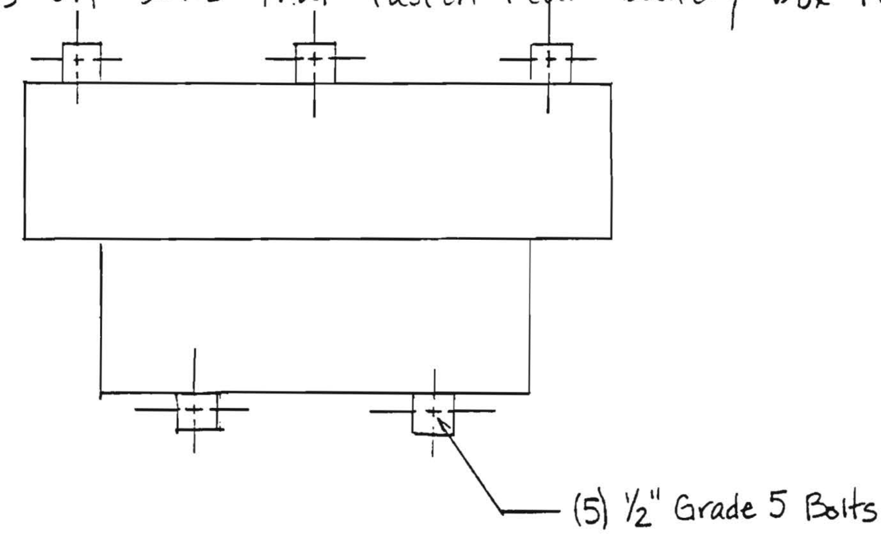
<u>Public Relations</u>
Edie Johnson
Billy Stone
Philip Neal *
April Moore *

Appendix B

Sample Calculation

STRESS ANALYSIS

Stress Analysis on bolts that fasten rear battery box to car



Assume each bolt carries equal portion of load $-(1/5)F$
Assume no friction between battery box and car
Assume loading causes direct shear in each bolt.

$F = ma$ $\qquad$ m - mass of batteries and box = 26.8 slugs

$$a = \frac{\Delta V}{\Delta t} = \frac{85\,\text{m/hr}\left(\frac{5280\,\text{ft}}{1\,\text{m}}\right)\left(\frac{1\,\text{hr}}{3600\,\text{s}}\right) - 0}{1\,\text{s}} = 125\ \text{ft/s}^2$$

$F = 26.8\ \text{slugs}\,(125\ \text{ft/s}^2)$

$F = 3341\ \text{lb}$

τ_{allow} - allowable shear stress $= 0.62\,(S_u)$

S_u - ultimate strength of bolts $= 120\ \text{ksi}$

A - shear plane area of bolt $= \pi r^2$

N - # of bolts

S.F. - Safety Factor

$$\frac{\tau_{allow}}{S.F.} = \frac{F}{N(A)}$$

$$S.F. = \frac{\tau_{allow}(A)(N)}{F} = \frac{0.62(120\ \text{ksi})[\pi(0.25\,\text{in})^2](5)}{3341\ \text{lb}}$$

$$\boxed{S.F. = 22.9}$$

clean air
GRAND PRIX

1993 CLEAN AIR GRAND PRIX

COMPETITION RULES
&
SCORING

Clean Air Vehicle Association, Suite N - 114, 430 Tenth Street, Atlanta, Ga. 30318
Phone: (404)875-4140 / FAX: (404)875-8733

COMPETITION RULES & SCORING

1.0. Safety Inspection: Safety will be of overriding importance during every event of the CAGP. Before any vehicle is allowed to participate in any of the GAGP events, it must pass a thorough safety inspection. The vehicle will receive a "Full Inspection" as described in Section 13 of the SCCA Club Racing General Competition Rules and Appendix A1 of this document. If any item is found deficient during the Safety Inspection, the team will be provided with a written description of the deficiency and the team will be required to remedy it before they can compete in any of the events. Each team will be allowed one reinspection to demonstrate all safety items pass inspection. It is the responsibility of the team to address all safety items at their cost. If teams have any questions about whether a feature on their vehicle is consistent with the intent of the Safety Guidelines, they are encouraged to submit a written request for interpretation from CAVA.

NO POINTS ....TEAMS MUST PASS TO PARTICIPATE !

2.0. Progress Report: All teams must submit an interim progress report not later than February 28, 1993. This report should include information about your critical path or other type of schedule and how actual progress compares. The report should also include a vehicle description that presents information such as make, model, weight, suspension and battery charger. Vehicle specification data may be presented in a tabular format. The Progress Report should be no more than five pages in length and may include photographs or slides. The paper judging form may be found in Appendix A2.

100 POINTS AVAILABLE;
SCORING: YOUR SCORE / BEST SCORE x 100 = YOUR POINTS

3.0 DESIGN

3.1. **Written Design Report:** All teams must submit a written report describing the electric vehicle conversion. The report should include information on the design process, innovative use of new and existing technology, vehicle testing and a chronological description of the construction process. Engineering drawings should be provided as needed to describe the design. Photographs, slides and video tape may also be used if desired. The written paper's organization should conform to SAE technical paper format. The paper should be seven pages in length. Ten copies of the Conversion Report must be received by CAVA by April 30, 1993. Late papers will not be judged and team will receive no points for this event. The paper must be signed by the faculty advisor prior to submittal. Paper judging forms may be found in Appendix A3.

300 POINTS AVAILABLE;
SCORING: YOUR SCORE / BEST SCORE x 175 = YOUR POINTS

3.2. **Oral Design Presentation:** Each team must make a ten minute oral presentation of their design and approach to the electric vehicle conversion. The rationale your team used to address practicality, driveability, efficiency and performance are issues that should be presented. Your presentation should be an attempt to convince the judges that your team did the best design job and your conversion should be put into production. Visual aids are recommended. A five minute question and answer session will follow the presentation. Oral judging forms may be found as Appendix A4.

300 POINTS AVAILABLE;
SCORING: YOUR SCORE / BEST SCORE x 150 = YOUR POINTS

3.3. **Execution of Design:** A panel of industry and government experts will judge each vehicle conversion on areas such as conformance to design documentation, quality of conversion component fit and finish, integration into the existing vehicle, production feasibility and overall quality and appearance. Teams must designate two representatives to answer questions from the judges. No other team members will be allowed to participate in the Execution of Design event judging. Execution of Design judging forms may be found as Appendix A5.

400 POINTS AVAILABLE;
SCORING: YOUR SCORE / BEST SCORE x 100 = YOUR POINTS

4.0. PERFORMANCE

4.1 **Solo Elapsed Time:** (May 14, 1993) After each team has had a short practice session their vehicle will be timed from a standing start to the completion of five laps around the infield section of Atlanta Motor Speedway's road course. Each team will be on the track separately. The course is approximately three quarters of a mile long and has a total grade change of eight feet. The lowest elapsed time will be the be the event winner.

100 POINTS AVAILABLE;
SCORING: BEST TIME / YOUR TIME x 200 = YOUR POINTS

4.2. **Acceleration:** (May 14, 1992) Vehicles will be timed from the standing start of the Solo Elapsed Time Event over the first one eighth of a mile. Each vehicle will continue on to the completion of the five laps of the Solo Elapsed Time Event. The lowest elapsed time for the first one eighth mile will be the winner.

100 POINTS AVAILABLE;
SCORING: BEST TIME / YOUR TIME x 100 = YOUR POINTS

4.2. **Endurance:** (May 15, 1993) The Endurance event will be run the next day after the Top Speed event. Vehicles must be run in the same configuration in both events. All teams will be on the track in head to head competition. Each vehicle will be timed and will be flagged from the track when their average lap speed falls below thirty five miles per hour. The team that goes the longest distance will be the winner.

200 POINTS AVAILABLE;
SCORING: YOUR DISTANCE / BEST DISTANCE x 300 = YOUR POINTS

4.3. **Efficiency:** (May 15, 1993) Each team will have a recording Watt-hour meter installed in their vehicle. Each vehicle's Watt-hour meter will be set to zero and sealed before the start of the endurance event. The total Watt-hours of energy used during the Endurance track event will be used to determine the energy consumed. The energy consumed will be read directly from the vehicle's Watt-hour meter. Thus, the definition of Efficiency for this event becomes:

EFFICIENCY = Watt-hours per mile (energy used / distance traveled)

200 POINTS AVAILABLE;
SCORING: LOWEST CONSUMPTION / YOUR CONSUMPTION x 200 = YOUR POINTS

5.0. EDUCATION: A major focus of the Clean Air Grand Prix is to increase public awareness and understanding of clean air vehicles. Each team will be judged on its Education achievements. The areas of interest include, your team's learning experience, quantity of outside publicity generated and documented and the best and most widely disseminated media story. A panel of judges will review the team's portfolio and score them based on both quantity and quality of media attention. It would be good to keep circulation figures for print media. Education judging forms may be found as Appendix A6.

250 POINTS AVAILABLE;
SCORING: BEST SCORE / YOUR SCORE x 250 = YOUR POINTS

clean air
GRAND PRIX

1993 CLEAN AIR GRAND PRIX

COMPETITION RESULTS

Clean Air Vehicle Association, Suite N - 114, 430 Tenth Street, Atlanta, Ga. 30318
Phone: (404)875-4140 / FAX: (404)875-8733

1993 GRAND PRIX COMPETITION RESULTS

OVERALL STANDINGS

1 University of Central Florida
2 Clemson University
3 Daytona Beach Community College
4 Kentucky Advanced Technology Center
5 Kentucky Tech/Ashland
6 Berea College
7 Louisiana Tech
8 Fort Valley State College
9 Duke University
10 Alcorn State University
11 Georgia Tech

RANGE (Saturday's race)

1 Central Fla.	2 Ky. Tech	3 La. Tech

WRITTEN REPORTS

1 Clemson	2 KATC	3 Daytona

ORAL PRESENTATIONS (top 2 presented to entire conference)

1 La. Tech	2 Berea	3 Clemson

DESIGN

1 Daytona	2 Ky. Tech	3 Central Fla.

ACCELERATION (1/8 mile from standing start)

1 Central Fla.	2 KATC	3 Berea

SOLO (best time - 5 laps)

1 Central Fla.	2 Clemson	3 Berea

EFFICIENCY

1 FVSC	2 KATC	3 Central Fla.

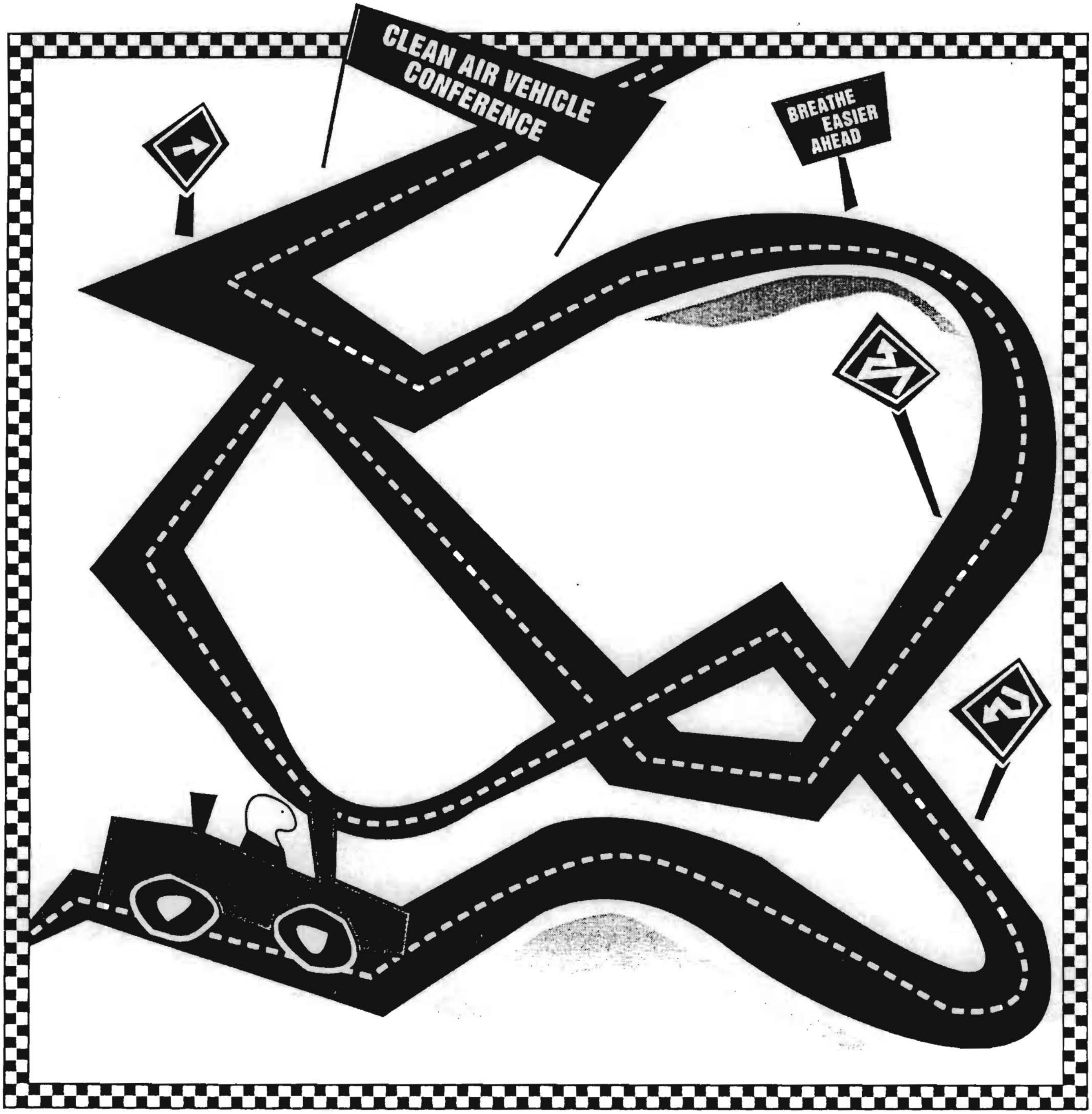
BEST TEAMWORK AWARD

Berea

AGAINST ALL ODDS AWARD

Fort Valley

Clean Air Vehicle Conference, Exposition & Grand Prix



Paving The Way For Tomorrow's Clean Air

May 13-15, 1993
Atlanta Marriott Marquis

Clean Air Vehicle

ASSOCIATION

Dear Friend,

We are pleased to welcome you to the inaugural Clean Air Vehicle Conference, Exposition & Grand Prix. May is National Clean Air Month, and what better way to celebrate than learning more about the fuels which can be used in vehicles to improve air quality and energy independence!

We are beginning a new era in transportation. The combined **Clean Air Vehicle Conference & Exposition** is providing a catalyst for increased use of clean air fuels. Fleet managers and administrators will be able to make more informed decisions about the use of clean air vehicles. Government and industry leaders will receive assistance as they continue to develop effective programs and initiatives for the future of clean air transportation. The conference and exposition are fuel-neutral, providing an open forum to evaluate applications for each clean air fuel.

The goal of the **Clean Air Grand Prix** is to give students a chance to work hands on with clean air vehicles. Electric vehicles were chosen as this year's fuel type because of their unique conversion characteristics and the aggressive research and development occurring with batteries and vehicle design.

We express our appreciation to the many people and organizations who have made this possible. These events are the culmination of the first year of the Clean Air Vehicle Association (CAVA), an Atlanta-based non-profit organization founded on the Georgia Tech campus. The mission of CAVA is to develop educational programs which will promote the use of cleaner vehicle fuels.

Clearly, such ambitious multiple events as a conference, exposition and grand prix in our first year would not have been possible without the support and time of the many sponsors and supporters shown on the following pages. Many people provided help above and beyond expectations, and for that we are grateful.

Thank you for being part of these special events!

Sincerely,

Wayne Parker
General Manager

14 Piedmont Center Suite 1205 Atlanta, Georgia 30305
Phone: (404) 237-1980 / FAX: (404) 237-2228

Department of Energy
Atlanta Support Office
Suite 876
730 Peachtree Street, N.E.
Atlanta, Georgia 30308

DEPARTMENT OF ENERGY WELCOMES PARTICIPANTS

On behalf of the U.S. Department of Energy, I would like to thank you for the interest you have shown for alternative motor fuels and vehicles by participating in this inaugural Clean Air Conference, Exposition and Grand Prix. A great deal of time, effort and resources have been exerted by the Clean Air Vehicle Association to make this one of the first programs combining a conference and exposition with student competition. We hope this regional program will continue and expand in future years.

The 1994 budget request for the Department of Energy reflects the Clinton administration's goal of creating clean sources of energy, enhancing energy efficiency, protecting the environment and utilizing DOE's laboratories and other assets to create jobs. This Conference represents a commitment to looking for ways to accelerate the acceptance of domestic and cleaner burning alternative motor fuels.

This program provides all participants with current and accurate information about alternative fuels, vehicles and supporting infrastructure. After you depart I am certain that many of you will have additional need for assistance or information. Please contact me or Charles Feltus at 730 Peachtree Street, Atlanta, GA 30308 (404)347-2380) for assistance or call the National Alternative Fuels Hotline for Transportation Technologies at 1-(800)423-1363.

Sincerely,

Buddy L. Jackson
Director

Clean Air Vehicle Association

Mission

The mission of the Clean Air Vehicle Association (CAVA) is to improve air quality and national energy independence by increasing the use of clean air (alternative fuel) vehicles. The methods for doing this include:

- Increase the awareness and understanding of clean air vehicles with educational programs and products
- Arrange conferences, competitions and demonstrations which show performance and focus attention on clean air vehicles
- Encourage increased availability of clean air vehicles and the infrastructure to support them
- Advocate and encourage improvements or additions to relevant federal and state legislation and regulations

History

The Clean Air Vehicle Association is a not-for-profit corporation formed in Atlanta in early 1992.

Personnel

The Board of CAVA includes Mr. Dean Alford, President of A&C Enercom and a former member of the Georgia House of Representatives; Dr. Michael Meyer, Professor of Civil Engineering and Director of the Georgia Tech Transportation Research and Education Center; Mr Mark Zwecker, President of EPTI, a battery research and development firm, and former Director of the Georgia Office of Energy Resources. The President and co-founder of CAVA is Mr. Lowell Evjen, President of Southern Technology Ventures, Inc. and founder and President of the Georgia Stadium Corporation, original developer of the Georgia Dome; the other co-founder, and General Manager of CAVA, is Mr. Wayne Parker, former Associate Vice President at Georgia Tech and a marketing specialist who also has extensive experience in environmental and energy issues. CAVA's staff includes Mr. Malcolm Durden, Manager of the Clean Air Grand Prix; Mr. Kent Igleheart, Conference Coordinator and Ms. Betty Rainwater, Director of Marketing.

Contents of the Clean Air Vehicle Conference, Exposition & Grand Prix Program

Clean Air Vehicle Conference Exposition & Grand Prix

Hosts

Clean Air Vehicle Association

in conjunction with

A&C Enercom

CleanAir Transportation-Atlanta

Georgia Tech Transportation Research & Education Center

Sponsors

Amoco Oil Company

Atlanta Gas Light

Blue Bird Corporation

Ford Motor Company

Georgia Department of Natural Resources

Georgia Power

LP Clean Fuels Coalition

U.S. Department of Energy/Atlanta Support Office

U.S. Federal Highway Administration

Supporters

Apple Computer

Argonne National Laboratory

Atlanta Motor Speedway

Duke Power Company

Florida Power & Light

General Electric

GM Hughes Electronics/
Hughes Power Control Systems

Goodyear Tire & Rubber Company

Manheim Auctions

National Association of Fleet Administrators

NGV Coalition

Southern Gas Association

Southern States Energy Board

Thomas Built Buses

Trojan Battery Company

CleanAir Transportation--Atlanta

730 PEACHTREE STREET, SUITE 876, ATLANTA, GEORGIA 30308

Jeffrey A. Rader, Chairman
(404) 586-8467

Buddy L. Jackson, Vice Chairman
(404) 347-2837

Mr. Wayne Parker
General Manager
Clean Air Vehicle Association
14 Piedmont Center
Suite 1205
Atlanta, Georgia 30305

Dear Wayne:

Clean Air Transportation-Atlanta is pleased to provide support for the first Clean Air Vehicle Conference in Atlanta. It is fitting that the conference is being held here in Atlanta, the model for the U.S. Department of Energy's Clean Cities Program.

Clean Air Transportation-Atlanta was formed in 1992 to facilitate an extensive demonstration of the market potential for alternative fueled vehicles in the metropolitan fleet. By attaining a "critical mass" in public and private sector alternative fueled fleets, a basic network of service and refueling infrastructure for these vehicles may be supported. With this infrastructure in place, the natural advantages of alternative fuels can command their rightful place in the market.

In addition to the Conference, Clean Air Transportation-Atlanta is also supporting a variety of efforts to heighten the profile of alternative fuels in the region. In coordination with fuel-specific working groups, Clean Air Transportation-Atlanta hopes to make alternative fueled vehicles pervasive in metro Atlanta in time for the 1996 Olympics.

Again, Clean Air Transportation-Atlanta welcomes the alternative fuels community and fleet operators to Atlanta for this important event. We hope that each of you will return home with alternative fuels firmly in your future.

Sincerely,

Jeffrey A. Rader
Chairman, Clean Air Transportation-Atlanta
Manager, Transportation Programs
Atlanta Chamber of Commerce

JAR:kb

An Alternative Fuel and Vehicle Coalition
Dedicated to Cleaner Air for Atlanta and Energy Security for America

Clean Air Vehicle Conference, Exposition & Grand Prix

Thursday, May 13, 1993

8:30 a.m.	**Welcome** Joe Tanner, Commissioner, Georgia Department of Natural Resources Bobby Rowan, Commissioner, Georgia Public Service Commission
9:00 a.m.	**Keynote Address-Federal Requirements** Introduction: Charlie J. Lail, Senior Vice President of Divisions, Atlanta Gas Light Susan Tierney, Assistant Secretary for Domestic and International Policy, U.S. Department of Energy Panel Discussion: Jeff Rader, Chairman, CAT-Atlanta Buddy Jackson, Director, Region IV DOE Office
10:00 a.m.	**Coffee Break** - Exposition Area
10:30 a.m.	**State Response** Paul Wuebben, Clean Fuels Officer, South Coast Air Quality Management District Carlton Bell, Executive Assistant, Texas General Land Office Dr. Michael Meyer, Director, Transportation Research & Education Center, Georgia Tech
11:45 a.m.	**Lunch** - Area Restaurants - Visit Exposition
1:45 p.m.	**Automotive Industry Response** Harvey Klein, Manager, Engineering & Planning, Ford Motor Company Gery Jankovits, Commercial/Specialty Group, Chevrolet Paul Glaske, President, Blue Bird Corp.
2:45 p.m.	**Break** - Visit Exposition
3:15 p.m.	**Fuel Industry Response** Bruce Cotterman, Business Development Manager, Amoco Larry O'Connell, Manager, Technical Support, Electric Power Research Institute (EPRI) Terry Wyatt, Chairman, Chairman, Engine Power Committee, National Propane Gas Association (NPGA)
4:15 p.m.	**Clean Air Grand Prix Preview** Student Team Presentation & Awards by Gale Klappa, Senior Vice President, Marketing, Georgia Power Robert Larsen, Argonne National Laboratory
5-7 p.m.	**Reception** - Exposition Area

Friday, May 14, 1993

8:30 a.m. **Opening Remarks**

8:45 a.m. **Economics** - Buying & Operating
Harold Idell, Senior Manager, Federal Express Corporation
Bill Gallagher, Director, Consulting Services, GE Capital
Robert Hall, Automotive Engineering, UPS

9:45 a.m. **Coffee Break** - Exposition Area

10:15 a.m. **Refueling & Conversions**
Dennis Smith, Director, Energy Services, Atlanta Gas Light
Tony Harris, Manager, Clean Air Vehicle Market Development, Pacific Gas & Electric
Allan Potter, Alternate Fuel Specialist, Manchester Tank

11:15 a.m. **Olympic Transportation** - 1996
Russ Chandler, Executive Director, 1996 Olympic Village

11:45 a.m. **Lunch** - Area Restaurants - Visit Exposition

1:30 p.m. **Fleet Operators Experiences** (Concurrent)
Cars & Trucks—
B.J. Smith, U.S. Postal Service
Michael Joyner, City of Savannah, Georgia
Lt. John Firmes, Lee County, Florida
Buses—
Mike McClung, Northside School District, San Antonio
John Capell, City of Chattanooga, Tennessee;
Don Francis, Electric Vehicle Program, Georgia Power Co.

3:00 p.m. **Site Visits**-Whitehall Natural Gas Refueling Station and Amoco Station
Transportation courtesy Blue Bird natural gas buses

Saturday, May 15, 1993

9:00 a.m. - Noon
Clean Air Grand Prix - Student Competition
Atlanta Motor Speedway

The first Clean Air Vehicle Exposition provides a close-up look at the clean air vehicles of today and tomorrow. Open to the public, it is held in the Atlanta Marriott Marquis, just one floor down from the Clean Air Vehicle Conference. Vehicles displayed include cars, trucks, vans, buses and a 1929 Roadster, all powered by clean fuels such as natural gas, propane or electricity. The exhibitors are listed at right:

Exhibitors

AA Technologies
A & C Ener com
Amoco Oil Company
Atlanta Gas Light
Blue Bird Corp.
Bowgen Fuel Systems
Chevrolet Motor Division
Combustion Labs
CP Industries
Ford Motor Company
General Electric
Georgia Power
Goodyear Tire & Rubber
General Services Administration
GMC Trucks
GM Hughes Electr onics/Hughes Power Control Systems
LP Clean Fuels Coalition
Manheim Auctions
Marcum Corp.
Moulden Supply
MVE Cryogenics
NGV Coalition
Nupro Technologies
Petroleum Source
Pressed Steel Tank Co.
Squibb-Taylor
Staubli Corp.
Thomas Built Buses
Trojan Battery Company
Clean Air Grand Prix Student V ehicles

Conference Participants Pioneer Use of Alternative Fuels

Clean air vehicle fuels such as natural gas, propane and electricity can significantly reduce air pollution, operating costs and dependence on foreign oil, and can improve safety. The following provides a brief background on these fuels and the sponsors of the Clean Air Vehicle Conference who are pioneering their use for transportation.

Natural Gas

Atlanta Gas Light and Amoco Oil Company are both Sponsors of the Conference and Exposition, and have both made major commitments to a natural gas future for transportation in the South. Both public and private natural gas refueling stations are opening across the Southeast. Amoco has already added natural gas dispensers to two of its Atlanta stations, with plans for more in 1993. This will allow a natural gas vehicle anywhere in metropolitan Atlanta to be within 20 minutes of an Amoco refueling station. A dedicated business unit has been formed by Amoco to market natural gas as a transportation fuel throughout the U.S. and internationally, and the company supports the goal of 10,000 natural gas vehicles in use in Atlanta by the time of the Olympics in 1996.

Atlanta Gas Light, which operates one of the largest fleets of natural gas vehicles in the country, is now promoting the idea to other fleet operators throughout its service area in Georgia and Tennessee. New customers beginning to use natural gas in their fleets include ADT Security, the City of Atlanta, Bell South, Derst Baking Company, Fort Gordon and many others. Atlanta Gas Light is also a partner in the new Natural Gas Vehicle Southeast Technology Center, which will open soon to convert vehicles of all kinds to run on natural gas. A free video is available on natural gas vehicles by calling 404/584-3800.

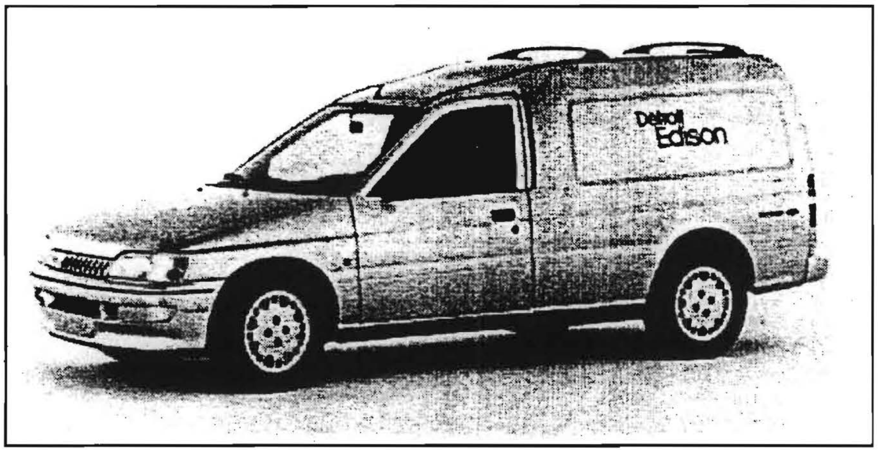
The Conference and Exposition are also supported by the Southern Gas Association and the NGV Coalition. At the Exposition, look for a natural gas Ford Crown Victoria, pickup trucks, the chassis of a natural gas school bus from Blue Bird Corporation, and many other displays of natural gas equipment. Also, Mike Joyner of the City of Savannah will be speaking during the conference about their experience using natural gas in police cars, and a representative of the U.S. Post Office will be talking about natural gas as a delivery vehicle fuel.

Ford Motor Company and several gas utility companies are evaluating a demonstration fleet of Ford Crown Victoria passenger cars powered by natural gas. "We're delighted to team up with these utilities to evaluate the Crown Victoria and help further our development of this alternative fuel system," said Harvey Klein, manager of Ford's Alternative Fuels Engineering and Planning activity, and a featured speaker at the Conference on Thursday, May 13.

The cars in the Ford test fleet will be dedicated natural gas vehicles (NGV's) operating solely on natural gas. The engines have an increased compression ratio to take advantage of the very high octane rating of natural gas for maximum power and economy. Four natural gas cylinders, located in the rear axle area, will replace the gasoline tank.

"Our goal," added Klein, "is to provide natural gas vehicles that have quality and performance equal or superior to gasoline-powered vehicles."

In a similar program conducted from 1984 through 1989, Ford Ranger trucks were driven more than



Ford's Ecostar electric van has a range of 100 miles in city driving and a top speed of 70-75 miles per hour.

1,000,000 miles and experienced virtually no operating difficulties.

Natural Gas is also being used to power buses, and Georgia's own Blue Bird Corporation is leading the way. As the nation's largest bus manufacturer, Blue Bird has supplied natural gas powered buses to a number of school districts and for other uses. We are honored to have Paul Glaske, President of the Blue Bird Corporation, as a featured speaker at the Conference.

Propane

The LP Clean Fuels Coalition is a Sponsor of the Conference and Exposition, in conjunction with the National Propane Gas Association and the Georgia Propane Gas Association. Vehicles have been using propane since the 1920's, and today there are more than 350,000 vehicles powered by propane in the U.S. On exhibit you will see propane-powered automobiles, including a 1929 Roadster and a law enforcement vehicle driven by the Lee County, Florida Sheriff's Department.

At the Clean Air Vehicle Exposition you can talk to propane equipment suppliers about the refueling and conversion characteristics of propane. The City of Claremont, California is one of the cities using propane for its police cars. Police Chief Robert Moody comments that "Reports from officers are excellent. We're really excited over the cost savings we'll see when the whole fleet is converted. All the tests were very positive—just as good as gasoline".

Ford Motor Company is also the only American manufacturer offering a factory-warranted production medium duty truck that uses liquified petroleum gas (LPG or propane), while meeting both the rigid California emission standards and federal clean-air amendments.

Peter Hubbard, the Ford Powertrain Planning supervisor who led the team which developed the new system, says "Besides being environmentally friendly, the Ford LPG trucks have a tremendous advantage for our customers since they are offered with factory limited warranties identical to the 7.0 liter gasoline versions."

Blue Bird Corporation has also supplied school buses powered by propane, and Mike McClung of the Northside School District in San Antonio, Texas will be speaking at the Conference about their experience with this clean air fuel.

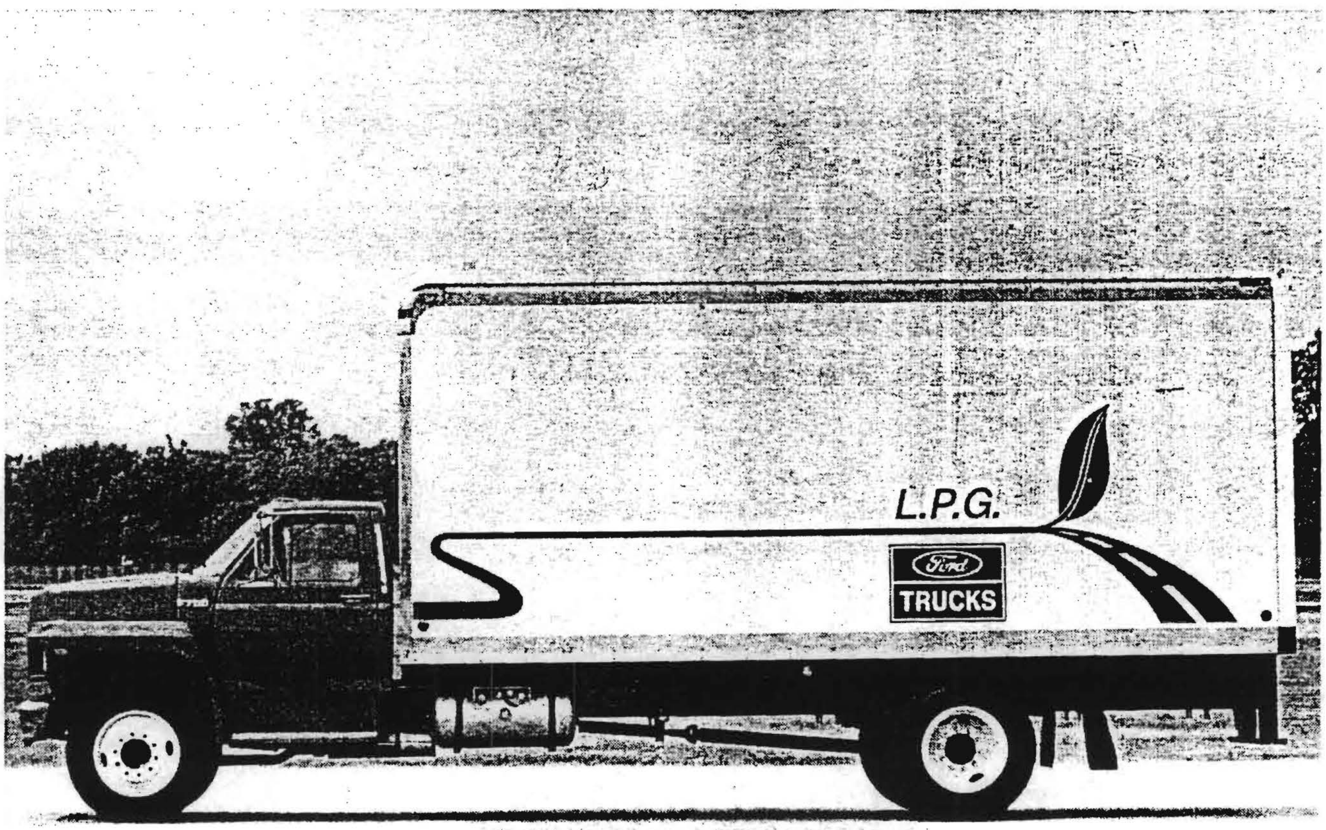
Electricity

Several electric vehicles will be on display at the Exposition, including the electric cars converted by the 14 student teams (Thursday only) entered in the Clean Air Grand Prix. Georgia Power Company is a Sponsor of these events, and their new Chrysler electric TEVan will be in the Exposition.

Ford is also active in electric vehicle development, with 82 electric-powered Ecostar vans to be tested in the United States, Europe and Mexico starting later this year.

"Ecostars will be driven in real working environments for several years before we will be satisfied enough to make electric vehicles generally available for sale," says John Wallace, director of Electric Vehicle Technology Programs at Ford. "We aren't going to put Ford electric vehicles on public sale until we are certain they meet quality and customer-satisfaction standards".

For more information on electric vehicles, see the section in this Program about the Clean Air Grand Prix.



Alternative Fuels Offer Light through the Urban Haze

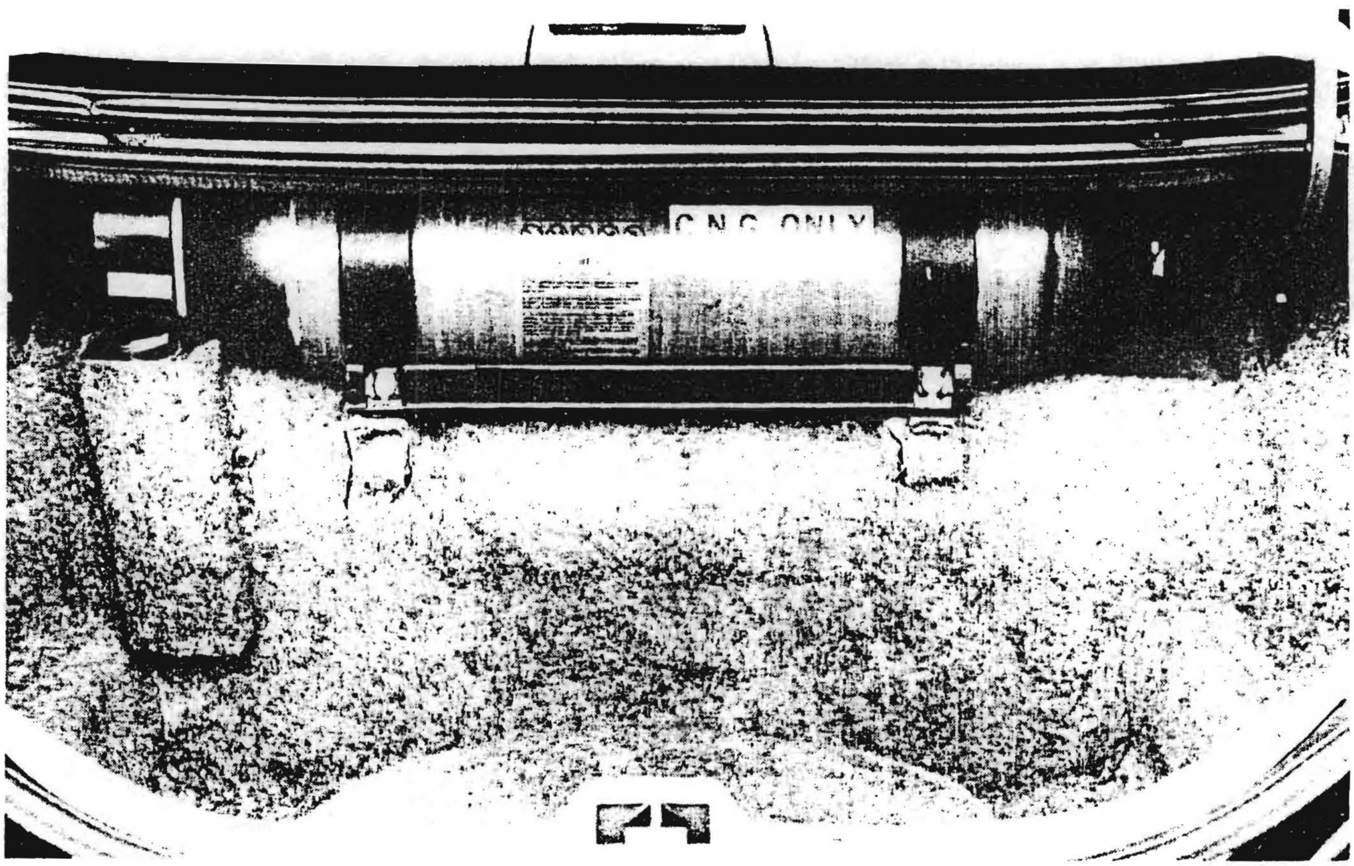
Has the end of the age of gasoline begun?

Almost unnoticed by the public, Congress late last year passed laws requiring that by 1995, most trucks, cars and vans purchased by the federal government and many others be powered by fuels other than gasoline. The alternatives include natural gas, propane and electricity. The new requirements extend to many state governments and fuel suppliers, and will increasingly apply to privately owned fleets. State governments, led by California, have also been active in implementing their own mandates for the use of alternative fuels.

This brewing revolution in transportation promises relief for the more than 100 million Americans living in urban areas which consistently violate Federal air-quality standards. Atlanta is one of 20 cities currently violating the maximum limits of ground-level ozone concentration. Despite tougher emissions requirements, the increasing use of cars and trucks has resulted in more air pollution. With over one-half billion vehicles operating worldwide, the planet's atmosphere is choking on the exhaust of gasoline and diesel fuels. Despite efforts in the U.S. to increase the use of mass transit and car pooling, Americans still account for over one-half of the total miles driven worldwide.

When evaluating alternative fuels, there is no single winner. In time, we may find our choices for fuel to be almost as broad as our choices in soft drinks. The leading candidates in the near term are natural gas, propane, methanol and cleaner versions of gasoline, with practical electric vehicles perhaps just around the corner.

It may come as a surprise to many that cars can run safely on natural gas or propane. Many people think of the possibility of gas explosions or other dangers, but experts say these fuels can actually be safer than gasoline. Some Environmental



Tanks for Compressed Natural Gas are heavier than gasoline tanks, but experts say that CNG is safer than gasoline.

Protection Agency officials have noted that if gasoline were introduced today as a transportation fuel, it would not be approved, based on safety and environmental considerations.

There is not much difference in the look or driving of most alternative fuel vehicles. They have different carbuerator systems, and natural gas or propane vehicles require heavier fuel tanks. In addition to lower emissions and longer engine life, natural gas and propane are also less expensive than gasoline. In Atlanta, Amoco has added natural gas pumps to two service stations, with a price of 74 cents per equivalent gallon of gasoline. Commercial fleet rates are as low as 45 cents per gallon. If these clean fuels were available at most service stations, the decision about buying a clean air car or truck might be easy. But, of course, it's not that simple—yet.

Alternative fuels aren't available everywhere, which is why the federal government requirement focuses on fleets that return to a central point each day. In fact, gas suppliers are installing some of these new pumps at steep discounts to capture the alternative fuel business. Is it worthwhile to add more pumps when there are not yet many customers? Why would there be customers if they can't refuel conveniently? The real question for fuel suppliers is: Are they willing to make the large investment in refueling with an uncertain market demand?

The other major cost is in converting cars to run on these fuels. A used vehicle can be converted from gasoline to propane or natural gas for $1,500 to $3,000. The good news is that once alternative fuel vehicles are produced in quantity, the cost of such vehicles should be roughly the same as those produced with gasoline engines.

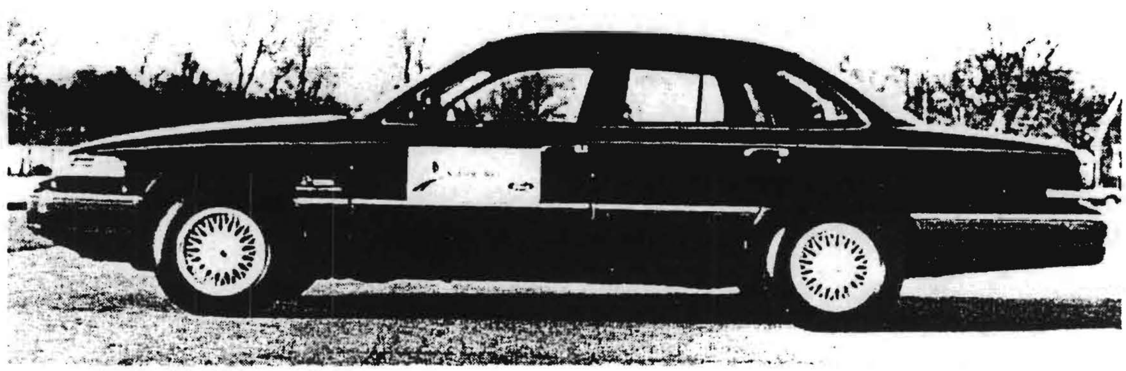
Electric cars provide another enticing option—one that has not yet reached its potential. Electric cars produce no exhaust, have no radiator, do not require oil changes or even a transmission. They can be as reliable as a refrigerator with an equivalent operating cost of 80 miles per gallon of gasoline. In fact, electric cars were common in the early days of the automobile, until they were supplanted by more powerful gasoline engines. Power is still a limitation of electric vehicles. A typical car battery has only one-eighth the power-per-pound of gasoline. Power can be increased with more batteries, but that adds cost and weight. The extra weight reduces range, so electric cars built with current technology have an average range of 60-80 miles, and a

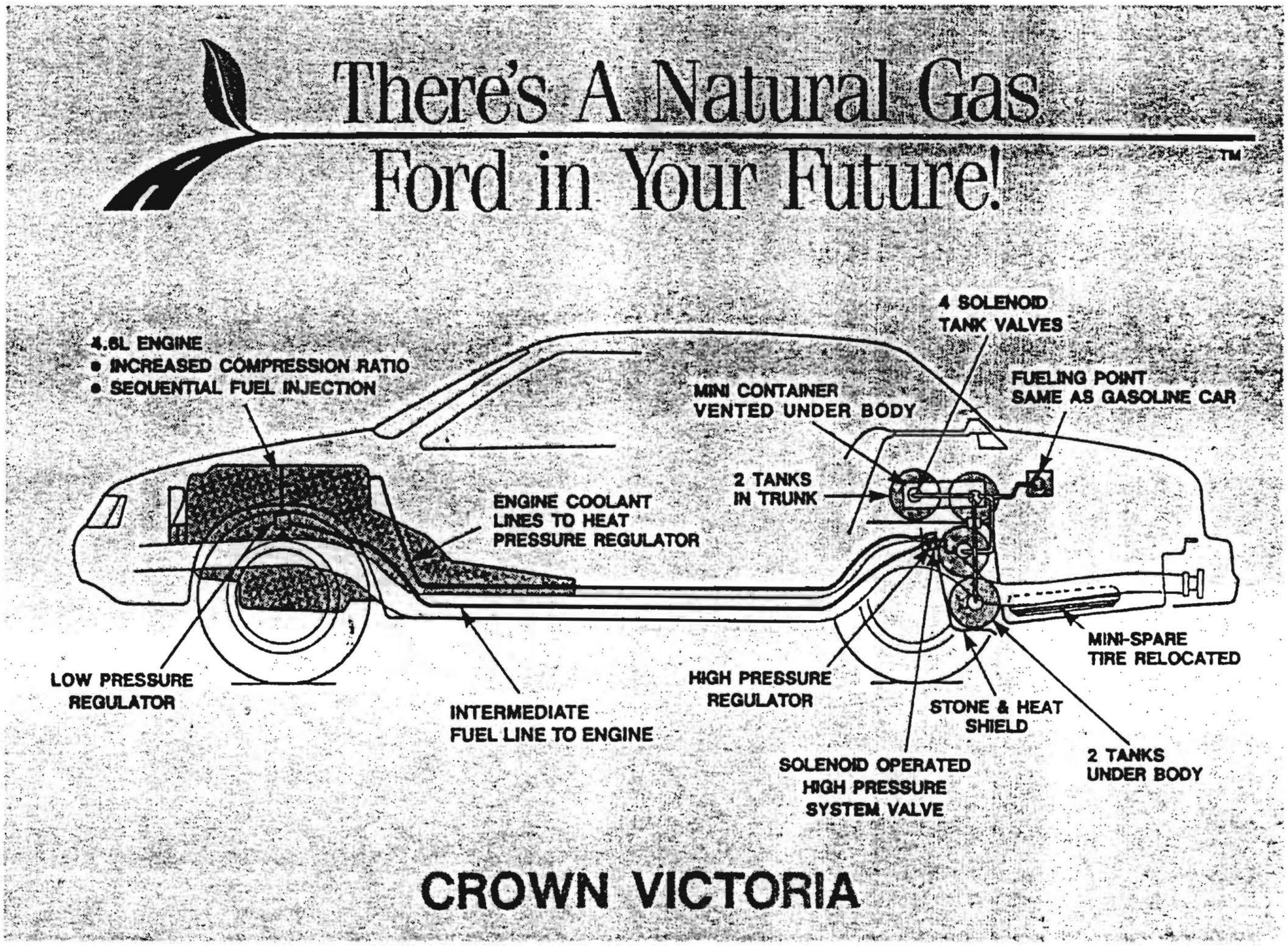
CNG and Propane: Clean Air Alternatives

According to the American Gas Association, natural gas vehicles can achieve an 85 percent reduction in carbon monoxide emissions, 30 percent reduction in oxides of nitrogen emissions, and 90 percent reduction in active hydrocarbons. They emit no particulates. The output of reactive hydrocarbons that contribute to smog pollution is 85 percent less than that of gasoline. Besides the energy used to dry and compress the gas, there are no high refining costs or refining-related emissions.

Also, Propane is much cleaner than gasoline, with a broad network of propane dispensers throughout the country. In fact, there are an estimated 3.5 million motor vehicles operating on propane gas worldwide, making it the most widely used clean air fuel.

A Ford Crown Victoria powered by Compressed Natural Gas.





long recharging time. While this might not get to the mountains and back, it might work well for commuting, which accounts for over 90 percent of the driving in the U.S.

The federal government and private industry are funding more research into better batteries, and some of the results are encouraging. California has decided to "jump-start" the technology by forcing auto manufacturers to find solutions, legislating that 2 percent of vehicles sold beginning in 1998 be powered by electricity.

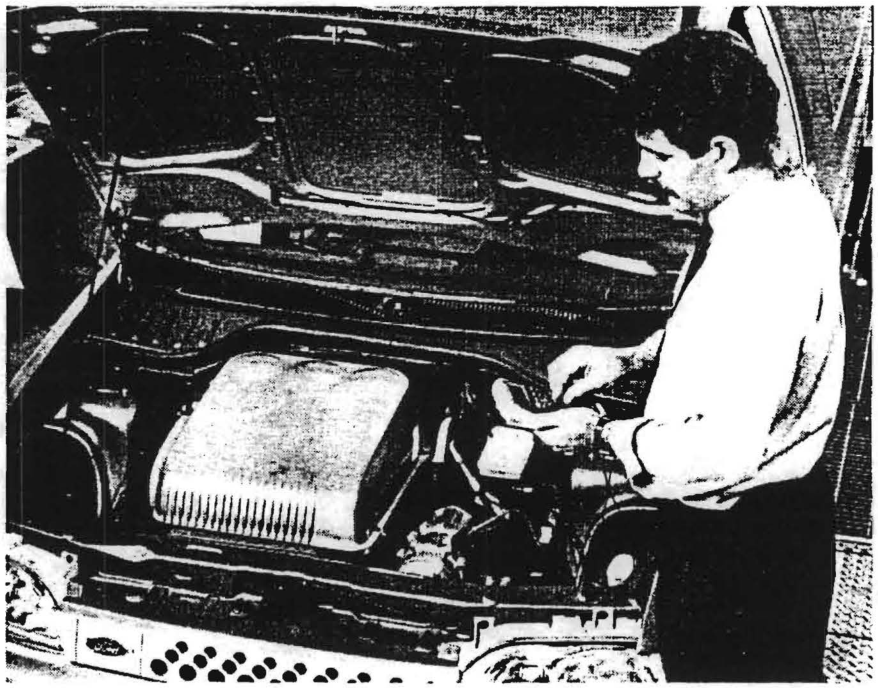
Want to eliminate visits to the service station? If natural gas, propane or electricity exists in your home, they can fuel a car adapted for them. Virtually all homes have electricity, and many have natural gas or propane. A special lightweight compressor can be attached to a natural gas line to refill a natural gas car at home. Propane is even easier, requiring lower pressures for refueling. Or an electric car can be plugged into an existing 110 volt circuit. Special adaptors exist for safe and easy use of 220 volt lines for faster recharging.

Another approach to cleaner air involves modifying gasoline itself. A mixture of 85 percent methanol and 15 percent gasoline is being promoted in California as a means of using the current fuel stations while still reducing air pollution. The engine must be built differently, but when methanol is not available the vehicle also runs fine on gasoline. The oil industry has also responded by re-formulating today's gasoline. What we call gasoline is as much a recipe as a product, and can be made from petroleum in many different ways. At somewhat higher cost, it can be made to produce fewer emissions, as we already discovered with lead-free gasoline. In fact, one of the greatest benefits from all the attention to alternative fuels may be the impetus to improve current versions of gasoline.

With so many choices and strong government support, the movement to alternative fuels is growing. It also benefits from an unusual coalition of energy companies, utilities and environmentalists. The move toward cleaner air is getting even more support from the Clinton Administration. The president has lauded alternative fuels as a means of improving air quality and reducing dependence on foreign oil. The new secretary of energy, Hazel O'Leary, is a former utility-company executive and drives a natural gas powered car.

This does not mean that gasoline will be replaced by other fuels anytime soon, but that our choices for fuel are broadening. With that, we may all breathe a little easier.

An engineer checks output voltage on a Ford electric vehicle motor.



Ready... Set... GO!

14 Teams Compete in 1993 Clean Air Grand Prix

Official Sponsors and Supporters of the 1993 Clean Air Grand Prix

Official Electric Motor—General Electric
Official Battery—Trojan Batteries
Official Tire—Goodyear
Car Supplier—Manheim Auctions
Government Supporters—U.S. Department of Energy
Argonne National Laboratory
Commonwealth of Kentucky
Utility Supporters—Georgia Power
Florida Power & Light
Duke Power

The goal of the Clean Air Grand Prix is to give students and faculty a chance to work hands on with clean air vehicles. Car races have long been used to explore new automotive technology, and the Grand Prix continues that tradition with performance tests in speed, acceleration, endurance, range, appearance and workmanship.

Electric vehicles (EV's) were chosen as this first year's fuel type because of their unique conversion characteristics and the aggressive research and development occurring with batteries and vehicle design. The Grand Prix is dedicated to the students who have worked so hard to prepare a vehicle. Some have already commented to us that this project is the highlight of their college experience.

There are few electric vehicles in existence, and many in the U.S. are located on the West Coast. The value of the Clean Air Grand Prix is that it creates new clean air vehicles which can be used for demonstration and education throughout the school year. The Clemson University team served as a pilot for the program, establishing the interest in the program and the excitement which could be generated. The following is a summary of how the Grand Prix was born:

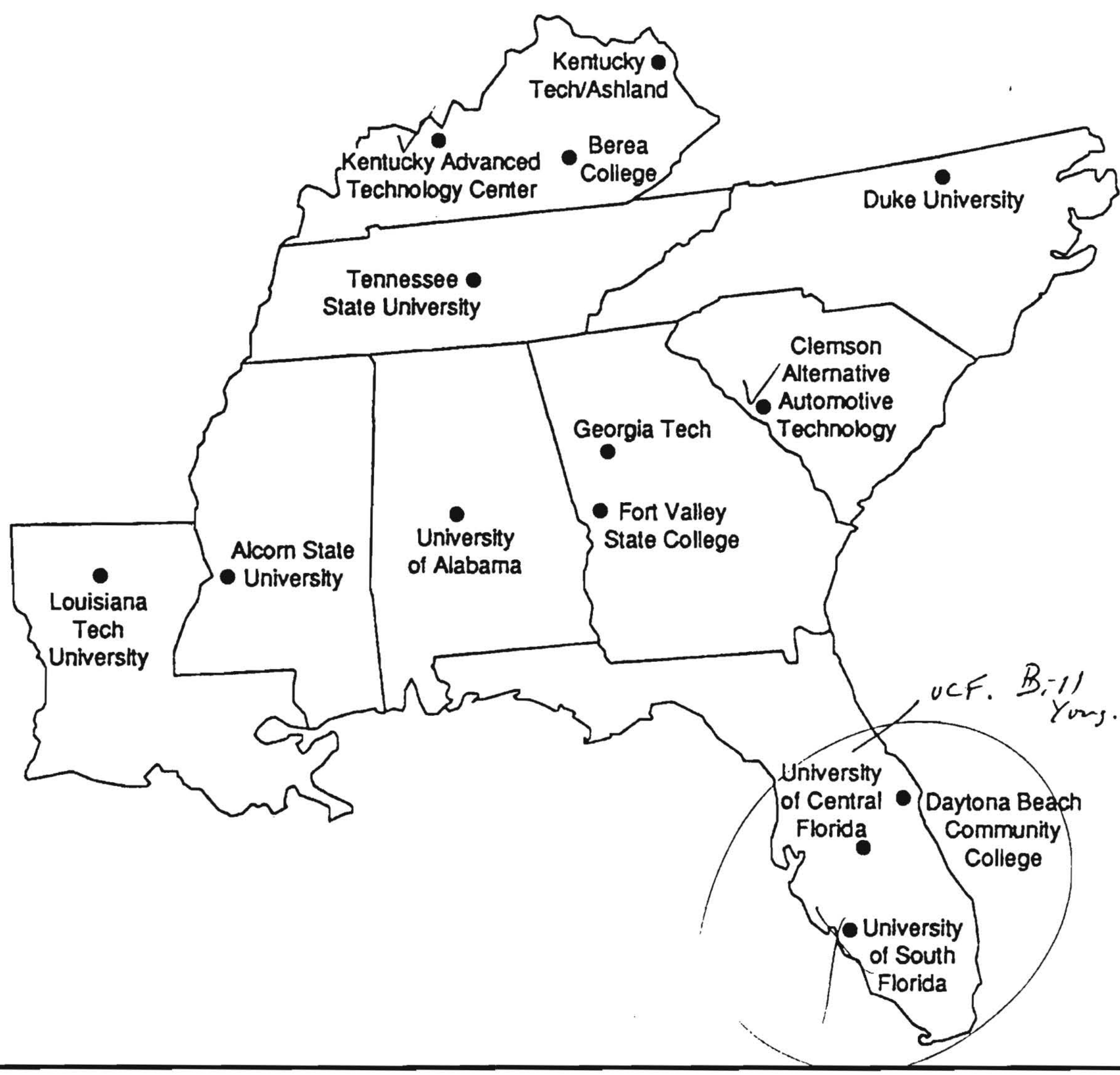
Initial Support - By providing early support in many areas, Georgia Power helped establish a base for the Clean Air Grand Prix. The company now has an active EV program which includes two buses shuttling passengers between the Civic Center MARTA station and the Georgia Power headquarters. They are also a pioneer with a fleet of the new Chrysler electric minivan, and you can see one of the first produced at the Clean Air Vehicle Exposition. Georgia Power has also announced the development of a major electric vehicle technology center at SciTrek, Atlanta's renowned science museum.

The U.S. Department of Energy through its Atlanta Support Office was the next link in the chain, providing additional support to help through the organizational phase, and later for the entire conference and exposition. From their initial support, each component of the vehicle required a significant commitment of assistance:

Cars - Manheim Auctions of Atlanta generously responded to our request for donation of 14 small used cars for the Grand Prix teams. Manheim is the world's largest operator of auto auctions, with 48 locations and 10,000 employees. Manheim arranged for auctions it owns throughout the South to provide used cars for each team for conversion to electric power. Not only did they provide the cars, but they also arranged delivery of each one to the winning colleges.

Electric Motors and Controllers - The GE Electric Vehicle Systems (EVS) operation is the world's leader in the design and manufacture of electric vehicle controls and motors for a broad spectrum of industrial,

Atlanta Clean Air Grand Prix
May 1993
Student Participants



utility, recreational and automotive applications. They provided not only electric motors and controllers, but they also volunteered many hours of technical assistance to the student teams. GE EVS continues to help commercialization efforts for electric vehicles worldwide.

Batteries - Winning at electric car races has become a commonplace event for Trojan Battery, located in Southern California since 1925. The name was selected because one of the founders, Carl Speer, played football for the Southern California Trojans in 1916. The company now has 450 employees, and a plant in Lithonia, Georgia.

Because of its commitment to the electric vehicle market, Trojan offered to supply batteries for the student teams. They also provided significant technical assistance and delivery directly to the teams. They have many successes in the young field of electric car racing. Their Trojan Car #17 won the Open Class of the APS Solar & Electric Race in Phoenix in 1992, and they had winners again in 1993.

Tires - It would not be surprising that the official tire of the Clean Air Grand Prix is Goodyear. In designing a special energy-efficient tire for electric vehicles, Goodyear engineers aren't reinventing the wheel—just perfecting it. The company is using customized computer software to fine-tune the technology to make the tire roll more freely. Already a key to improved fuel economy in today's gasoline cars, tire-rolling technology will help increase an electric car battery's range between charges. In 1993, Goodyear has introduced the Momentum tire, with 40% less rolling resistance than standard original equipment tires. It carried the much-publicized Chrysler electric TEVan on a record-setting trek from Detroit to Los Angeles. The student teams will have the benefit of Goodyear's state of the art technology in the Clean Air Grand Prix.


The University of South Florida Grand Prix team.

Prize Money & Technical Support - The U.S. Department of Energy and the Center for Transportation Research (CTR) at Argonne National Laboratory are providing extensive technical support, along with $7,500 of prize money for the winning teams. With experience in several clean air vehicle competitions around the country, they have developed sophisticated measuring devices which track the progress of EV and battery development.

Robert Larsen, of CTR, says the Atlanta Clean Air Grand Prix is "a really excellent hands-on opportunity for students to learn about future technology." The Argonne and DOE team has been involved in every step of the Grand Prix, helping us progress much farther along than would have otherwise been possible, especially with a first-year event.

Utility Support - After Georgia Power's initial support, Duke Power and Florida Power and Light provided resources for the colleges in their service territories. FP&L is bringing a whole caravan of their three student teams to the Grand Prix, and has provided extensive assistance to those colleges.

Equipment Grants - Once the equipment grants were arranged, applications were distributed to colleges throughout the Southeast with the assistance of the U.S. Department of Energy/Atlanta Support Office. Of the ones received, 14 were selected because of the quality of their teams and presentation.

We congratulate the student teams, their advisors and supporters for the accomplishment of participating in the Clean Air Grand Prix.

Clean Air Grand Prix Participants

Alcorn State

Located in southwest Mississippi, from which it draws half its enrollment, Alcorn is dedicated to academic excellence, and producing students with good citizenship qualities.

Berea College

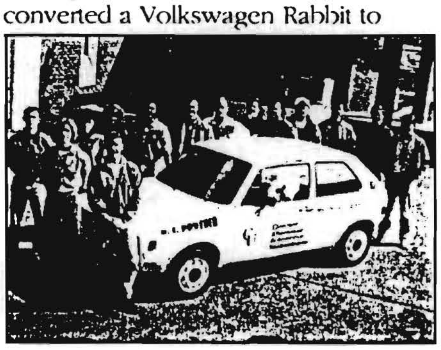
Founded in 1855, Berea College is an independent, non-denominational college located 42 miles south of Lexington, Kentucky. It charges no tuition, admits only low-income students, and requires all students to work in a college job. The college seeks individuals who have high ability but limited financial resources. Bachelor's degree are offered in four areas: agriculture, business administration, technology and industrial arts, and nursing.

Working on an electric motor at Berea

The Fort Valley State College team

Clemson

Clemson Alternative Automotive Technologies (CAAT) is a group of 17 undergraduate students that has converted a Volkswagen Rabbit to electric. The year-old group promotes awareness and use of alternative fueled vehicles, and has been studying the feasibility of converting university service vehicles to electric. CAAT's electric vehicle work has been incorporated into the mechanical engineering senior design course. The group has recently purchased two vehicles for testing and evaluation that run on both compressed natural gas and gasoline.



The Clemson CAAT

Daytona Beach Community College

The mission of Daytona Beach Community College is to provide high-quality and affordable post-secondary education and training opportunities, and enrichment programs to the people of the district. Currently, DBCC is serving 9,850 students in college and vocational credit, adult high school/GED, adult basic education and life-long learning programs. The college offers 64 programs of study for the associate of arts degree, 38 for the associate of science, 32 certificvate programs, and four apprenticeship programs.

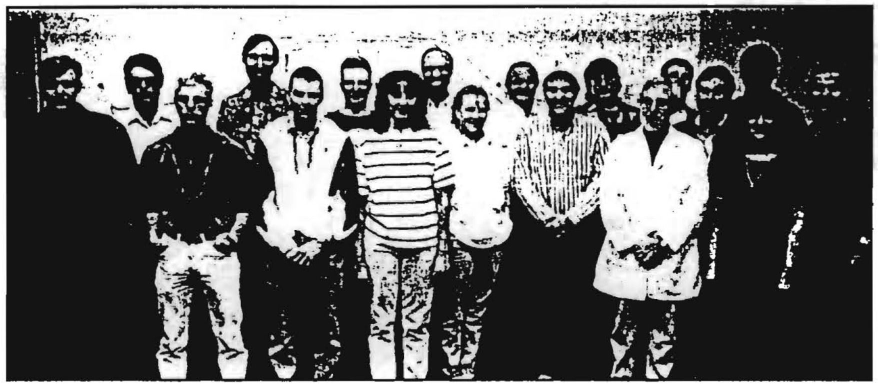
Duke University

The Duke Solar Electric Automotive Society (SEAS) consists of 10 active members. For the Clean Air Grand Prix, they have converted a 1970 Karmann Ghia to electric. The Grand Prix has given the Duke team an invaluable opportunity to realize three important aims. Through the project, the society has increased awareness, knowledge and understanding of electric vehicles on the Duke campus. It has afforded Duke SEAS members an opportunity to take an engineering class coupled with hands-on experience. Finally, it has given SEAS a chance to establish itself as a permanent program, providing an avenue of real-world experience for future engineers at Duke.

Fort Valley State

All 10 students on the team are enrolled in the Mathematics/Electrical Engineering 3+2 year dual degree program. They will spend three years studying at Fort Valley State College and two years at the University of Nevada, Las Vegas. Six of the team members are freshmen, one is a sophomore and three are juniors. They are all scholarship students in the Cooperative Developmental Energy Program (CDEP). The students

Kentucky Advanced Technology Center's Grand Prix team



have participated in summer internships through the program, where they gained engineering experience.

Georgia Tech

For each of the five members of Georgia Tech's team, converting the Volkswagen Rabbit from diesel to electric has been a first-time experience. The students, primarily with mechanical engineering and electrical engineering backgrounds, have been working on the project for about five months, with most of the work being devoted to making the Rabbit road-worthy. They are using the car's original transmission and suspension system. The car is powered by 20 six-volt lead-acid

Georgia Tech's engineers

batteries that were specially selected for the vehicle.

Kentucky Advanced Technology Center

The close ties between industry and the Kentucky Advanced technology Technology Center (KATC) motivated the formation of a KATC student chapter of the Society of Manufacturing Engineers. The chapter is less than a year old, yet the members agreed to take on the responsibility for building the electric conversion car for the Clean Air Grand Prix. Although KATC does not offer engineering programs, its graduates routinely work with design and production engineers. There will be additional projects springing out of the electric car conversion process. The team-centered learning experience derived from this complex project adds realism and real-world urgency to their academic experience. The lessons learned will extend across many professional careers.

Kentucky Tech

The student team from the Kentucky Tech, Ashland campus was formed with members from the local chapter of the Vocational Industrial Clubs of America. Participation primarily consists of students from automotive technology, machine tool technology, welding technology, computer-aided drafting, and electricity/electronics technology, along with student services personnel. Industry representatives from Kentucky Power Co., Ashland Oil Inc., General Motors and Ashland Electric provided assistance. The school is part of a system of state vocational-technical schools.

Louisiana Tech

The Louisiana Tech University Department of Mechanical and Industrial Engineering has a team of undergraduate students participating in the Clean Air Grand Prix as part of their senior design program. The vehicle being converted to all-electric drive is a 1981 Volkswagen Rabbit. All of the student participants are graduating seniors, and they are building the car as their senior design project. Most of them are student members of the Society of Automotive Engineers and the American Society of Mechanical Engineers.

Tennessee State

Located in Nashville, Tennessee State University's College of Engineering and Technology offers bachelor's degrees in aeronautical and industrial technology, architectural engineering, civil engineering, electrical engineering, and mechanical engineering. It also has colleges in Business, Arts and Sciences, and Education. The university's three degree-granting schools are Nursing, Agriculture and Home Economics, and Allied Health Professions.

University of Alabama

The University of Alabama's electric car is part of a flexible independent study program through the New School. The program also involves lectures and required reading.

University of Central Florida

The University of Central Florida is a general-purpose state university which serves the needs of the immediate community and the larger region in whichit is located. UCF offers education and research programs in such diverse fields as aerospace, banking, electronics, health and tourism. It also offers an engineering curriculum, and an engineering technology curriculum.

University of South Florida

The electric car team is composed of 10 engineering students and a faculty advisor. The vehicle is a joint project between the Univeristy of South Florida College of Engineering and the Florida Gamma chapter of Tau Beta Pi. All team members belong to Tau Beta Pi, the national engineering honor society. The engineering college designed, developed and is currently operating the first comprehensive electric vehicle solar-powered charging station and test facility in the U.S.

Corpus Christi State University
Laredo State University
Prairie View A&M University
Tarleton State University
Texas A&I University
Texas A&M University
West Texas State University

Texas Agricultural Experiment Station
Texas Agricultural Extension Service
Texas Animal Damage Control Service
Texas Engineering Experiment Station
Texas Engineering Extension Service
Texas Forest Service
Texas Transportation Institute
Texas Veterinary Medical Diagnostic Laboratory

THE TEXAS A&M UNIVERSITY SYSTEM

OFFICE OF THE CHANCELLOR

May 24, 1993

Major Richard C. Cope
Program Manager
Land Systems Office
ARPA/LSO
3701 North Fairfax Drive
Arlington, VA 22203-1714

Dear Major Cope:

With this letter I would like to inform you of our commitment to following through with the State of Texas matching fund effort for the ELPH project. State Senate Bill No.5 is presently the main piece of legislation which is intended for this kind of project. I am enclosing a copy of a letter from our political liaison that explains the status of this bill at the present time.

In addition to the above, the state provides $60 million dollars, biannually, under the title of Texas Advanced Technology and Research in Applications Program (TATRAP) to the universities, on a competitive basis. The ELPH project can receive additional funding directly or through its subsidiary groups from this fund. This will be an additional source of cash matching funds for the ELPH proposal. Texas A&M has typically received up to $15 million dollars of this fund.

Finally, I would like to mention that Texas A&M is the third largest university in the U.S., with the eighth largest research budget ($305 million in 1992). We have several large projects which required matching support structures that were similar to the ELPH project. Among them are Foundation for Engineering Education, $15 million dollars; Alliance for Minority Participation, $5 million dollars; Offshore Technology Research Center, $2.5 million and others. In each case we have met the matching fund requirements, as we would intend to do in the ELPH proposal.

Sincerely,

Herbert H. Richardson
Chancellor

HHR:sy

State Headquarters Building
301 Tarrow, 7th Floor • College Station, Texas 77843-1122
(409) 845-8552 • (Fax) (409) 845-2490

COLLEGE OF ENGINEERING TEXAS A&M UNIVERSITY · TEXAS ENGINEERING EXPERIMENT STATION · TEXAS TRANSPORTATION INSTITUTE · TEXAS ENGINEERING EXTENSION SERVICE

ENGINEERING PROGRAM · THE TEXAS A&M UNIVERSITY SYSTEM

301 Wayne E. Wisenbaker Engineering Research Center · Texas A&M University · College Station, Texas 77843-3126 · (409) 845-1321

May 19, 1993

Dr. Herbert H. Richardson
Chancellor
Texas A&M University System
College Station, Texas 77843-1122

Dear Dr. Richardson:

In Senate Bill No. 5, the General Appropriations Bill, the 73rd Texas Legislature is creating a "state matching pool" under the Office of State-Federal Relations to be used to attract federal grants to Texas. This $10 million fund will be allocated with priority given to projects that will ultimately create jobs and that will be leveraged with other sources of funding. The conference committee on the Appropriations Bill has completed its work and the bill should be finally passed by May 31, 1993.

Although this pool of funds will not be available for distribution until the beginning of the fiscal year on September 1, 1993, I believe that Dr. Ehsani's Electric and Electric Hybrid Vehicle proposal to ARPA fits the criteria for funding from the state matching pool. As you know, the State of Texas is quite active in pursuing the use of alternatively-fueled vehicles and in enhancing economic development for the state and the nation. If I can provide you with more information on this legislative action, please do not hesitate to call me.

Sincerely,

Cathy Reiley
Asst. Director for External Affairs

cc: Dr. K.L. Peddicord
Dr. M. Ehsani

A A TECHNOLOGIES INC

9330 INDUSTRIAL TRACE
ALPHARETTA, GA 30201

TEL:404-664-6644
FAX:404-664-1868

A.A. TECHNOLOGIES, INC

FAX #409-845-6259 DATE: May 25, 1993

TO: Texas A&M, Department of Electrical Engineering

ATTN: Dr. Mark Ehsani

FROM: Walter Goodman

This is page 1 of 4 pages.

NATIONAL FAX # (404) 664-1868 INTERNATIONAL FAX # 1-404-664-1868

Dear Dr. Ehsani,

I have enclosed our response to SCAT's questionnaire dated May 24, 1993, for your review. I wanted your approval of our stated responsibilities and roles in ELPH to avoid any possible misunderstandings. I will await your comments before forwarding this response. We trust that the proposal writing and your efforts for State funding are meeting with success. If you need as
sistance with the proposal, please do not hesitate to ask.

With best regards,

Walter A. Goodman
Project Coordinator

9330 INDUSTRIAL TRACE * ALPHARETTA, GA 30201 *
(404) 664-6644

A.A. Technologies Inc

Industrial and Design Engineering Consultants

Specialists in Electrically Powered Vehicles

9330 INDUSTRIAL TRACE
ALPHARETTA, GA 30201

TEL:404-664-6644
FAX:404-664-1868

Point of Contact: Walter A. Goodman, Project Coordinator

Description of Company's Expertise: A. A. Technologies has twenty years of experience in designing, prototyping, testing, and evaluating electric vehicles. We are an electric vehicle systems integrator combining the component technologies of various manufacturers to produce working prototypes. Our expertise provides us with the resources to rapidly prototype electric and hybrid vehicles.

List of Company's Resources and Facilities:

A.A. Technologies Resources include:
The custom vehicle fabrication facilities of Carrosseries et Composites (CCA). CCA fabricated the CAT EV-1 which is a pure electric vehicle developed by A.A. Technologies.
A.A. has an extensive component supplier database and working relationship with component manufacturers throughout the world.
A.A. Technologies has the necessary infrastructure for prototyping electric and hybrid vehicles in Alpharetta, Georgia.

A.A. Technologies Facilities include:

1. Land, Building, and Equipment
Office Building/Warehouse
Office Building/ Warehouse Support Equipment
Including:
- Furniture
- Office Support Equipment
- CAD System
- Drafting Board and Drafting Tools
- Computer System
- Car Lift
- Engine Hoist
- 3 Battery Charging System
- 3 5000lbs Battery Pallet Mules
- 2 forklifts
- Workshop Tools and equipment

2. Component/subsystem testing prototype electric vehicles at cost
   Including:
   - 1 CAT EV-1 electric pickup
   - 1 Electric Yugo conversion
   - 2 electric two wheel scooters
   - Battery monitoring equipment
3. Electric Vehicle and component supplier database

List of Company's Related Contract Experience:
The SCAT and ARPA projects are A.A. Technologies' first involvement in a government contract.

Company's Role and Responsibilities:
A. A. Technologies is a participant in the ELPH project as the systems integrator and fabricator of the two mule and three prototype vehicles. A.A. Technologies' major project goals are listed below.

A.A. Technologies will work within the ELPH management team to establish mule and prototype design goals, specifications, procurement, testing, integration, and fabrication. The specific responsibilities of A.A. Technologies are to be the prime contractor for the integration and fabrication of the mule and prototype vehicles.

Six months after contracting A.A. Technologies for participation in the ELPH project, one S-10 pickup ELPH mule will be completed for test and evaluation of the ELPH concept. A second mule, from an Oldsmobile Cutlass or similar vehicle which is to be determined, will be completed six months later. Three prototype vehicles will be completed 6 months after the delivery of the second mule. The total time of completion of the two mule and three prototype vehicles will be Eighteen months.

Key Personnel:
1) Anil Ananthakrisna
PATENTS AND PUBLISHED PAPERS

1980	***Patent Number 150176**, India, Electric Propulsion System.
1990	***Patent Application Number. 603808**, Europe/USA, for Electric Traction Range Extender Systems
1992	***Design Notarization,** Netherlands, Hybrid Two Wheeler.
1982	*__Support Structures for Electric Vehicles__, Electric Vehicle Symposium 2, India
1984	*__Demonstration of the Commercial Feasibility of Electric Vehicles for Personal Use__., Electric Vehicle Symposium 7, France
1988	*__Electric Two & Three Wheelers for Personal and Public Transport__ Electric Vehicle Symposium 9, Toronto, Canada.
1991	*__A Commercially Viable Electric Vehicle__, SAE Passenger Car Meeting, Nashville, Tennessee

Anil Ananthakrisna, cont.

PRODUCTS

1974	Developed **Centrifugal Oil Purifiers** for Gera Auto Industries, India
1975	Developed **Digital Display Systems** and **Vehicle Flashers.**
1975 - Present	Conceptualized and developed the following electrically powered personal and industrial commercially viable vehicles:

***Vidyut Electric Bike,**
***Indra Electric Car,**
***Pushpak Electric Car,**
***CMC Electric Mini Bus**
***Surya Electric Car,**
***Vayu Electric Car,**
***Electric Tractor,**
***Lilliput EV three wheeler**

PROFESSIONAL ORGANIZATIONS

***Co-Founder member** of World Electric Vehicle Association. EVS 9,Canada
***Member** of Society of Automobile Engineers, India.
***Member** of the Electric Vehicle Association, India
***Member** of the Electric Vehicle Association of Netherlands (ASNE).

CAREER BACKGROUND

1974	***Founder**, Electro Anil, Bangalore, India to develop prototypes of various classes of electric vehicles for the purpose of subsystem testing and evaluation.
1982-	***Converted** Electro Anil to Public Corporation Electro Anil Limited, Bangalore, India ***Technical Director** of Electro Anil Limited
1983 -1986	***Pilot Production** of 500 Vidyut Electric Bikes, for market testing in India.
1987	***Pilot Production** of 100 Vidyut Electric Bikes for market testing in Germany.
1989-	*Takeover of Electro Anil Limited by Private Investor
1989 -1991	*Functioned as the **Chief Executive Officer** of MTC, Netherlands a research and development center for Environmentally Friendly vehicles.
1991-	***Founded**, A.A. Technologies, for the commercialization of electric vehicles ***Vice President** of A.A. Technologies Inc.

Mr. Anil Ananthakrisna, the Vice President of A.A. Technologies' will be responsible for directing and managing all technical aspects of the ELPH contract.

2) **Mr. Alan Rubenstein** the President of A. A. Technologies has enjoyed a long career of successful ownership and management of companies engaged in distribution of auto repair parts on a national level. Mr. Rubenstein also owns and directs companies engaged in computer software design, coatings, and distribution of personal care products. Mr. Alan Rubenstein will be responsible for the business aspects to the ELPH contract.

Mr. Walter A. Goodman, Project Coordinator, is a graduate of the Southern College of Technology, Atlanta, Georgia, with a Bachelor of Science degree in Mechanical Engineering Technology. He is certified as both an Engineer-In-Training (EIT) and as a Certified Manufacturing Technologist. Mr. Goodman co-authored "The Air Quality Impact of Alternatively Fueled Vehicles," under subcontract to the Department of Natural Resources of the State of Georgia.
Mr. Goodman will be responsible for coordinating and directing the prototyping activities of the ELPH contract.

A.A. Technologies Inc

Industrial and Design Engineering Consultants

Specialists in Electrically Powered Vehicles

9330 INDUSTRIAL TRACE
ALPHARETTA, GA 30201

TEL:404-664-6644
FAX:404-664-1868

May 20, 1993

Dr. Mark Ehsani
Haliburton Professor and Director
Texas A&M University
FAX: 409-845-6259

Dr. Ehsani,
I trust this fax finds you well. Below I have listed an infrastructure valuation of A. A. Technologies for the ELPH proposal to ARPA. If you need any assistance in preparing the proposal, please do not hesitate to call. We are looking forward to working with you on ELPH.
A.A. Technologies, Inc.Infrastructure facilities:

1. Land, Building, and Equipment
Office Building/Warehouse $ 800,000.00
Office Building/ Warehouse Support Equipment $ 50,000.00
Including:
Funiture
Office Support Equipment
CAD System
Drafting Board and Drafting Tools
Computer System
Car Lift
Engine Hoist
3 Battery Charging System
3 5000lbs Battery Pallet Mules
2 forklifts
Workshop Tools and equipment
2. Componet/subsystem testing prototype electric vehicles at cost $ 150,000.00
Including:
1 CAT EV-1 electric pickup
1 Electric Yugo conversion
2 electric two wheel scooters
Battery monitoring equipment
3. Electric Vehicle and componet supplier database $ 150,000.00
Total Infrastructure facilities valuation $1,150,000.00

Walt.

Micon Engineering is a full service engineering design firm specializing in real time data acquisition, monitoring, and control applications. Micon engineers have specialized expertise in the application of microcomputer technologies and state-of-the-art embedded systems design for hardware and software based systems. Micon provides a full range of research, design, development, and manufacturing services. We are regularly called upon to support the design and development of computer and data acquisition products to be manufactured and sold by other companies.

Micon's capabilities include:

- Design, development, and application of data acquisition and monitoring systems
- Design of analog signal conditioning modules for harsh environments
- Instrumentation and recording of process or system parameters
- Design, development, and testing of real time, computer based control systems
- Development for expert system applications.

Micon has specialized hardware and software capabilities. These include:

Hardware

- Design and development of digital, analog and hybrid boards
- Acquisition of low level signals in harsh environments
- Specialized hardware for high voltage isolation in instrumentation systems
- Experience with a wide variety of emulators
- Experience with a wide variety of bus architectures.
- Extensive design experience with Motorola and Intel processor families
- Experience with DSP hardware design

Software

- Extensive experience with C applications
- Development of real time data acquisition and control software
- Experience with UNIX applications
- Multi tasking, real time environments under VRTX
- Relational data base applications
- Extensive experience in data compression
- Windows applications and interactive systems
- Extensive experience in various data communications protocols
- Extensive experience in the design of real time systems

In support of the above areas, Micon has extensive computing, instrumentation, and hardware development laboratories with state-of-the-art equipment and software support. Micon has participated in numerous large scale projects, some of which involve extensive team effort. Examples related to this project include:

- Power system automation on space platforms

  Micon, working under contract to NASA, has designed a new concept for an automated power system which includes protection, control, and monitoring functions. It is proposed that this distribution system be placed on Space Station Freedom.

- Data analysis station

  In a cooperative project with Schlumberger-Sangamo Electric, Micon designed a computer based data analysis system for storing, retrieving, and analyzing large quantities of data.

- Telecommunications controller

  In a cooperative effort for 3M-Sumotomo (Japan), Micon designed test instrumentation for use in diagnostics associated with the Japanese telephone network. This real time system allowed for testing and switching of in-use voice and data circuits with no loss of connection, data, and no bit errors. This system involved closed loop control and real time data analysis.

- Water treatment process controller

  Micon, in conjunction with another design firm, developed and designed a real time, computer based control and monitoring system for a reverse osmosis water purification system.

- Data acquisition and monitoring system

  In cooperation with General Electric Company, Micon developed a commercial data acquisition and monitoring system for application in industrial and electric utility environments. The sensor and instrumentation requirements for this project are similar to those which would be needed to support this effort.

Micon has extensive experience in large, team projects and is skilled in coordinating the hardware and software implementation of design concepts and methodologies formulated by other companies. Our experience in real time systems, data acquisition and control, and microcomputer based design uniquely fit this project.

Micon is housed in a modern office/laboratory building in College Station, Texas. There are currently eleven design engineers with support staff. Various consultants support specialized design needs on demand. All design staff have degrees in electrical or computer engineering either B.S., M.S., or Ph.D.

COST SHARING

Micon is in a position to provide considerable hardware and software support to this project. Computing systems and work stations with a value of $105,000 will be dedicated to the project as needed. In addition, $20,000 of specialized software will also be contributed, without normal cost recovery.

Micon also has available software tools and software foundations which can be used in support of the goals of this project. These include:

- System Architect (case tool)
- Turbo C++ for Windows
- Borland C Compiler 3.
- Microsoft C Development System
- Polytron Version Control System
- Windows Word, Excel, Power Point
- Project Work Bench
- Foundation software for multi tasking design

Under normal project billing, this software and hardware would be charged to the project in proportion to the programing and development labor hours. Micon has been approved by federal audit (DCAA) to charge a $1.626 for every labor hour on development projects to recover software and hardware costs. It is agreed that Micon will forgo this expense and will contribute these software and hardware tools to the project as cost sharing.

GE Drive Systems

Electric Vehicle Controls

EV2000

Leading supplier of components and systems for battery powered vehicles

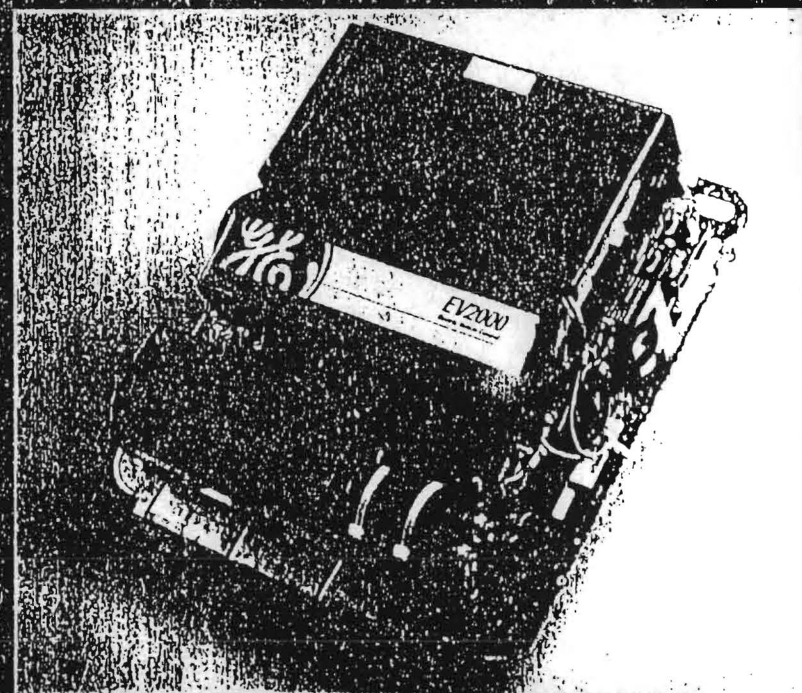
For three decades, GEDS has maintained active programs both internal and with automobile and battery manufacturers

Thomas Edison and Proteus Steinmetz were actively involved with electric vehicle development

EV2000

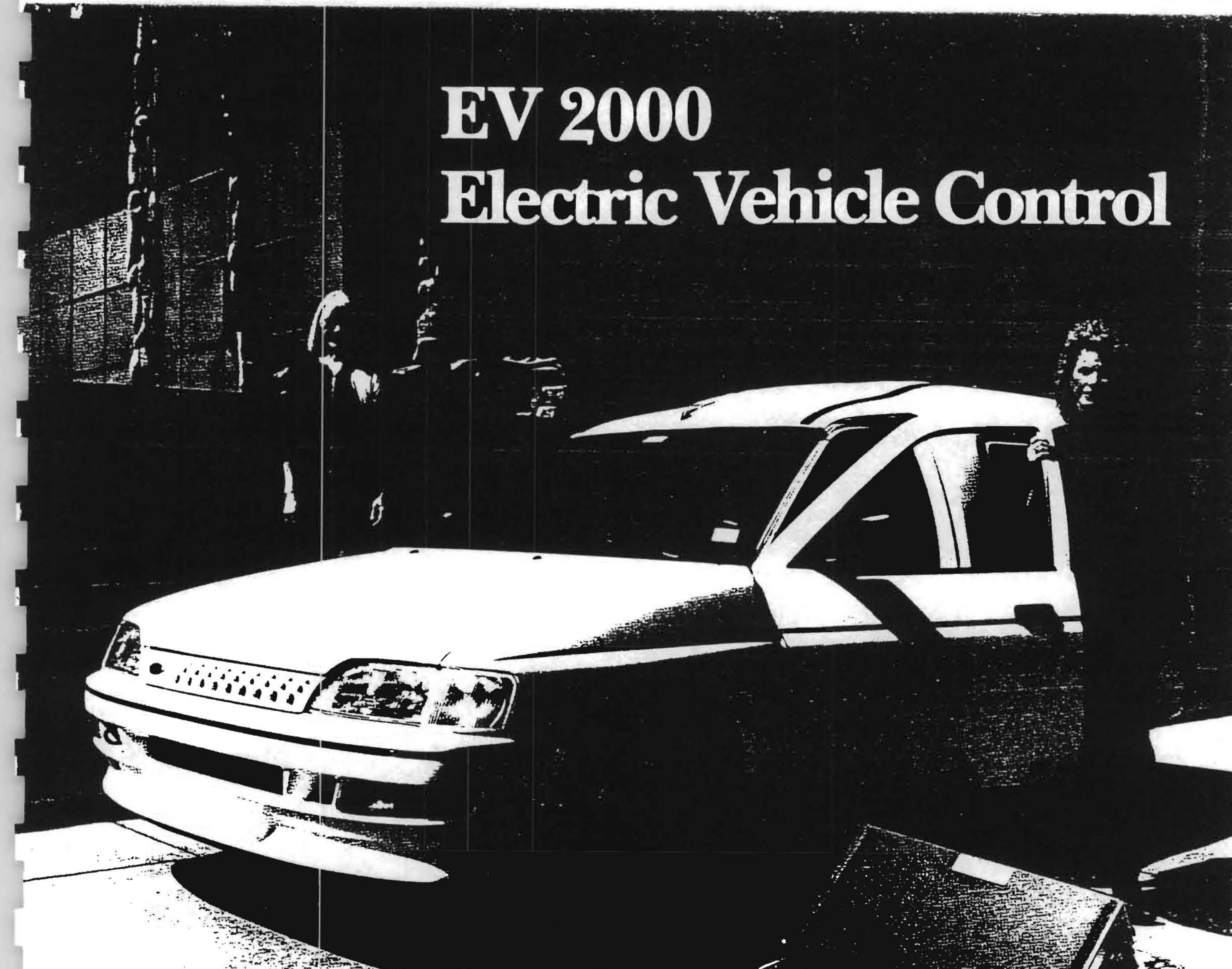
Traction Inverter

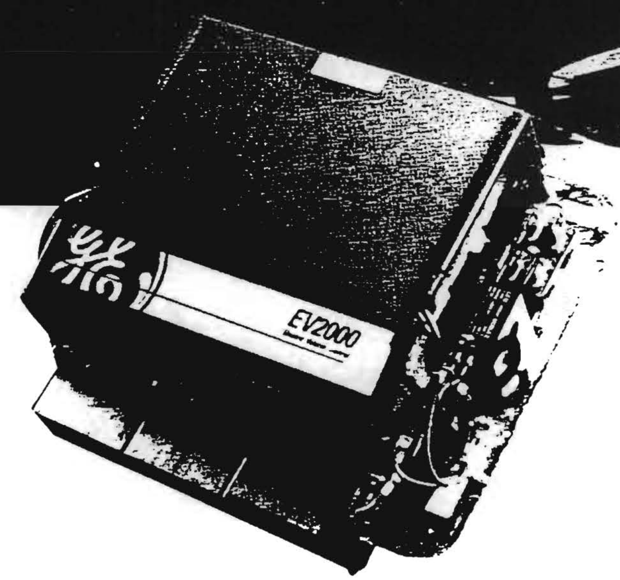
- Input voltage 210 to 385 volts
- Insulated Gate Bipolar Transistor (IGBT) power devices
- 50, 75 and 100 horsepower
- Air cooled
- Microprocessor control
- Field oriented control
- Serial interface to vehicle control computer



Size (l x w x h) - 13" x 15" x 9.6" (33 cm x 38 cm x 24.4 cm)
Weight - 50 lb. (23 kg)

EV 2000
Electric Vehicle Control





GE Company has been a pioneer in electric vehicles since the company was founded by Thomas Edison in the beginning of the century. Both Thomas Edison and Proteus Steinmetz were actively involved in the design and development of electric cars.

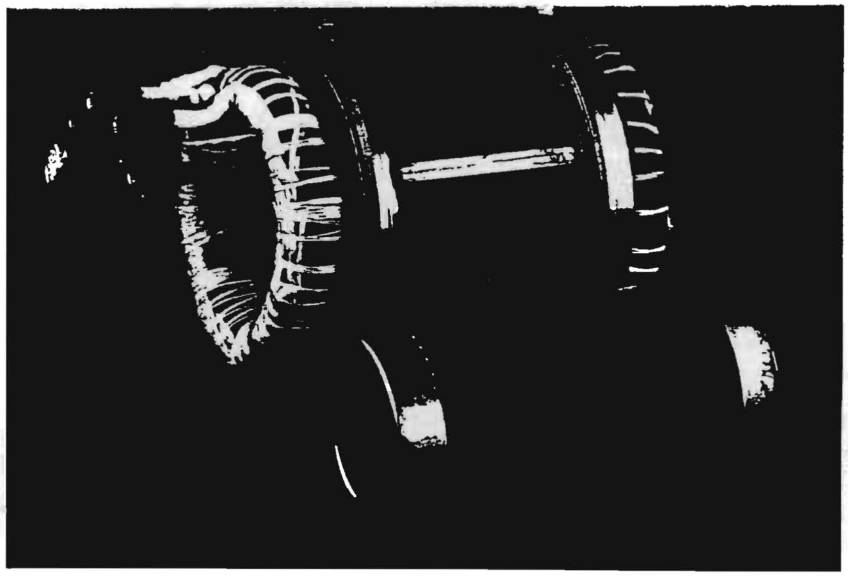
As a leading supplier of components and systems for battery powered vehicles for specialized industrial applications, GE Drive Systems has maintained active programs within the company and has worked closely with automobile and battery manufacturers. GE has had a 10 year advanced development relationship with the Department of Energy and Ford Motor Company. GE is committed to continued electric vehicle research and product development and to continued improvement in production technologies, and will be the supplier of drives for the Ford Ecostar demonstration fleet being introduced in 1993.

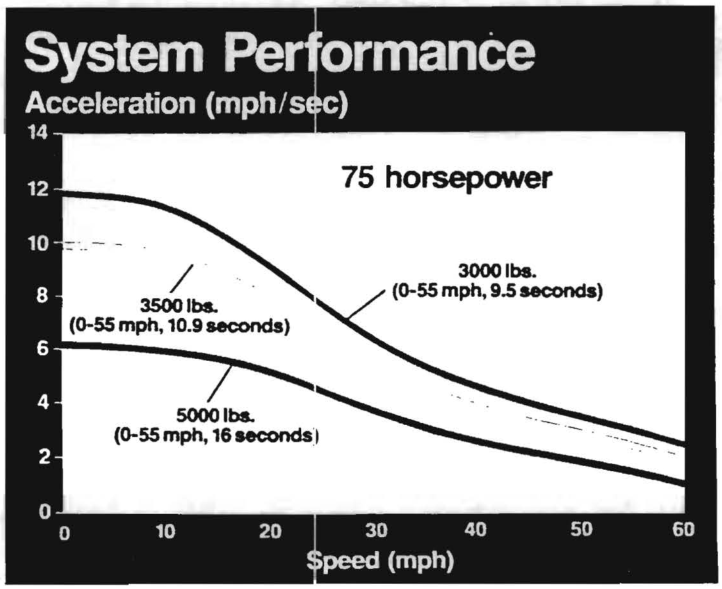
GE Drive Systems has over thirty years experience in on-road and off-road electric vehicle systems using both ac and dc technologies.

The EV 2000 Electric Vehicle Control from GE Drive Systems is designed to provide a cost effective efficient non-poluting means of transportation in a commercially viable package. It utilizes a single heavy-duty ac induction motor for reliability, light weight, maximum efficiency, and low cost.

Inverter costs are minimized by maintaining nominal battery voltages up to 350 volts. Insulated Gate Bipolar Transistors (IGBT) are used for low cost, high switching frequency.

Regenerative braking increases the system's efficiency. A serial interface is used to communicate between the system and the vehicle control computer.





System sizes range from 30 to 100 horsepower. The maximum motor speed is 13,000 rpm, and typical efficiencies exceed 95%.

The specially designed electric vehicle ac induction motor is fully compatible with existing high volume production lines.

The system has a 4 to 1 constant horse-power range which provides performance similar to an internal combustion engine without the need for a multiple speed transmission.

General Electric Company
1501 Roanoke Blvd.
Salem, Virginia 24153

LONE STAR ENERGY COMPANY

Clean fuels for transportation

Lone Star Energy Company, a wholly-owned subsidiary of ENSERCH Corporation and an affiliate of Lone Star Gas Company, is dedicated to the commercialization of natural gas as a motor fuel. Lone Star Energy Company created the CNG Division in March, 1991 and has evolved as a leader in providing natural gas fueling and vehicle conversions.

Lone Star Energy Company has formed two joint venture companies to facilitate market development:

FleetStar of Texas, L.C. was organized in December, 1991 and has since opened six public natural gas fueling stations in the greater Dallas/Fort Worth area. FleetStar formed a partnership with Fina Oil and Chemical and has installed three of the six stations at existing Fina retail outlets. FleetStar plans to open six additional stations by the end of 1993. FleetStar has also signed letters of intent with fuel marketers in Waco and Wichita Falls, Texas to install public natural gas fuel stations. FleetStar provides natural gas fuel through 24-hour access, credit card systems networked across the state. FleetStar provides a monthly fuel management report that summarizes the customers transactions and includes such information as vehicle ID#, odometer reading, date and time of fill, gallons dispensed, product code, and cost per mile of operation. FleetStar is currently serving over 900 natural gas vehicles through its public fueling network.

TRANSTAR Technologies, L.C., organized in December, 1991, was created to provide customers a single-source for natural gas vehicle equipment including equipment sales, installation, warranty service, driver and mechanic training. TRANSTAR initiated commercial operations in June, 1992 in a 20,000 square foot facility located near downtown Dallas. TRANSTAR's shop includes 19 vehicle bays, two-pole lifts, an in-ground 500 hp chassis dynamometer, four gas analyzers, iron/sheet metal fabrication equipment and a training room. TRANSTAR was involved in the conversion of 300 vehicles in 1992 and is budgeted to convert approximately 600 vehicles in 1993. In addition, TRANSTAR is authorized by GMC to perform warranty service on the Sierra, GMC's dedicated natural gas pickup trucks.

FleetStar

FleetStar of Texas, L.C.

TECHNOLOGIES

LONE STAR ENERGY COMPANY

Clean fuels for transportation

PUBLIC NATURAL GAS REFUELING STATIONS AVAILABLE IN METROPLEX

Dallas, TX...(May 19, 1993)...Now, there is a way to convert your gasoline vehicles to run on clean-burning natural gas and refuel them at public refueling stations in the metroplex. FleetStar of Texas, an affiliate of Lone Star Energy, and FINA Oil Company have opened three, public, natural-gas fueling stations. Two are in Dallas and one is in Fort Worth. The Dallas stations are strategically located on Buckner Blvd., just north of I-30, and at Inwood Road and I-35 near the Apparel Mart. The Fort Worth station is at Alta Mesa and Crowley, south of I-20. Another station, in Grapevine, is expected to open later this year.

This brings to six the number of stations currently available to the public. Other stations owned and operated by FleetStar of Texas are located in Arlington, Fort Worth and Dallas.

Fleet users wishing to use these six stations may fill their vehicles with natural gas using either a FINA or a FleetStar credit card. They will be able to receive a monthly, fuel-management report providing such information as vehicle ID number, product code, number of equivalent gallons dispensed, monthly miles traveled, average miles per equivalent gallon and cost per mile of operation for each vehicle.

Both Federal and Texas clean air legislation will require certain Dallas and Tarrant County fleet operators to begin converting to alternative fuels in order to comply with stringent EPA air quality standards. Many of these owners have delayed converting to

-more-natural gas because of a lack of available, public-fueling stations. This is no longer the case. Fleet operators can now take advantage of a cleaner burning fuel that costs 30 to 40 percent less than an equivalent gallon of gasoline. In addition to the lower fuel costs, natural gas provides savings through extended oil-change and tune-up intervals due to it's clean-burning properties.

Finally, if you are concerned about converting your vehicles to run on natural gas as well as gasoline, you need not worry. TRANSTAR Technologies, also an affiliate of Lone Star Energy, offers a complete line of natural-gas, conversion services that include equipment sales, turn-key conversions, training and warranty work.

If you would like further information on how to convert your vehicles to run on clean burning natural gas, please contact us at 214/573-3853 or 1-800-545-3427.

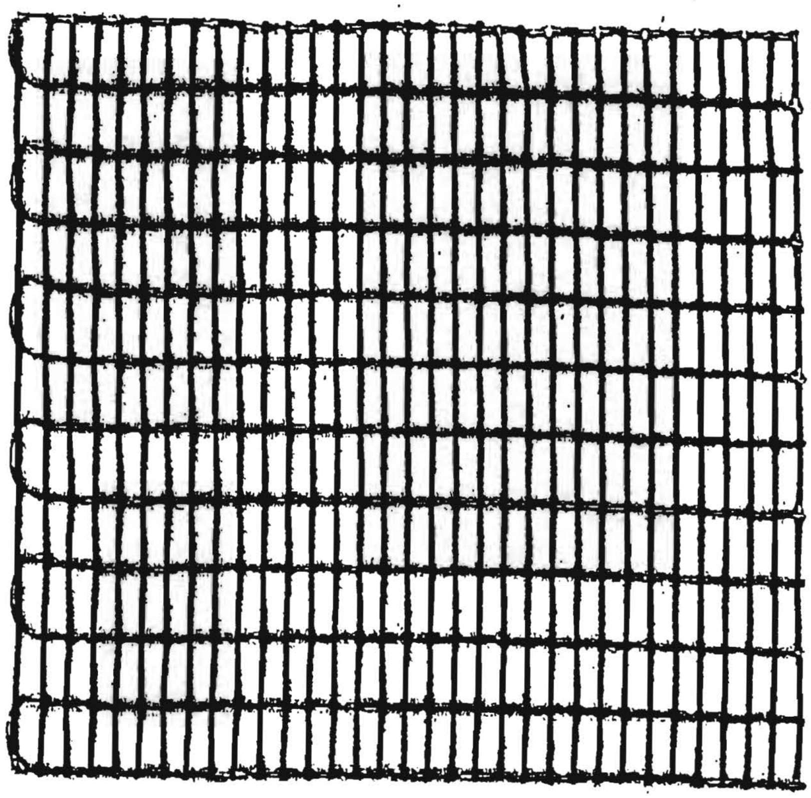
-30-

ngv.sol

Electrosource

Technical Summary

Horizon®
Advanced Lead-Acid Battery Technology



Electrosource Inc

3800 Drossett Drive ▪ Austin, TX 78744-1131 USA
512.445-6606 ▪ fax: 512.445-6819

Horizon® Advanced Lead-Acid Battery Technology

EXECUTIVE SUMMARY

Electrosource technology brings to the battery industry exceptional performance gains and substantial reduction in manufacturing costs.

Company

In 1987 Electrosource, Inc., was formed to develop and commercialize innovative battery technologies. Using patented technology, Electrosource has developed a high specific energy, long cycle life, valve-regulated lead acid battery. Electrosource developed its Horizon® battery and manufacturing process with aerospace defense technology and materials used in strategic airborne countermeasure devices. The battery has a wide range of applications that require a high performance, maintenance-free, long-lasting battery that is inexpensive to produce and is recyclable.

Core Technology

Using a patented process, Electrosource co-extrudes an alloy of lead and tin onto a high tensile strength filament, making a small diameter wire that is woven into lightweight mesh grids. The grids are coated with a proprietary paste and assembled into electrical plates. Horizontal placement of the plates makes the Horizon® battery stronger and more able to withstand charge and discharge cycles than other battery technologies. The Horizon® battery can be manufactured with a continuous process.

Performance Characteristics

The Company's patented technology makes it possible to rapid charge the Horizon® battery to 50 percent of capacity in 8 minutes and 99 percent in half an hour, with an optimum recharge time of three hours. The battery has sustained more than 900 charge/discharge cycles (at C/2 rate and 80% DOD). The Horizon® battery has a significantly higher storage-capacity-to-weight ratio than previous batteries and delivers more than 45 wh/kg of specific energy (at C/3 rate and 100% DOD). The Electrosource design provides the highest acceleration — or peak power — of any other battery technology being evaluated for the electric vehicle (EV) market. The Horizon® battery can be manufactured at a significantly lower cost than any other advanced battery. The battery is abuse tolerant and can be easily recycled using the existing lead-acid recycling infrastructure.

Market Potential

Spurred by public concern about air quality and over dependence on petroleum, interest in electric vehicles is gaining momentum worldwide. In some areas such as California, regulations require the sale of zero-emission vehicles or EVs. In California alone, projected sales of EVs will reach 500,000 soon after mandates take affect in 1998. Presently the Horizon® battery from Electrosource is the only technology that has the performance and cost effectiveness to make electric vehicles practical and affordable. The battery is part of an on-going test program at Argonne National Laboratory and is being evaluated in major automakers' prototype EVs. In addition to the EV market, Electrosource advanced lead-acid battery technology has applications in a broad range of commercial and industrial applications including uninterruptable power supplies, utility load-leveling, consumer power tools and cellular phones, fiber optic backup systems, internal-combustion automobile starting batteries, portable computer batteries, and many industrial applications.

Strategic Alliances

BDM International and Electrosource together have formed a new company that will begin manufacturing Horizon® advanced lead-acid batteries to power electric vehicles in the U.S. and overseas. The company, Horizon Battery Technologies, Inc. (HBTI), grew out of a strategic partnership formed early in 1993 between BDM and Electrosource. BDM Technologies, a subsidiary of BDM International, will design and integrate the manufacturing plants to produce the Electrosource batteries. BDM Technologies is widely recognized as a leader in professional and technical services. BDM's comprehensive range and focus include national defense policy research, industrial automation, information systems design and integration, and assessment of space program risks. BDM expertise encompasses robotic manufacturing techniques and other advanced manufacturing and quality control methods. Headquartered in McLean, Virginia, BDM employs more than 4,500 people in 60 countries and provides professional and technical services to the defense community, civil government departments and agencies, manufacturers, other businesses, foreign governments and companies, and other clients. "The potential of the Electrosource advanced lead-acid technology is enormous and encompasses space and defense, as well as a myriad of private sector applications," said BDM President and CEO Philip A. Odeen. "Reaction to the Horizon® battery in the U.S., Asia and the Pacific Rim has been outstanding."

The Electric Power Research Institute has provided funding for Electrosource research through contracts and other support. EPRI is a participant in the U.S. Advanced Battery Constortium (USABC). The USABC does not support the development of near-term battery technology. EPRI's independent battery program has identified Electrosource's technology for its near-term focus. EPRI is a nonprofit consortium of domestic power utilities and operates with a $500 million annual research budget. Work at EPRI covers a wide range of technologies related to the generation, delivery, and use of electricity, with special attention paid to cost-effectiveness and environmental concerns. EPRI is headquartered in Palo Alto, Calif., and employs more than 350 engineers and scientists managing some 1600 projects worldwide. "To date, our battery programs have not produced anything as exciting as the battery that we see at Electrosource," said Jack Guy, EPRI manager for technology commercialization.

Electrosource, Inc.
Taking Charge of a New Horizon.

3800 Drossett Drive • Austin, TX 78744-1131 USA
512.445-6606 • Fax 512.445-6819

Charles Mathews
Chairman of the Board
Mathews is the co-inventor of the patented technology that forms the co-extruded lead wire used in the Horizon• battery. He is a director of Blanyer-Mathews Associates Inc., which specializes in co-extrusion process engineering. Before helping organize Electrosource in 1987, Mathews was associated with the University of Texas Defense Research Laboratory (now the Applied Research Laboratories) and was co-founder and former officer and director of Austin-based Accelerators Inc., a company specializing in high-energy neutron applications. Before founding Blanyer-Mathews in 1981, Mathews was a program manager for electronic countermeasures systems at Tracor Inc. from 1974 to 1980. Mathews is widely recognized for developing ion-implantation processes and engineering that led to the popularization and mass production of the silicon micro-chip.

Benny E. Jay
President and CEO
Jay is a chemical engineer and theoretical physicist. Jay has led the Horizon® battery development team for nearly seven years. Before joining Electrosource in 1987, Jay was corporate vice president for Planning and Special Projects at Tracor Inc., a high-technology firm based in Austin, Texas. While at Tracor, Jay was part of the senior management team of the aerospace division, overseeing projects that included the Minuteman II program, global sales, and marketing and product support for aerospace and defense-electronic products. Tracor revenues exceeded $840 million. Jay graduated magna cum laude, B.S. in physics from Abilene Christian University and completed graduate studies in physics at Carnegie Mellon University. He received his M.S. in engineering mechanics from the University of Texas.

Rick Blanyer
Director, Production Engineering
Blanyer is currently director of process, production and evaluation engineering for Electrosource and is the co-inventor of the co-extrusion manufacturing process for the Horizon• battery. Blanyer is president and director of Blanyer-Mathews Associates Inc., which specializes in co-extrusion process engineering. Before starting B.M.A. in 1981, Blanyer directed the electrical engineering, instrumentation, robotics engineering and construction of a glass-filament chaff manufacturing plant for Tracor Inc., an Austin-based high-technology firm. Blanyer and Tracor developed the ability to adhere aluminum onto glass filaments at high speeds. The materials are used in strategic airborne countermeasure devices.

Ajoy Datta
VP, Product Engineering and R&D
Datta developed Electrosource's proprietary high-energy paste formulation used in the Horizon• battery. He is a 20-year veteran of the battery manufacturing industry and is known for his developments in active material formulation. Datta has held progressively responsible engineering management positions during 26 years with seven major lead-acid battery manufacturers around the world. He has extensive experience in problem analysis, process engineering, product design and development, planning, and evaluation. Datta completed his B.S. in general science at Gauhati Unversity, India, and received his B.S. in electrical engineering I.I.T. (honors), at Kharagpur, India.

William B. Craven
VP, Business Development
Craven is well known in the field of alternatively fueled vehicles. Besides directing Electrosource programs for the commercialization of the electric vehicle and general business development, Craven is co-founder and executive director of the South Central Electric Vehicle Consortium. The consortium consists of electric utilities in the south central portion of the United States dedicated to the commercialization of electric vehicles. He is co-founder, board member and past president of Lynntech, Inc., an advanced electrochemical research and development firm. Lynntech has been awarded more than 30 federal Small Business Innovative Research contracts in the past three years totaling more than $3 million. He also is currently director of the National Electric Vehicle Service and Maintenance Program sponsored by the Electric Power Research Institute (EPRI) of Palo Alto. Craven received his M.B.A. from the University of Texas and a B.B.A. from Lynchburg College in Lynchburg, Virginia.

Dr. Norman Hackerman
Science Advisor
Member, Electrosource Board of Director's Advisory Board
Dr. Hackerman is a leading scientist and corrosion specialist. He is a noted member of the National Academy of Sciences and has published widely in chemical science and engineering journals. He has edited and published articles in the Journal of Electrochemistry and is the Journal's current editor. He is former president of the University of Texas at Austin and former president of Rice University. Dr. Hackerman is a recipient of the Palladium Medal from the Electrochemistry Society and has received the American Institute of Chemists' Gold Medal. He is a member of the American Philosophical Society and the American Academy of Arts and Sciences. Dr. Hackerman is a member of the Department of Defense Defense Science Board and is currently Professor Emeritus of Chemistry at the University of Texas.

Battery Features

- High specific energy density
- Excellent power capability at any state of charge
- Long life
- Rapid recharge
- Cold temperature performance
- Maintenance free
- Technology available now
- Production scale-up minor compared to other technologies
- Significant performance advantages over competitors
- Lighter than conventional lead-acid batteries
- Environmental and safety considerations

  - Lead recycling infrastructure available
  - No leachate if ruptured
  - Stable and safe materials
  - Does not vent gases under normal operation

- Wide applicability

  - Electric vehicles
  - Uninterruptable power supplies
  - Utility load leveling
  - Consumer power tools and cellular phones
  - Fiber optic system power backup
  - Automobile starting, lighting and ignition
  - Industrial applications
  - Aviation and military uses

Texas Applied Power Electronics Center
(TAPC)

- A Multidisciplinary R&D Center for Developing System Prototypes in which Power Electronics is the Enabling Technology

- Present Main Project: electrically Peaking Hybrid (ELPH) Vehicle

Power Electronics Laboratory
at
Texas A&M University

- Two Faculty Members
- One Visiting Faculty
- Two Adjunct Faculty
- 23 Graduate Students
- Three Labs
- Established in 1981
- Over 90 Publications, 2 Books
- $500k Annual Projects

Projects of the Power Electronics Laboratory

High Power Converters

- Zero-Current Switching Converters (IDC, C*3)

Motor Drives

- Technology Simplification is AC Motor Drives
- Sensorless SRM Drives
- Sensorless ECM Drives
- Sensorless SynRM Drives
- Custom Integrated Circuits for Sensorless SRM Drives
- Electromagnetic Automobile Transmission
- Non Magnetic Motor Drive (AUGUR Motor Drive)

Unconventional Power Systems

- Superconductive Power Systems
- Airborne, Space Borne Power Systems (ATF, SPS, Space Station)

Power Quality Control

- Switching Power Filters
- Harmonic Controlled AC and DC converters

Miscellaneous Projects

- Integrated LCT
- Electronic Voltage Ratchet
- Switching Impedance Transmutator

TABLE 1 CESHR ORGANIZATION
CENTER FOR ELECTROCHEMICAL SYSTEMS AND HYDROGEN RESEARCH

DIRECTOR
A. John Appleby

DEPUTY DIRECTOR
Supramaniam Srinivasan

ASSISTANT TO DIRECTOR
Dale W. Cleckner

TECHNOLOGY R&D

RESEARCH COLLABORATORS
William B. Craven[1]
David H. Swan[2]

ASSISTANT RESEARCH ENGINEER/ SCIENTIST
A. Cesar Ferreira

RESEARCH ASSOCIATES
Junbom Kim
Konstantin Petrov
M.P. Sridhar Kumar

GUEST RESEARCH ASSOCIATES
Abbas A. Rostami[3]
Masanobu Wakizoe[4]

GRADUATE STUDENTS
Muralidaharan Arikara[5]
Blake Dickinson[6]
Ron Paetzold[6]
Sanjeev Mukerjee[7]
Marc Kohler
Doanh Tran

TECHNOLOGISTS
Imran Kakwan

ADMINISTRATION

ADMINISTRATIVE ASSISTANT
Betty Mahan

STAFF ASSISTANT
Amrita Sidhu

STUDENT WORKER
Jacqueline Curtin

FOOTNOTES
1. Electrosource, Inc.
2. University of California- Davis
3. University of Mazandaran
4. Asahi Chemical Industry, Ltd.
5. Electrical Engineering
6. Mechanical Engineering
7. Chemistry Department

TABLE 2 PROGRAMS, PROJECTS and INVESTIGATORS.
CENTER FOR ELECTROCHEMICAL SYSTEMS AND HYDROGEN RESEARCH
TEXAS ENGINEERING EXPERIMENT STATION
TEXAS A&M UNIVERSITY
MAY 1993

PROGRAM, PROJECTS, SPONSORS, AND INVESTIGATORS

- **POWER SOURCES SPACE AND TERRESTRIAL APPLICATIONS**
  - Proton Exchange Membrane Fuel Cells
    NASA-JSC, NASA-Lewis, HSU[1], Mazda
    A.C. Ferreira*, J. Kim, M. Wakizoe[2], S. Mukerjee[3]
  - Ni/H_2 and Ni/MH_x Batteries
    Hughes/ CSP
    K. Petrov*, A.A. Rostami, M.P. Sridhar Kumar
  - Molten Carbonate Fuel Cells
    M-C Power
  - Proton Exchange Membrane Fuel Cell Multi-Cell Stack
    MTI/ CSP
    J. Lee, D.H. Swan, I.J. Kakwan, A. C. Ferreira
- **ELECTRIC VEHICLES**
  - Sodium Sulfur/ Zinc Bromine Powered EVs
    THECB - ERAP
    D.H. Swan+, I.J. Kakwan*, B. Dickinson, R. Paetzold, M. Arikara, M. Kohler
  - Electric Vehicle Consortium
    Electric Utilities
    D.W. Cleckner, W.B. Craven+, D.H. Swan
  - EV Site Operators
    DOE
    I.J. Kakwan*, W.B. Craven+, D.H. Swan+,
- **HYDROGEN TECHNOLOGY**
  - Metal Hydrides
    DOE - NREL
    M.P.Sridhar Kumar*

NOTES:
* Senior Investigator
+ Research Collaborator
1. Humboldt State University
2. Asahi Chemical Industry, Co.
3. Chemistry Department
4. University of Mazandaran

ANTHONY JOHN APPLEBY

Center for Electrochemical Systems and Hydrogen Research
Texas Engineering Experiment Station
Texas A&M University
College Station, Texas 77843-3402
Phone (409) 845-8281; Fax (409) 845-9287

EDUCATION

1958-1961	Queens' College, Cambridge (B.A. in Chemistry)
1961-1965	Cambridge University (Ph.D. in Chemistry)

AREAS OF RESEARCH

Electrode Kinetics, Electrocatalysis, Fuel Cells, Batteries, Hydrogen Energy Systems, Global Warming, Corrosion and Passivation, and Bioelectrochemistry

EMPLOYMENT

1987-present	Director, Center for Electrochemical Systems and Hydrogen Research; Professor of Applied Electrochemistry, Department of Chemical Engineering.
1979-1986	Consulting Professor of Chemical Engineering, Stanford University, Palo Alto, CA.
1978-1986	Project Manager, Advanced Fuel Cell Technology, Electric Power Research Institute, Palo Alto, CA.
1980	Visiting Professor, University of La Plata, Argentina.
1979	Visiting Professor, Universidad Simon Bolivar, Caracas, Venezuela.
1972-1978	Research in Industrial Electrochemistry, Laboratoires de Marcoussis, Research Center of the Compagnie Generale d'Electricite, Marcoussis, France; Thesis advisor, Engineer's theses at Conservatoire Nationale des Arts et Metiers, Paris, France.
1971	Visiting Scientist, C.N.R.S. Electrochemistry Laboratory, Bellevue, France (Prof. M. Bonnemay); Visiting Scientist, University of Pennsylvania (Prof. J. O'M. Bockris), Philadelphia, PA.
1967-1970	Electrochemist, Supervisor of Electrochemical Research, Institute of Gas Technology, Illinois Institute of Technology, Chicago, IL.
1965-1966	Post Doctoral Research Associate, Corrosion Laboratory, Cambridge University, Cambridge, England.

CONSULTANCY

Electric Power Research Institute
Booz-Allen
Tracor, Inc.
ABB - Combustion Engineering
MC Power Corporation
Italian Government

PROFESSIONAL ACTIVITIES

Electrochemical Society, Treasurer, Secretary,
Vice-President and President of Energy Technology Group, 1980-85.

4. AVAILABLE TECHNIQUES, DATA, AND FACILITIES

CESHR is well equipped for the fundamental and technological investigations described in this proposal. Its electrochemical equipment items include PAR 273 potentiostats with lock-in amplifiers, Solatron Frequency Response Analyzer, Tektronix digital storage Scopes. Other equipment includes Buehler polishers, diamond-cutting tools, power supplies, etc. CESHR has also built five computerized fuel cell test stations for obtaining cell potential vs current density measurements and for life-testing at desired temperatures and pressures. A three channel high current density, high voltage Bitrode Battery cycler, with data monitoring and acquisition system coupled to an IBM-PC computer, has been added to the available facilities. A number of high pressure vessels for Ni/H_2 Battery and other experimental studies have been designed and built. CESHR has a four cell Tronac calorimeter and two microcalorimeters for corrosion and battery self-discharge studies. Two sets of modified Sieverts apparatus have been assembled for determination of the pressure-composition/desorption of metal hydrides as a function of temperature and pressures. CESHR has access to all the facilities available within Texas A&M University System for material science research and surface science. High resolution electron microscopes, Energy Dispersive X-ray Analyzer, X-ray Diffraction equipment, ESCA, LEED, Atomic Absorption Spectroscopy, FTIR, Differential Scanning Calorimetry, Thermo-Gravimetric Analysis, Mass Spectroscopy, and a Scanning Tunneling Microscope are available for certified users.

CESHR has access to all the Computing facilities available at Texas A&M University. These include a Cray Y-MP 2/116 Supercomputer and VAX, VM, UNIX and IBM mainframes. CESHR has Macintosh and Sun Microsystems work-stations for general use and access to central facilities.

CESHR's investigations in the electrochemical technology related field are carried out in two laboratories with 1,937 square feet with fumehoods and the necessary electrical, gas and chemical facilities. In addition, the office space for the administrative and technical staff has a floor area of 2,062 square feet. A further 6075 square feet are used for fuel cell equipment and for modification and maintenance of electric vehicles. CESHR has been engaged in the Electric Vehicle R&D for six years, and has six electric vehicles. It is also the site of the South Central Electric Vehicle Consortium involving area electric utilities and the Electric Power Research Institute, as well as being one of the members of the Department of Energy Electric Vehicle Site Operators Program.

A primary aim of CESHR's R&D activity is on the performance evaluation of Advanced Batteries, as they become available. These include advanced lead-acid designs (including the edge-collected bipolar Electrosource Horizon® high-power advanced lead-acid battery), the SEA zinc-bromine battery, together with nickel-hydride and sodium-sulfur batteries. Major emphases are on long vehicle range, e.g., 210 km at 89 km/hr, and 190.0 km in two hours, with a zinc-bromine powered Geo Metro, and on high power batteries (450 W/kg for the Electrosource Horizon®) for hybrid vehicle applications. These include fuel cell powered systems. CESHR is an acknowledged world and national leader in the development of high-performance low-catalyst-loading proton-exchange-membrane and other types of fuel cells. It has demonstrated the highest performance yet announced with low-loading electrodes (0.3 A/cm^2 at 0.7 V, and 0.5 A/cm^2 at 0.6 V with hydrogen-air at atmospheric pressure with 0.1 mg/cm^2 platinum loading air cathodes). It is also a pioneer in the development of ultra-light, compact fuel cell stack designs using composite materials. These may be able to attain 1.8 kW/kg and 0.75 kW/liter It is also acquiring the existing equipment and property from the Alsthom-Exxon-OxyChem alkaline fuel cell program, which puts it in a unique position with this lightweight technology.

All fuel cells operate on hydrogen fuel, whether pure or manufactured as reformate from fossil fuels. CESHR was established in 1986 as a national center for the storage, production, and handling of hydrogen. Since 1987, it has operated as a subcontractor to the Solar Energy Research Institute and its successor, the National Renewable Energy Laboratory.

5. METHODOLOGY, TECHNIQUES, AND APPROACH TO TECHNOLOGY DEMONSTRATION AND TRANSFER

The objective of the proposer is to demonstrate the feasibility of an ultra-lightweight hydrogen generator, integrated with a lightweight PEMFC or AFC. Both have their drawbacks and their advantages. On balance, the latter is preferred since the integration of the generator and the fuel cell via a circuit using recovered water is much easier. The generator-fuel cell package is to be supplied by a fresh 750 g cartridge containing free-flowing non-clogging safe encapsulated hydride at the beginning of each 72 hour mission. The AFC will also require an air purification cartridge weighing about 50 g.

During the 18 month period of performance, the proposer will be capable of demonstrating the performance of a small integrated cartridge and fuel cell, in both PEMFC and AFC varieties. Scale-up must then be effected via technology transfer to a company, since the proposer, being a University, is not capable of progressing further towards the hardware demonstration and manufacturing stage. The property developed during the project shall be transferred at the end to a suitable developer, which may be either a small business set up by the proposer, or an established fuel cell developer, as the sponsor shall require.

6. IDENTIFY TECHNICAL DATA PROPOSED TO BE DELIVERED WITH LESS THAN UNLIMITED RIGHTS

There shall be no technical data which shall be delivered with less than unlimited rights under this program.

7. ORGANIZATION STRUCTURE AND ROLES/QUALIFICATIONS OF EACH TEAM MEMBER AND BRIEF RESUMES OF PERSONNEL

An organizational chart of CESHR and a chart on the current programs, projects and investigators are presented in Tables 1 and 2. Dr. A. John Appleby and Dr. Supramaniam Srinivasan are the Director and Deputy Director of CESHR respectively. They are both internationally recognized for their contributions in electrode kinetics, electrocatalysis, electrochemical energy conversion and storage and bioelectrochemistry. Dr. A. C. Ferreira, Assistant Scientist, has expertise in electrochemistry, in phosphoric and PEM fuel cell technology, in water and H_2S electrolyzers, water purification systems, nickel/metal hydride batteries and carbon dioxide disposal systems.

Dr. Appleby and Dr. Srinivasan are proposed as the Principal and Co-Principal Investigators of the project. Their roles shall be in its overall guidance and direction. Dr. Ferreira shall be responsible for the experimental work, which shall focus on the design and development of the hydrogen generator. His experience in fuel cell R&D is most valuable for the coupling of the hydrogen generation system with the proton exchange membrane and alkaline fuel cells. Brief resumes of these Key Personnel are given in the Appendix to this proposal.

8. BREAK-OUT OF MATERIALS, INCLUDING TYPES AND QUANTITIES

The materials required for this project are relatively simple and easily obtained chemical compounds. They include lithium hydride (LiH), lithium aluminum hydride

($LiAlH_4$), lithium borohydride ($LiBH_4$), and sodium borohydride ($NaBH_4$). Some organic compounds will be required for the coating of the hydrides, as necessary. Other compounds are common laboratory chemicals. It is difficult to make an exact assessment of the quantities which will be required, but they are not expected to exceed a few kilograms. The fuel cell component materials for both the PEM and the AFC are all available in CESHR.

TEXAS TRANSPORTATION INSTITUTE

HISTORY AND OBJECTIVE

Organized research at the Texas Transportation Institute (TTI) began in 1914. Early work grew into the Cooperative Research Program, which the Texas Highway Department (now the State Department of Highways and Public Transportation) established at the University in September, 1948. The Texas A&M University System created the Texas Transportation Institute in 1950 to conduct research in all modes of transportation (highway, rail, water, air, pipeline) involved in the movement of persons, goods, and services. The objective of its research and educational programs is to develop transportation to its greatest potential in serving the public. The Institute participates on local, state, regional, and national levels in conducting interdisciplinary research programs that extend into the planning, design, construction, operation, maintenance, enforcement, safety, economic, ecological, and social aspects of transportation.

TTI RESEARCH PHILOSOPHY AND SCOPE OF OPERATIONS

The Institute has an established philosophy that research findings should be applied as rapidly as possible toward meeting the demands of today. Therefore, much of TTI's work stresses the implementation of findings, both during and after research (in cooperation with the contracting agency) to minimize lag time between research findings and applications.

The Institute is an official research agency of the Texas State Department of Highways and Public Transportation, the Railroad Commission of Texas and the Texas Aeronautics Commission. The Texas Legislative Council has designated TTI as one of two State agencies to provide technical assistance on matters relating to transportation. The Institute conducts research for other agencies and organizations including private industry, cities, foundations, technical societies, trade associations.

In 1988 the Department of Transportation (DOT) selected TTI as the Region VI Regional Transportation Center. The Center will provide support for transportation studies of critical importance to the states of Region VI (Arkansas, Louisiana, New Mexico, Oklahoma and Texas).

More than 500 people work in TTI's seven research divisions, the Aggregates Research Center and the Southwest Region University Transportation Center. The Divisions are Economics and Planning; Materials, Pavements and Construction; Safety; Transportation Systems; Structural Systems; Traffic Management; and Systems Planning. Each division is divided into research programs.

EQUIPMENT AND FACILITIES

The Texas A&M University System (TAMUS), headquartered in College Station, TX, is home and headquarters for TTI. A new 51,000 sq.ft. building houses most of TTI, and interconnects to several laboratory and office buildings, including the Wisenbaker Engineering Laboratory Center (WERC), the McNew Materials Laboratory, the Concrete Laboratory and the Spectrum Analysis Laboratory. Laboratories and buildings are large and modern. The Safety Division is located at the Proving Ground Research Facility remains on the Riverside Campus, about 12 miles from the main campus.

In addition to its own resources, TTI has access to Texas A&M University. Most of the literature researchers need is available in the collections of the University's Sterling C. Evans Library. Texas A&M University Computing Services Center (CSC) houses mainframe and other large systems. The CSC is one of the finest and most sophisticated computing centers of any educational institution in the nation.

PROJECT NUMBER: 0458F
START DATE: 12-May-92
TERMINATION DATE: 30-Aug-92
TITLE: Crash Testing and Evaluation of a Median-Barrier System
PI: Mak, K.
DIVISION: 3
SPONSOR: Alan R. McKay & Associates
ABSTRACT: TTI conducted a safety performance evaluation of the MGS barrier system, a transportable concrete median barrier similar in size and shape to the New Jersey concrete safety-shaped barrier. Researchers conducted two crash tests in accordance with NCHRP Report 230. The first involved a 4,500-pound passenger car impacting the test installation at a nominal speed of 60 miles per hour and at an angle of 25 degrees, and the second involved a 1,800-pound passenger car impacting the test installation at a nominal speed of 60 miles per hour and at an angle of 20 degrees.

PROJECT NUMBER: 09911
START DATE: 31-Nov-89
TERMINATION DATE: 31-Aug-91
TITLE: Development of Performance Specifications for Truck Mounted Attenuators
PI: Griffin, L.
Mak, K.
DIVISION: 3
SPONSOR: Texas Department of Transportation
ABSTRACT: TTI developed a set of performance specifications for Truck Mounted Attenuators (TMAs) to be used by the Texas State Department of Highways and Public Transportation in defining minimum standards for TMA manufacturers. Crash tests were conducted on seven different TMAs (4 commercially available models and 3 prototypes). Vibration and moisture tests were conducted on the TMAs that met crash test criteria.

PROJECT NUMBER: 1179
START DATE: 01-Sep-87
TERMINATION DATE: 31-Aug-89
TITLE: Crash Test of Modified C-202 Bridge Rail
PI: Hirsch, T.
DIVISION: 5
SPONSOR: Texas Department of Transportation
ABSTRACT: This research, required by FHWA to qualify for federally-aided projects, crash tested the high-performance, modified C-202 bridge rail with a 4500-pound and an 1800-pound passenger car.

PROJECT NUMBER: 12191
START DATE: 01-Sep-90
TERMINATION DATE: 31-Aug-91

TITLE: Two-Post Driveable Sign Supports
PI: Morgan, J.
Ross, H.
DIVISION: 5
SPONSOR: Texas Department of Transportation
ABSTRACT: This project developed and crash tested a two-post, driveable anchor/ tubular sign post system that will both minimize field maintenance requirements and satisfy nationally recognized impact performance standards.

PROJECT NUMBER: 12793
START DATE: 01-Sep-91
TERMINATION DATE: 31-Aug-93
TITLE: Air Pollution Implications of Urban Transportation Investment
PI: Krammes, R.
DIVISION: 4
SPONSOR: Texas Department of Transportation
ABSTRACT: This study will support the Department's efforts to comply with the new transportation/air quality requirements of the Clean Air Act Amendments of 1990 by (1) providing evaluations of pertinent legislation and regulations, transportation control measures, other states' practices, and other issues outside the purview of the Department that may influence the Department, and (2) developing improved planning procedures and analysis tools. The evaluations can be used by the Department in making planning procedures and analysis tools. The planning procedures and analysis tools will be designed for immediate implementation by the Department.

PROJECT NUMBER: 13753
START DATE: 01-Apr-92
TERMINATION DATE: 31-Aug-93
TITLE: Develop Air Quality Data for Federal Submission
PI: Dresser, G.
DIVISION: 1
SPONSOR: Texas Department of Transportation
ABSTRACT: The pupose of this project is to provide professional and technical staff services to TxDOT Division-10 in performing transportation-air quality planning activities required by the Clean Air Act Amendments (CAAA) and federal implementing regulations. Project staff will investgate the transportation-air quality data required by the CAAA implementing guidance and regulations. TTI will assist the Department and non-attainment MPOs (El Paso, Beaumont, Houston-Galveston, and Dallas-Fort Worth) in preparing by EPA's implementing regulations. TTI will also assist the Department in preparing the Travel damand modeling documentation required by EPA regulations.

PI: Mak, K.
DIVISION: 3
SPONSOR: WYO
ABSTRACT: This study evaluated and crash tested the transition from the Wyoming standard steel box-beam guardrail to the Wyoming steel tube-type bridge rail to determine compliance with the requirements specified under NCHRP Report 230.

PROJECT NUMBER: 385
START DATE: 01-Jul-88
TERMINATION DATE: 01-Apr-89
TITLE: Crash Testing Florida DOT Standard Guardrail
PI: Bligh, R.
DIVISION: 5
SPONSOR: FLA
ABSTRACT: The purpose of this project was to crash test and evaluate the performance of Florida's guardrail transition to a bridge traffic-rail wing post. The testing, evaluation, and reporting were in accordance with the guidelines presented in NCHRP 230.

PROJECT NUMBER: 4444
START DATE: 01-Jan-81
TERMINATION DATE: 09-Sep-88
TITLE: Road Coastdown Testing
PI: Tonda, R.D.
DIVISION: 0
SPONSOR: VMS
ABSTRACT: This project performed testing and evaluation of new model vehicles for road-load and fuel economy information needed by the EPA as part of the "New Vehicle" certification process.

PROJECT NUMBER: 60013
START DATE: 15-Mar-90
TERMINATION DATE: 31-Aug-93
TITLE: New Method of Estimating Energy Use for Transit and Other Vehicles
PI: McFarland, W. F.
DIVISION: 1
SPONSOR: Office of the Governor of Texas
ABSTRACT: Researchers reviewed the literature on vehicle fuel efficiencies, reviewed computer simulation programs for estimating fuel consumption, and developed a procedure for updating fuel efficiency tables. They also developed a program to estimate vehicle efficiencies that takes into account vehicle characteristics as well as the signalization and pavement type of the roadway.

PROJECT NUMBER: 60039

THE TEXAS ENGINEERING EXTENSION SERVICE

The Texas Engineering Extension Service is an internationally recognized state agency which provided training, continuing education, technical assistance and technology transfer services to public and private agencies, businesses and industries. More than 110,000 people annually take advantage of the services provided by the agency. The Texas Engineering Extensions Service is a member of the Texas A&M University System. This membership permits the utilization of the resources which are available through a land grant university. The strength of this agency is reflected in the total resources of the agency. More than 400 researchers, trainers, and support personnel make up the staff of the Texas Engineering Extension Service. There are over 200 professional staff members within the organization and each individual possesses the academic and experience necessary to qualify as an expert in their chosen discipline. The Texas Engineering Extension Service is one of the largest providers of engineering training services in the nation. The Texas Engineering Extension Service annual budget is in excess of $40 million. The Agency headquarters is located adjacent to Texas A&M University in College Station, Texas. In addition to an outstanding staff, the agency occupies in excess of 300,000 square feet of office, classrooms, and laboratory space. Cornerstone of the agency's services is the state-of-the-art training aids, valued in excess of $75 million.

The Texas Engineering Extension Service was created as a state agency in July of 1948. However, many of the more than 700 training programs date back to the early 1900's. Many of the training programs meet the federal and state educational requirements for certification and licensing. The training programs of the Texas Engineering Extension Service are conducted through 14 divisions. Two of the training division, Transportation and Occupational and Environmental Safety, have programs with emphasis on Energy Conservation and Environmental issues. Protecting the environment while meeting the transportation needs of a mobile society is a goal of these two training divisions.

The mission of the agency is:

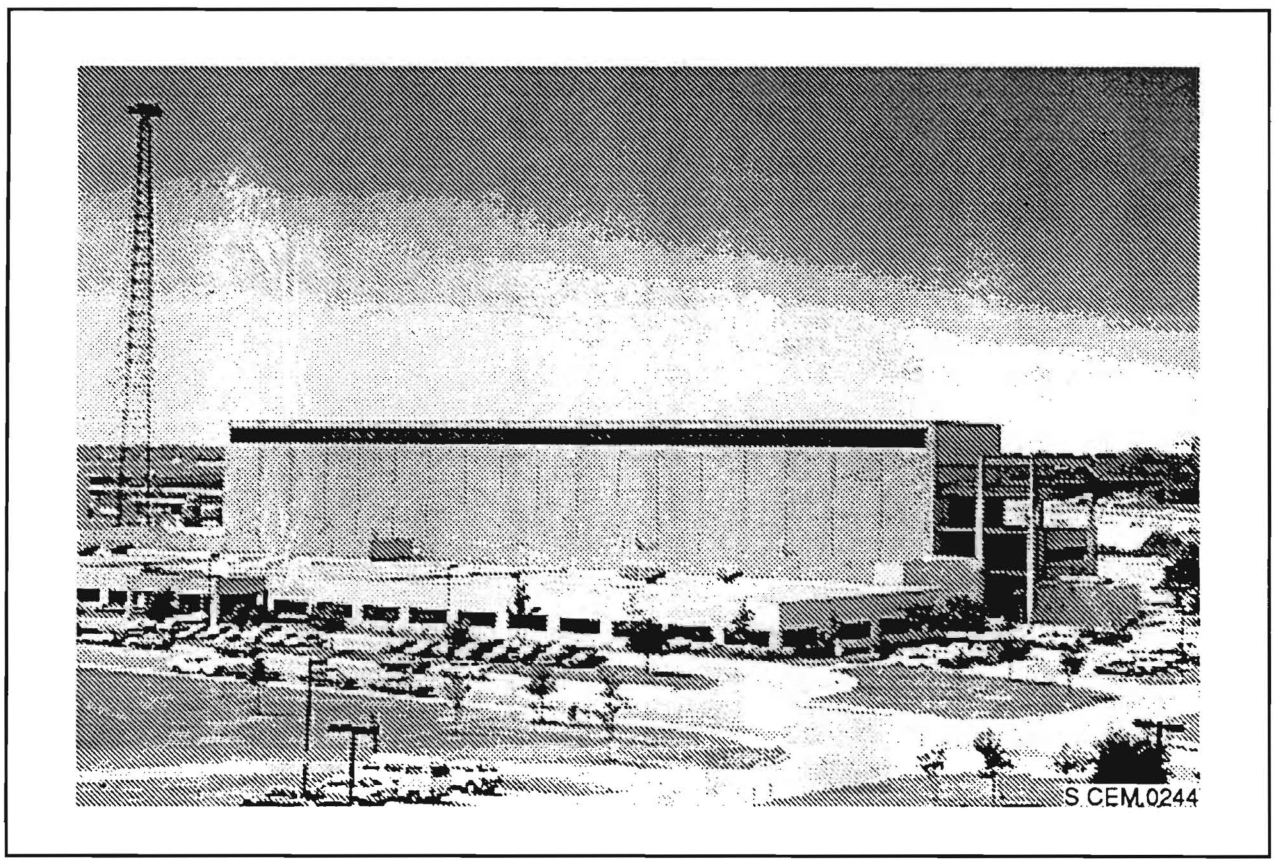
> The Texas Engineering Extension Service, as a state agency, focuses on developing a highly skilled and educated workforce that enhances the global competitiveness of the state through training, retraining, continuing education and technical assistance in new and emerging technologies.

The success of the agency is directly related to providing quality training programs, technical assistance and technology transfer services at a times and places that meets the clients needs. The integration of new technology into existing processes and procedures is a trademark of the agency.

The Center for Electromechanics is the largest contract research center (~$10M per year) in the College of Engineering at The University of Texas. Our expertise is in the development of very high specific power electromechanical devices. We have developed complete systems including prime power (turbine and hydraulic) energy storage, motor/generator, power electronics, controls and auxiliaries. These systems have been developed to power tokomak fusion magnets, high power lasers and electromagnetic guns. All of the technology is applicable to hybrid electric or all electric vehicles. We are an Army Center for Excellence in Electromechanics and have been one of the principal contractors on the Army's electromagnetic gun program. We have also been heavily involved in the DARPA/Navy submarine electric drive program and are a subcontractor to General Dynamics Land Systems on the U.S. Army - TACOM Electric Drive Technology Demonstrator Program.

CEM is housed in the Electromechanics and Energy Building at the University's Balcones Research Center (shown below). The building is a state of the art research facility complete with a 450 ft long experimental highbay, full capability machine and electronics shops, and Cray supercomputers. We are staffed by full time research professionals, faculty associates, and students. Because we are nonprofit and have a low overhead rate (47%), we produce excellent return on sponsors' investments.

For electric or hybrid drive systems to be successful, a compact energy storage device which can be rapidly charged and discharged must be developed. Rapid charging is required for convenience when the energy is initially being stored, but more importantly is required for regenerative braking. Rapid discharging, which implies high power, is required for the vehicle to have acceptable acceleration.



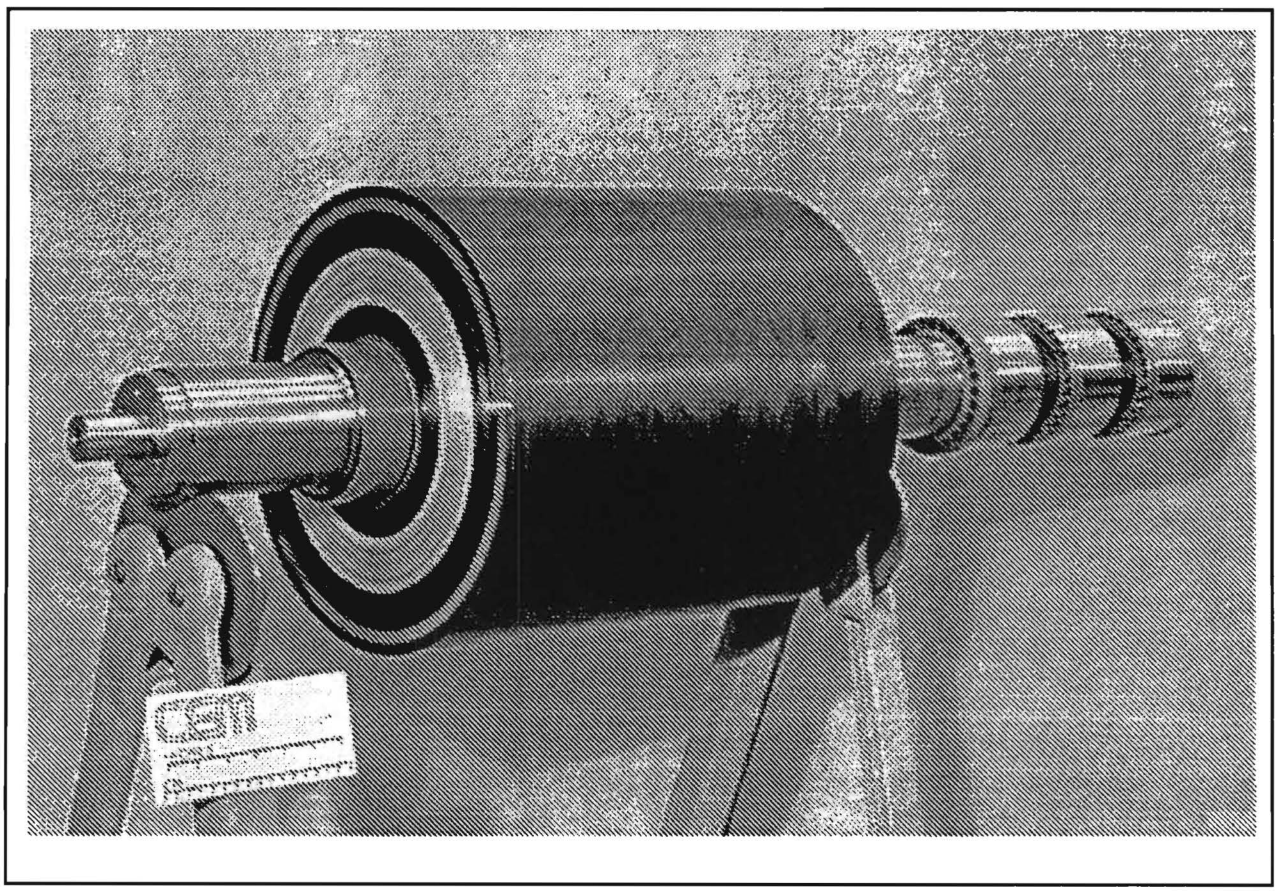
The EME building, located at Bolcones Research Center, The University of Texas at Austin

Efforts to develop high energy density, high power batteries, and fuel cells have met with limited success. Flywheel energy storage devices which have an electrical motor/generator integrated into the flywheel for energy conversion are technically feasible and have very good performance characteristics. However, they are a less mature technology, especially the higher performance composite-based flywheels, and must be shown to be reliable, efficient, and cost effective.

In an all-electric drive system, composite flywheel/generators can be used to store all of the energy required for the mission or could be used with batteries to provide energy and power for acceleration and regenerative braking capability while the batteries would provide continuous power. When used with batteries, the amount of energy which must be stored is precisely defined by the mass of the vehicle and the desired top speed. The power is defined by either the desired acceleration or regenerative braking requirements.

In a hybrid drive system, the engine could be run at a continuous speed at its optimum efficiency with the flywheel/generator providing load averaging during acceleration and regenerative braking. The engine, like the batteries, provides continuous power. Once again the energy and power requirements are well defined.

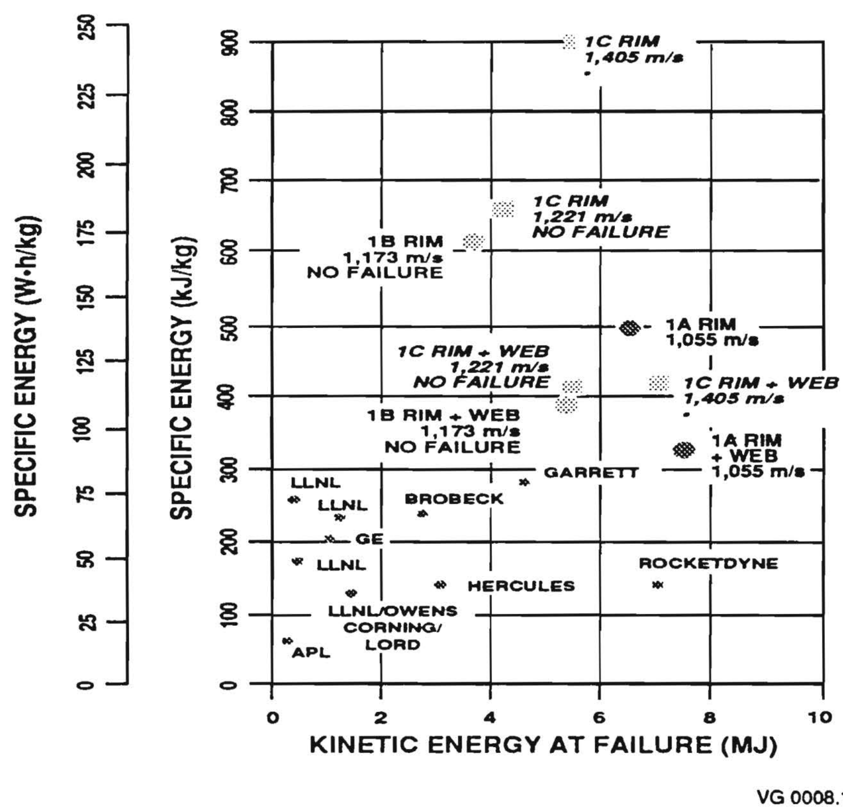
CEM has a great deal of expertise applicable to this technology. Shown below is the composite rotor for a compensated pulsed alternator.



25,000 rpm, 9 MJ composite rotor

The single phase armature winding for the two-pole alternator is integrated into the rotor and is located near the outer diameter of the rotor. Because of the high tip speed of the armature winding, very high peak power (2,400 V at 380 kA) can be generated by the 800 kg machine. This machine is currently being tested for U.S. Army ARDEC.

Below is a plot of energy densities achieved by Oak Ridge National Laboratory and comparing them to the previous state of the art. The work was done by ORNL under subcontract to CEM. ORNL developed its expertise in filament wound, graphite flywheels for the DOE centrifuge program and transferred this technology to CEM for the electric gun program. We are also developing flywheels using new advanced tape winding approaches. We have full capability in house to design, fabricate, and test the complete machine, including the composite flywheel and the generator.



Composite flywheel technology

At this time, most designers feel that either a permanent magnet, switched reluctance, or induction motor/generator are the most appropriate types for integration into the flywheel. Each of the machines have advantages and disadvantages with the selection being dictated by system integration. Performance, weight, efficiency, maintainability, and cost are some of the primary considerations to be evaluated. We have designed and built reluctance and induction machines and have worked with several industrial concerns on the development of permanent magnet motors/generators.

We propose to design, build, and test a flywheel motor generator for an application of interest. Permanent magnet machines, switched reluctance machines, and induction machines will be investigated for electromechanical energy conversion performance as required for the system in which the flywheel/motor generator is to be integrated. If required, scaling laws will be developed and a subscale flywheel/generator will be designed, built, and tested to demonstrate the concept at reduced cost.